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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
17/860,950	07/08/2022	Corban I. Tillemann-Dick	M1567.70000US04	9208

23628 7590 05/27/2025

WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

EXAMINER	
NOUKETCHA, LIONEL W	

ART UNIT	PAPER NUMBER
3763	

NOTIFICATION DATE	DELIVERY MODE
05/27/2025	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

Patents_eOfficeAction@WolfGreenfield.com
WGS_eOfficeAction@WolfGreenfield.com

EXHIBIT 1004 – Page 1 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

APPLICATION NO.	ISSUE DATE	PATENT NO.
17/860,950	27-May-2025	12313320

WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

EGRANT NOTIFICATION

Your electronic patent grant (eGrant) is now available, which can be accessed via Patent Center at https://patentcenter.uspto.gov

The electronic patent grant is the official patent grant under 35 U.S.C. 153. For more information, please visit https://www.uspto.gov/electronicgrants

UNITED STATES PATENT AND TRADEMARK OFFICE

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United States Patent and Trademark Office
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APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
17/860,950	05/27/2025	12313320	M1567.70000US04	9208

23628 7590 05/14/2025

WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

ISSUE NOTIFICATION

The projected patent number and issue date are specified above. The patent will issue electronically. The electronically issued patent is the official patent grant pursuant to 35 U.S.C. § 153. The patent may be accessed on or after the issue date through Patent Center at https://patentcenter.uspto.gov/. The patent will be available in both the public and the private sides of Patent Center. Further assistance in electronically accessing the patent, or about Patent Center, is available by calling the Patent Electronic Business Center at 1-888-217-9197.

The USPTO is implementing electronic patent issuance with a transition period, during which period the USPTO will mail a ceremonial paper copy of the electronic patent grant to the correspondence address of record. Additional copies of the patent (i.e., certified and presentation copies) may be ordered for a fee from the USPTO's Certified Copy Center at https://certifiedcopycenter.uspto.gov/index.html. The Certified Copy Center may be reached at (800)972-6382.

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment is 399 day(s). Any patent to issue from the above-identified application will include an indication of the adjustment on the front page.

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Center (https://patentcenter.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Application Assistance Unit (AAU) of the Office of Patents Stakeholder Experience (OPSE), Stakeholder Support Division (SSD) at (571)-272-4200.

EXHIBIT 1004 – Page 3 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

INVENTOR(s) (Please see PATENT CENTER site https://patentcenter.uspto.gov for additional inventors):

Corban I. Tillemann-Dick, Denver, CO;
Kyle J. Thompson, Boulder, CO;
Bryan J. Choo, New York, NY;
John Ogando Dos Santos Allan, Boulder, CO;
Jonathan Michael Byars, Golden, CO;

APPLICANT(s) (Please see PATENT CENTER site https://patentcenter.uspto.gov for additional applicants):

Maybell Quantum Industries, Inc., Denver, CO;

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage and facilitate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.

EXHIBIT 1004 – Page 4 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

FORM PTO-1449/A and B (modified PTO/SB/08)	APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
	FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet 1 of 2	GROUP ART UNIT: Not Yet Assigned	EXAMINER: Not Yet Assigned

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		4,296,609		Severijns et al.	10-27-1981
		4,672,823		Benoit et al.	06-16-1987
		4,986,077	A	Shao et al.	01-22-1991
		5,172,554	A	Swift et al.	12-22-1992
		5,207,674	A	Hamilton	05-04-1993
		2004-0223300	A1	Fink et al.	11-11-2004
Change(s) applied to document, /C.C.B./ 4/9/2025		2005-0223714	A1	Li et al. 10/2005	~~10-13-2015~~
		2009-0275476	A1	Atrey	11-05-2009
		2015-0160702	A1	Franz	06-11-2015
		2018-0051937	A1	Thiers et al.	02-22-2018
		2019-0226724	A1	Kotsubo et al.	07-25-2019
		2020-0370792	A1	Matthews	11-26-2020
		2021-0076530	A1	Hart et al.	03-11-2021
		2021-0402407	A1	Hoehne	12-30-2021
		2021-0402407	A1	Hoehne	12-30-2021
		2022-0221108	A1	Corcoles-Gonzalez et al.	07-14-2022

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		CN	111089436	A	Csic Pride Nanjing Cryogenic Tech Co., Ltd .	05-01-2020	Y; Abstract Only
		FR	2 184 536	A1	Anvar	12-28-1973	Y; Abstract Only
		GB	2 282 437	A	Hitachi Europe Limited	04-05-1995	
		WO	2015-004904	A1	Denso Corp.	01-15-2015	Y; Abstract Only

EXAMINER:	DATE CONSIDERED:

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

11455735.1

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

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ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**04/24/2025 04:18:40 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Morgan Ryan
PATENT CENTER #	70150859	FILING DATE	07/08/2022
CUSTOMER #	23628	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	Randy Pritzker

Documents

TOTAL DOCUMENTS: 2

DOCUMENT	PAGES	DESCRIPTION	SIZE (KB)
M156770000US04-TRN-RJP.pdf	1	Miscellaneous Incoming Letter	25 KB
M156770000US04-ISSFEE-RJP.pdf	1	Issue Fee Payment (PTO-85B)	36 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
M156770000US04-TRN-RJP.pdf	8C3FE5492F23A7A778CD962B4014FF4161484972263F1CC47A4923C4686B55FD01D4B24AE1B61B471A3E43CF08856C672FF2BC273BE2166E9CD54E411F44DDA2
M156770000US04-ISSFEE-	A119E15CE9C573A9E15192AF39513332E88A7B78D3B71B5B8

RJP.pdf

1092D47BB988B82DB3B71AD6A006DCF0A7B96737AD654650A59322019D182B1120E4004DBF03DDB

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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ELECTRONIC PAYMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**04/24/2025 04:18:40 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Morgan Ryan
PATENT CENTER #	70150859	AUTHORIZED BY	Randy Pritzker
CUSTOMER #	23628	FILING DATE	07/08/2022
CORRESPONDENCE ADDRESS	-	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick

Payment Information

PAYMENT METHOD	PAYMENT TRANSACTION ID	PAYMENT AUTHORIZED BY
CARD / 8576	**E20254NG20089527**	**Morgan Ryan**

FEE CODE	DESCRIPTION	ITEM PRICE($)	QUANTITY	ITEM TOTAL($)
2501	UTILITY ISSUE FEE	516.00	1	516.00
			TOTAL AMOUNT:	**$516.00**

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

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Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission	

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban I. Tillemann-Dick
Art Unit	3763
Examiner Name	L. W. Nouketcha
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

- [ ] Fee Transmittal Form
  - [ ] Fee Attached
- [ ] Amendment/Reply
  - [ ] After Final
  - [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [ ] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Reply to Missing Parts/ Incomplete Application
  - [ ] Reply to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) _____
  - [ ] Landscape Table on CD
- [ ] After Allowance Communication to TC
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- [ ] Proprietary Information
- [ ] Status Letter
- [x] Other Enclosure(s) (please Identify below):
  - Issue Fee Payment (PTO-85B)

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Randy J. Pritzker/		
Printed name	Randy J. Pritzker		
Date	April 24, 2025	Reg. No.	35,986

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: April 24, 2025 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

13832374

PART B–FEE(S) TRANSMITTAL

Complete and send this form, together with the applicable fee(s), by mail or fax, or via EFS-Web.

By mail, send to: Mail Stop ISSUE FEE
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P.O. Box 1450
Alexandria, VA 22313-1450

By fax, send to: (571) 273-2885

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WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206

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Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being transmitted via the USPTO electronic filing system or by facsimile to (571) 273-2885, on the date below.

Morgan L. Ryan	(Typed or printed name)
/Morgan L. Ryan/	(Signature)
April 24, 2025	(Date)

APPLICATION NO	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO	CONFIRMATION NO
17/860,950	07/08/2022	Corban I. Tillemann-Dick	M1567.70000US04	9208

TITLE OF INVENTION: INTEGRATED DILUTION REFRIGERATORS

APPLN: TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$516.00			$516.00	07/03/2025

EXAMINER	ART UNIT	CLASS-SUBCLASS
L. W. Nouketcha	3763	

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363)

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☐ "Fee Address" indication (or "Fee Address" Indication form PTO/AIA/47 or PTO/SB/47; Rev 03-09 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list

(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,

(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1. Wolf, Greenfield & Sacks, P.C.
2.
3.

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: Maybell Quantum Industries, Inc.

(B) RESIDENCE: (CITY and STATE or COUNTRY): Denver, Colorado

Please check the appropriate assignee category or categories (will not be printed on the patent): ☐ Individual ☒ Corporation or other private group entity ☐ Government

4a. Fees Submitted: ☒ Issue Fee ☐ Publication Fee (if required)

4b. Method of Payment (*Please first reapply any previously paid fee shown above*):

☒ Electronic Payment via Patent Center or EFS-Web ☐ Enclosed check ☐ Non-electronic payment by credit card (Attach form PTO-2038)

☒ The Director is hereby authorized to charge ~~the required fee(s)~~, any deficiency, or credit any overpayment to Deposit Account No. 23/2825

5. Change of Entity Status (from status indicated above)

☐ Applicant certifying micro entity status. See 37 CFR 1.29. NOTE: Absent a valid Certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.

☐ Applicant asserting small entity status. See 37 CFR 1.27. NOTE: If the application was previously under micro entity status, checking this box will be taken as a notification of loss of entitlement to micro entity status.

☐ Applicant changing to regular undiscounted fee status. NOTE: Checking this box will be taken as a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature: /Randy J. Pritzker/ Date: April 24, 2025

Typed or printed name: Randy J. Pritzker Registration No.: 35,986

13832375

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
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NOTICE OF ALLOWANCE AND FEE(S) DUE

23628 7590 04/03/2025

WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

EXAMINER	
NOUKETCHA, LIONEL W	
ART UNIT	PAPER NUMBER
3763	

DATE MAILED: 04/03/2025

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
17/860,950	07/08/2022	Corban I. Tillemann-Dick	M1567.70000US04	9208

TITLE OF INVENTION: INTEGRATED DILUTION REFRIGERATORS

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$516	$0.00	$0.00	$516	07/03/2025

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE DOES NOT REFLECT A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE IN THIS APPLICATION. IF AN ISSUE FEE HAS PREVIOUSLY BEEN PAID IN THIS APPLICATION (AS SHOWN ABOVE), THE RETURN OF PART B OF THIS FORM WILL BE CONSIDERED A REQUEST TO REAPPLY THE PREVIOUSLY PAID ISSUE FEE TOWARD THE ISSUE FEE NOW DUE.

HOW TO REPLY TO THIS NOTICE:

I. Review the ENTITY STATUS shown above. If the ENTITY STATUS is shown as SMALL or MICRO, verify whether entitlement to that entity status still applies.

If the ENTITY STATUS is the same as shown above, pay the TOTAL FEE(S) DUE shown above.

If the ENTITY STATUS is changed from that shown above, on PART B - FEE(S) TRANSMITTAL, complete section number 5 titled "Change in Entity Status (from status indicated above)".

For purposes of this notice, small entity fees are 40% the amount of undiscounted fees, and micro entity fees are 20% the amount of undiscounted fees.

II. PART B - FEE(S) TRANSMITTAL, or its equivalent, must be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed. If an equivalent of Part B is filed, a request to reapply a previously paid issue fee must be clearly made, and delays in processing may occur due to the difficulty in recognizing the paper as an equivalent of Part B.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Maintenance fees are due in utility patents issuing on applications filed on or after Dec. 12, 1980. It is patentee's responsibility to ensure timely payment of maintenance fees when due. More information is available at www.uspto.gov/PatentMaintenanceFees.

PTOL-85 (Rev. 11/23)

EXHIBIT 1004 – Page 12 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

PART B - FEE(S) TRANSMITTAL

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BOSTON, MA 02210-2206

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(Typed or printed name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
17/860,950	07/08/2022	Corban I. Tillemann-Dick	M1567.70000US04	9208

TITLE OF INVENTION: INTEGRATED DILUTION REFRIGERATORS

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EXAMINER	ART UNIT	CLASS-SUBCLASS
NOUKETCHA, LIONEL W	3763	062-610000

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2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 _____
2 _____
3 _____

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE (B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) : ❑ Individual ❑ Corporation or other private group entity ❑ Government

4a. Fees submitted: ❑ Issue Fee ❑ Publication Fee (if required)

4b. Method of Payment: *(Please first reapply any previously paid fee shown above)*

❑ Electronic Payment via the USPTO patent electronic filing system ❑ Enclosed check ❑ Non-electronic payment by credit card (Attach form PTO-2038)

❑ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment to Deposit Account No. _____

5. **Change in Entity Status** (from status indicated above)

❑ Applicant certifying micro entity status. See 37 CFR 1.29
NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.

❑ Applicant asserting small entity status. See 37 CFR 1.27
NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.

❑ Applicant changing to regular undiscounted fee status.
NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature _____ Date _____

Typed or printed name _____ Registration No. _____

PTOL-85 Part B (11/23) Approved for use through 03/31/2026 OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

EXHIBIT 1004 – Page 13 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
17/860,950	07/08/2022	Corban I. Tillemann-Dick	M1567.70000US04	9208

23628 7590 04/03/2025

WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

EXAMINER	
NOUKETCHA, LIONEL W	
ART UNIT	PAPER NUMBER
3763	

DATE MAILED: 04/03/2025

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(Applications filed on or after May 29, 2000)

The Office has discontinued providing a Patent Term Adjustment (PTA) calculation with the Notice of Allowance.

Section 1(h)(2) of the AIA Technical Corrections Act amended 35 U.S.C. 154(b)(3)(B)(i) to eliminate the requirement that the Office provide a patent term adjustment determination with the notice of allowance. See Revisions to Patent Term Adjustment, 78 Fed. Reg. 19416, 19417 (Apr. 1, 2013). Therefore, the Office is no longer providing an initial patent term adjustment determination with the notice of allowance. The Office will continue to provide a patent term adjustment determination with the Issue Notification Letter that is mailed to applicant approximately three weeks prior to the issue date of the patent, and will include the patent term adjustment on the patent. Any request for reconsideration of the patent term adjustment determination (or reinstatement of patent term adjustment) should follow the process outlined in 37 CFR 1.705.

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at 1-(888)-786-0101 or (571)-272-4200.

EXHIBIT 1004 – Page 14 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

OMB Clearance and PRA Burden Statement for PTOL-85 Part B

The Paperwork Reduction Act (PRA) of 1995 requires Federal agencies to obtain Office of Management and Budget approval before requesting most types of information from the public. When OMB approves an agency request to collect information from the public, OMB (i) provides a valid OMB Control Number and expiration date for the agency to display on the instrument that will be used to collect the information and (ii) requires the agency to inform the public about the OMB Control Number's legal significance in accordance with 5 CFR 1320.5(b).

The information collected by PTOL-85 Part B is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 30 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450. Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. The United States Patent and Trademark Office (USPTO) collects the information in this record under authority of 35 U.S.C. 2. The USPTO's system of records is used to manage all applicant and owner information including name, citizenship, residence, post office address, and other information with respect to inventors and their legal representatives pertaining to the applicant's/ owner's activities in connection with the invention for which a patent is sought or has been granted. The applicable Privacy Act System of Records Notice for the information collected in this form is COMMERCE/PAT-TM-7 Patent Application Files, available in the Federal Register at 78 FR 19243 (March 29, 2013).
https://www.govinfo.gov/content/pkg/FR-2013-03-29/pdf/2013-07341.pdf

Routine uses of the information in this record may include disclosure to:

1) law enforcement, in the event that the system of records indicates a violation or potential violation of law;
2) a federal, state, local, or international agency, in response to its request;
3) a contractor of the USPTO having need for the information in order to perform a contract;
4) the Department of Justice for determination of whether the Freedom of Information Act (FOIA) requires disclosure of the record;
5) a Member of Congress submitting a request involving an individual to whom the record pertains, when the individual has requested the Member's assistance with respect to the subject matter of the record;
6) a court, magistrate, or administrative tribunal, in the course of presenting evidence, including disclosures to opposing counsel in the course of settlement negotiations;
7) the Administrator, General Services Administration (GSA), or their designee, during an inspection of records conducted by GSA under authority of 44 U.S.C. 2904 and 2906, in accordance with the GSA regulations and any other relevant (i.e., GSA or Commerce) directive, where such disclosure shall not be used to make determinations about individuals;
8) another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c));
9) the Office of Personnel Management (OPM) for personnel research purposes; and
10) the Office of Management and Budget (OMB) for legislative coordination and clearance.

If you do not furnish the information requested on this form, the USPTO may not be able to process and/or examine your submission, which may result in termination of proceedings, abandonment of the application, and/or expiration of the patent.

Notice of Allowability	Application No. 17/860,950	Applicant(s) Tillemann-Dick et al.	
	Examiner LIONEL W NOUKETCHA	Art Unit 3763	AIA (FITF) Status Yes

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☑ This communication is responsive to the correspondence filed on 02/07/2025.
   ☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2. ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

3. ☑ The allowed claim(s) is/are 1-21 . As a result of the allowed claim(s), you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see **http://www.uspto.gov/patents/init_events/pph/index.jsp** or send an inquiry to **PPHfeedback@uspto.gov.**

4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

   Certified copies:

   a) ☐ All b) ☐ Some* c) ☐ None of the:

   1. ☐ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____ .

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date _____ .

   Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).

6. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☐ Notice of References Cited (PTO-892)
2. ☑ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date _____.
3. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material _____.
4. ☐ Interview Summary (PTO-413), Paper No./Mail Date. _____.
5. ☐ Examiner's Amendment/Comment
6. ☑ Examiner's Statement of Reasons for Allowance
7. ☐ Other _____.

/LIONEL NOUKETCHA/
Primary Examiner, Art Unit 3763

EXHIBIT 1004 – Page 16 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Notice of Allowance

Information Disclosure Statement

1. The information disclosure statements (IDS) submitted on 01/17/2025 and 03/06/2025 are in compliance with the provisions of 37 CFR 1.97. Accordingly, the information disclosure statement is being considered by the examiner.

Reasons for Allowance

2. Claims 1-21 are allowed.

3. The following is an examiner's statement of reasons for allowance:

The prior art does not anticipate nor render obvious the combination set forth in the independent claims, and specifically does not disclose an outer vacuum chamber comprising an outer housing having at least one substantially planar surface; and an opening in the at least one substantially planar surface of the outer housing configured to provide access to an experimental volume disposed within an interior of the outer vacuum chamber. There is no teaching in the prior art of record that would, reasonably and absent impermissible hindsight, motivate one of ordinary skill in the art to modify the teachings of Hart to incorporate the aforementioned limitations.

Any comments considered necessary by applicant must be submitted no later than the payment of the issue fee and, to avoid processing delays, should preferably accompany the issue fee. Such submissions should be clearly labeled "Comments on Statement of Reasons for Allowance."

Conclusion

4. Any inquiry concerning this communication or earlier communications from the examiner should be directed to LIONEL W NOUKETCHA whose telephone number is (571)272-8438. The examiner can normally be reached on Mon - Fri: 08:00 AM - 04:00 PM.

Examiner interviews are available via telephone, in-person, and video conferencing using a USPTO supplied web-based collaboration tool. To schedule an interview, applicant is encouraged to use the USPTO Automated Interview Request (AIR) at http://www.uspto.gov/interviewpractice.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Frantz Jules can be reached on 571-272-6681. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/LIONEL NOUKETCHA/
Primary Examiner, Art Unit 3763

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	17/860,950	Tillemann-Dick et al.
	Examiner	**Art Unit**
	LIONEL W NOUKETCHA	3763

CPC						
Symbol					**Type**	**Version**
F25B	/	9	/	12	F	2013-01-01
F25B	/	9	/	10	I	2013-01-01
F25D	/	19	/	006	I	2013-01-01
F25B	/	9	/	145	I	2013-01-01
F25B	/	25	/	005	I	2013-01-01
H05K	/	7	/	208	I	2013-01-01
H05K	/	7	/	20827	A	2013-01-01
F25B	/	2500	/	13	A	2013-01-01
B33Y	/	80	/	00	A	2014-12-01

CPC Combination Sets							
Symbol					**Type**	**Set**	**Ranking**	**Version**
	/		/					

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 21	
/LIONEL NOUKETCHA/ Primary Examiner, Art Unit 3763 (Primary Examiner)	21 March 2025 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1

U.S. Patent and Trademark Office — Part of Paper No.: 20250321

EXHIBIT 1004 – Page 19 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	17/860,950	Tillemann-Dick et al.
	Examiner	**Art Unit**
	LIONEL W NOUKETCHA	3763

INTERNATIONAL CLASSIFICATION				
CLAIMED				
F25B9/12	/	9	/	12
F25B9/10	/	9	/	10
F25D19/00	/	19	/	00

NON-CLAIMED				
	/		/	

US ORIGINAL CLASSIFICATION	
CLASS	**SUBCLASS**

CROSS REFERENCES(S)						
CLASS	**SUBCLASS (ONE SUBCLASS PER BLOCK)**					

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 21	
/LIONEL NOUKETCHA/ Primary Examiner, Art Unit 3763 (Primary Examiner)	21 March 2025 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1

U.S. Patent and Trademark Office — Part of Paper No.: 20250321

EXHIBIT 1004 – Page 20 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	17/860,950	Tillemann-Dick et al.
	Examiner	**Art Unit**
	LIONEL W NOUKETCHA	3763

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIMS

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1	6	10	14	19										
2	2	7	11	15	20										
3	3	8	12	20	21										
17	4	9	13												
4	5	10	14												
5	6	11	15												
18	7	12	16												
18	8	13	17												
21	9	16	18												

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	21	
/LIONEL NOUKETCHA/ Primary Examiner, Art Unit 3763	21 March 2025	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1

U.S. Patent and Trademark Office

Part of Paper No.: 20250321

EXHIBIT 1004 – Page 21 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	17/860,950	Tillemann-Dick et al.
	Examiner	Art Unit
	LIONEL W NOUKETCHA	3763

CPC - Searched*		
Symbol	**Date**	**Examiner**
F25B9/12 F25B9/145 F25D2317/043 F25B9/14	11/04/2024	LN

CPC Combination Sets - Searched*		
Symbol	**Date**	**Examiner**

US Classification - Searched*			
Class	**Subclass**	**Date**	**Examiner**

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	**Date**	**Examiner**
F25B9/12 F25B9/145 F25D2317/043 F25B9/14	11/04/2024	LN
CPC combined with text	11/04/2024	LN
Inventors and applicant names searched	11/04/2024	LN
Concept searched in IP.com	11/04/2024	LN
Search history attached	11/04/2024	LN
Search updated	03/21/2025	LN

/LIONEL NOUKETCHA/ Primary Examiner, Art Unit 3763	

EXHIBIT 1004 – Page 22 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	17/860,950	Tillemann-Dick et al.
	Examiner	Art Unit
	LIONEL W NOUKETCHA	3763

Interference Search			
US Class/CPC Symbol	**US Subclass/CPC Group**	**Date**	**Examiner**
	Text searched claimed keywords in all classifications	03/21/2025	LN
	Refer to search history for details	03/21/2025	LN

/LIONEL NOUKETCHA/ Primary Examiner, Art Unit 3763	

EXHIBIT 1004 – Page 23 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	17/860,950	Tillemann-Dick et al.
	Examiner	**Art Unit**
	LIONEL W NOUKETCHA	3763

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

CLAIMS

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
Final	Original	11/04/2024	03/21/2025							
1	1	✓	=							
2	2	✓	=							
3	3		=							
17	4	✓	=							
4	5		=							
5	6	✓	=							
18	7	✓	=							
19	8	O	=							
21	9		=							
6	10		=							
7	11		=							
8	12	O	=							
9	13		=							
10	14	O	=							
11	15	O	=							
12	16	✓	=							
13	17	✓	=							
16	18	✓	=							
14	19	✓	=							
15	20	✓	=							
20	21		=							

EXHIBIT 1004 – Page 24 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

FORM PTO-1449/A and B (modified PTO/SB/08) **INFORMATION DISCLOSURE STATEMENT BY APPLICANT**				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet	1	of	1	GROUP ART UNIT: 3763	EXAMINER: L. W. Nouketcha

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	U.S. Patent Document Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		6,202,439	B1	Mikheev et al.	03-20-2001
		2013-0014518	A1	Aigouy et al.	01-17-2013
		2014-0202179	A1	Batey et al.	07-24-2014
		2017-0167475	A1	MORI et al.	06-15-2017
		2018-0216684	A1	GRUSS et al.	08-02-2018
		2020-0262013	A1	NISHIO et al.	08-20-2020

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Foreign Patent Document Number	Foreign Patent Document Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		JP	2006-138851	A	Bruker Biospin AG	06-01-2006	Y; Abstract Only
		JP	2007-048973	A	Sumitomo Heavy Industries	02-22-2007	Y; Abstract Only

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)
		Korean Notice of Preliminary Rejection dated November 26, 2024, in connection with Korean Application No. 10-2024-7004190, with English translation. (M1567.70000KR00).	Y

[NOTE – No copies of U.S. patents, published U.S. patent applications, or pending, unpublished patent applications stored in the USPTO's Image File Wrapper (IFW) system, are included. See 37 CFR § 1.98 and 1287OG163. Copies of all other patent(s), publication(s), unpublished, pending U.S. patent applications, or other information listed are provided as required by 37 CFR § 1.98 unless 1) such copies were provided in an IDS in an earlier application that complies with 37 CFR § 1.98, and 2) the earlier application is relied upon for an earlier filing date under 35 U.S.C. § 120.]

EXAMINER: /LIONEL NOUKETCHA/	DATE CONSIDERED: 03/21/2025

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

PE2E SEARCH - Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	British Equivalents	Time Stamp
L1	1	"20210402407".pn.	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 09:33 AM
L2	3	jp-2012182176$.did.	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/03 10:26 AM
L3	4	"17860950"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/03 10:30 AM
L4	1	"20220279927".pn.	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:06 AM
L5	144	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment)	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:43 AM
L6	74	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:43 AM
L7	0	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment) AND opening near3	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:46 AM

		(hermetic OR door) AND @pd<="20210708"					
L8	74	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:46 AM
L9	8	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment) AND (hermetic OR door) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:52 AM
L10	6	("2014/0007596").urpn. AND (PGPB | USPT | USOC).dbnm.	(US-PGPUB; USPAT; USOCR)	OR	ON	ON	2024/11/03 12:04 PM
L11	10	("4432216" | "5323112" | "5611207" | "5744959" | "20030122543" | "20050202976" | "20080098752" | "20100109666").pn. OR ("9458969").urpn. AND (PGPB | USPT | USOC).dbnm.	(US-PGPUB; USPAT; USOCR)	OR	ON	ON	2024/11/03 12:04 PM
L12	9	(F25B9/12).cpc. AND (F25D2317/043).cpc.	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/03 12:13 PM
L13	1	(F25B9/12).cpc. AND (hermetic OR door) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/03 03:49 PM
L14	12	("20140137571"|"20180112928"|"20190042968"|"9779360"|"20140137571"|"20140326001"|"20180112928"|"20190042968"|"20090007573"|"20110120147"|"20170284725"|"4136526"|"4300360"|"4485640"|"5347819"|"20140137571").PN.	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 04:05 PM
L15	21	(F25B9/12).cpc. AND cover AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/03 04:07 PM
L16	74	dilution ADJ refrigerator AND vacuum ADJ (chamber) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 10:04 PM
L17	178	((("TILLEMANN-DICK") near3 ("Corban")) OR (("THOMPSON") near3	(US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT)	OR	ON	ON	2024/11/03 10:13 PM

EXHIBIT 1004 – Page 27 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

		("Kyle")) OR (("CHOO") near3 ("Bryan")) OR (("OGANDO") near3 ("DOS") near3 ("SANTOS") near3 ("ALLAN") near3 ("John")) OR (("BYARS") near3 ("Jonathan"))).INV.					
L18	10	((("MAYBELL") near3 ("QUANTUM") near3 ("INDUSTRIES") near3 ("INC"))).AS,AANM.	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 10:13 PM
L19	515	L18 L17	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/03 10:13 PM
L20	0	L19 dilution ADJ refrigerator AND vacuum ADJ (chamber) AND @pd<="20210708"	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:14 PM
L21	9	L19 dilution ADJ refrigerator AND vacuum ADJ (chamber)	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:14 PM
L22	1	L19 dilution ADJ refrigerator AND (sample ADJ stage).clm.	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:17 PM
L23	8	dilution ADJ refrigerator AND (sample ADJ stage).clm.	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:18 PM
L24	15	("20040223300" OR "20050223714" OR "20090275476" OR "20150160702" OR "20180051937" OR "20190226724" OR "20200370792" OR "20210076530" OR "20210402407" OR "20220221108" OR	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:27 PM

		"4296609" OR "4672823" OR "4986077" OR "5172554" OR "5207674").pn.					
L25	1	("6202439").pn.	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 11:24 PM
L26	6	("5542256" | "5816071").pn. OR ("6202439").urpn. AND (PGPB | USPT | USOC).dbnm.	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/03 11:33 PM
L27	2	dilution ADJ refrigerator AND (lid OR cover) near10 (hinged OR easy OR access) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 08:46 AM
L28	2	dilution ADJ refrigerator AND (lid OR cover OR panel) near10 (hinged OR easy OR access$3) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 08:47 AM
L29	54	dilution ADJ refrigerator AND (lid OR cover OR panel OR opening) near10 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:07 AM
L30	1409	cryostat AND (lid OR cover OR panel OR opening) near10 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:51 AM
L31	1176	cryostat AND (lid OR cover OR panel OR opening) near6 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:51 AM
L32	919	cryostat AND (lid OR cover OR panel OR opening) near6 (vacuum OR shell OR chamber) AND vacuum AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:52 AM
L33	305	cryostat AND (lid OR cover OR panel OR opening) near6 (vacuum OR shell OR chamber) AND vacuum AND shield AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:52 AM

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IPR2026-00291 - U.S. Patent No. 12,313,320

L34	517	cryostat AND (lid OR cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND vacuum AND shield AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:53 AM
L35	380	cryostat AND (lid OR cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND vacuum near5 (shell OR chamber OR housing OR casing) AND shield AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:53 AM
L36	21	cryostat AND ((lid OR cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND vacuum near5 (shell OR chamber OR housing OR casing) AND shield).clm. AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:54 AM
L37	23	cryostat AND ((cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND (vacuum OR seal$3 OR hermetic) near5 (shell OR chamber OR housing OR casing) AND shield).clm. AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:57 AM
L38	1255	cryostat AND ((cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND (vacuum OR seal$3 OR hermetic) near5 (shell OR chamber OR housing OR casing) AND shield) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA,	AND	ON	ON	2024/11/04 09:58 AM

			VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)				
L39	2091	(cryostat OR (dilution ADJ refrigerator)) AND (cover OR panel OR opening OR plate) near3 (vacuum OR shell OR chamber OR housing OR casing) AND (vacuum OR seal$3 OR hermetic) near3 (shell OR chamber OR housing OR casing) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	AND	ON	ON	2024/11/04 09:59 AM
L40	134	(cryostat OR (dilution ADJ refrigerator)) AND (cover OR panel OR opening OR plate OR door) near3 (vacuum OR shell OR chamber OR housing OR casing) AND (vacuum OR seal$3 OR hermetic) near3 (shell OR chamber OR housing OR casing) AND (cover OR panel OR opening OR plate OR door) near6 (srew OR hinged OR fasten$4) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	AND	ON	ON	2024/11/04 10:02 AM
L41	346	(F25B9/12 OR F25B9/145 OR F25D2317/043 OR F25B9/14).cpc. AND (lid OR cover OR panel OR opening) near6 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/04 02:46 PM
L42	1565	(F25B9/12 OR F25B9/145 OR F25D2317/043 OR F25B9/14).cpc. AND (lid OR cover OR panel OR opening) near3 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO,	OR	ON	ON	2024/11/04 02:46 PM

			RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)				
L43	387	(F25B9/12 OR F25B9/145 OR F25D2317/043 OR F25B9/14).cpc. AND (lid OR cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND vacuum near5 (shell OR chamber OR housing OR casing) AND shield AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AP, AT, AU, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, MC, MD, MY, NL, NO, NZ, OA, PH, PL, PT, RO, RS, RU, SE, SG, SI, SK, SU, TH, TN, TR, TW, UA, VN, WO); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/04 02:48 PM
L44	24	L43 AND dilution ADJ refrigerator	(US-PGPUB; USPAT; USOCR; FIT (AP, AT, AU, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, MC, MD, MY, NL, NO, NZ, OA, PH, PL, PT, RO, RS, RU, SE, SG, SI, SK, SU, TH, TN, TR, TW, UA, VN, WO); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/04 02:48 PM

PE2E SEARCH - Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	British Equivalents	Time Stamp
N1	2	(dilution ADJ refrigerator AND (door OR (access ADJ panel))).clm.	(US-PGPUB; USPAT)	OR	ON	ON	2025/03/21 03:02 PM
N2	44	(Artificial Intelligence) More like doc: US-20230008279-A1 Text: (FR-2184536-A1 OR NL-7902438-A OR EP-0089391-B1 OR FR-2574914-B1 OR GB-9814546-D0 OR EP-1321822-A1 OR US-	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO,	OR	ON	ON	2025/03/21 03:02 PM

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

		7046514-B2 OR EP-1669634-A1 OR GB-0408425-D0 OR US-20090206229-A1 OR FR-2958025-A1 OR GB-2493553-B OR US-20150160702-A1 OR KR-101885017-B1 OR EP-3265737-A4 OR FR-3035937-B1 OR JP-7311275-B2 OR DE-102019203341-A1 OR GB-2584135-A OR US-20230008279-A1).did.	NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)				
N3	17	(((dilution OR cryogenic) ADJ (unit OR refrigerator) OR cryostat) AND (door OR (access ADJ panel))).clm.	(US-PGPUB; USPAT)	OR	ON	ON	2025/03/21 03:09 PM
N4	6	("20130014518"|"20140202179"|"20170167475"|"20180216684"|"20200262013"|"6202439").PN.	(US-PGPUB; USPAT)	OR	ON	ON	2025/03/21 03:15 PM

FORM PTO-1449/A and B (modified PTO/SB/08) **INFORMATION DISCLOSURE STATEMENT BY APPLICANT**				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet	1	of	1	GROUP ART UNIT: 3763	EXAMINER: L. W. Nouketcha

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	U.S. Patent Document Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		4,987,102	A	Nguyen et al.	01-22-1991
		2005-0229620	A1	Kirichek et al.	10-20-2005

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Foreign Patent Document Number	Foreign Patent Document Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)

[NOTE – No copies of U.S. patents, published U.S. patent applications, or pending, unpublished patent applications stored in the USPTO's Image File Wrapper (IFW) system, are included. See 37 CFR § 1.98 and 1287OG163. Copies of all other patent(s), publication(s), unpublished, pending U.S. patent applications, or other information listed are provided as required by 37 CFR § 1.98 unless 1) such copies were provided in an IDS in an earlier application that complies with 37 CFR § 1.98, and 2) the earlier application is relied upon for an earlier filing date under 35 U.S.C. § 120.]

EXAMINER: /LIONEL NOUKETCHA/	DATE CONSIDERED: 03/21/2025

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

FORM PTO-1449/A and B (modified PTO/SB/08)				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet	1	of	1	GROUP ART UNIT: 3763	EXAMINER: L. W. Nouketcha

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document		Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		Number	Kind Code		
		4,987,102	A	Nguyen et al.	01-22-1991
		2005-0229620	A1	Kirichek et al.	10-20-2005

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document			Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		Office/ Country	Number	Kind Code			

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)

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EXAMINER:	DATE CONSIDERED:

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

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ELECTRONIC PAYMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**03/06/2025 04:21:45 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Jamie. Shepard
PATENT CENTER #	69471838	AUTHORIZED BY	John Otterbein
CUSTOMER #	23628	FILING DATE	07/08/2022
CORRESPONDENCE ADDRESS	-	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick

Payment Information

PAYMENT METHOD	PAYMENT TRANSACTION ID	PAYMENT AUTHORIZED BY
CARD / 8543	**E202536G22548497**	**Jamie. Shepard**

PRE-AUTHORIZED ACCOUNT	PRE-AUTHORIZED CATEGORY
232825	**37 CFR 1.17 (Patent application and reexamination processing fees)**

FEE CODE	DESCRIPTION	ITEM PRICE($)	QUANTITY	ITEM TOTAL($)
2806	SUBMISSION OF AN INFORMATION DISCLOSURE STATEMENT	112.00	1	112.00
			TOTAL AMOUNT:	**$112.00**

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**03/06/2025 04:21:45 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Jamie. Shepard
PATENT CENTER #	69471838	FILING DATE	07/08/2022
CUSTOMER #	23628	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	John Otterbein

Documents

TOTAL DOCUMENTS: 4

DOCUMENT	PAGES	DESCRIPTION	SIZE (KB)
M156770000US04-TRN-JAO.pdf	1	Miscellaneous Incoming Letter	25 KB
M156770000US04-IDSBODY-JAO.pdf	3	Letter specifying the conditions for filing under 37 CFR 1.97	27 KB
M156770000US04-IDS1449-JAO.pdf	1	Information Disclosure Statement (IDS) Form (SB08)	20 KB
Warning: This is not a USPTO supplied IDS fillable form. Data in the form cannot be automatically loaded to other USPTO systems.			
M156770000US04-FEE-JAO.pdf	2	Fee Worksheet (SB06)	76 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
M156770000US04-TRN-JAO.pdf	3B013B5E6C740C2A826EC81BFE05E32DA608D7749DD518B826E2FE255A5F64FD9FB91762BB3C3D59C462CCE7D4052BA44F7C0B35D453282592ABD436F197A665
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M156770000US04-IDS1449-JAO.pdf	D46A84400E39E06A1E61759AD4FB6E859F5D7248A236F506F8EAF5308CB00964BFD3AD142805FF13A14B7783942636E7922F90FF9498AA15CDB831CFDD4B5FB5
M156770000US04-FEE-JAO.pdf	6CBC935A73747602538C835D5150D19700E26E267FAB7C64927DC2384C91863A6BA17DDE026C7936F0E3B463247E6163339970E5E9A61AC3CBD0E01F5A3C7075

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

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New International Application Filed with the USPTO as a Receiving Office

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DOCKET NO.: M1567.70000US04

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	L. W. Nouketcha
Art Unit:	3763

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: March 6, 2025 Electronic Signature for Jamie L. Shepard: /Jamie L. Shepard/

MAIL STOP AMENDMENT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

STATEMENT FILED PURSUANT TO THE DUTY OF DISCLOSURE UNDER 37 C.F.R. §§ 1.56, 1.97 AND 1.98

Commissioner:

Pursuant to the duty of disclosure under 37 C.F.R. §§ 1.56, 1.97 and 1.98, the undersigned requests consideration of this Information Disclosure Statement.

PART I: Compliance with 37 C.F.R. § 1.97 and 37 C.F.R. § 1.98

This Information Disclosure Statement is being filed before the mailing date of any of a final action under 37 C.F.R. § 1.113, a Notice of Allowance under 37 C.F.R. § 1.311, or an action that otherwise closes prosecution in this application.

Please charge our Credit Card in the amount of $112.00 covering the fee set forth in 37 C.F.R. § 1.17(p).

The undersigned hereby states, as specified in 37 C.F.R. §§ 1.97(a) and 1.98(a)(4), that:

This Information Disclosure Statement does not cause the cumulative number of items of information cited in the above-identified application to exceed any item threshold specified in 37 C.F.R. § 1.17(v).

PART II: Information Cited

The undersigned hereby makes of record in the above-identified application the information listed on the attached form PTO-1449 (modified PTO/SB/08). The order of presentation of the references should not be construed as an indication of the importance of the references.

PART III: Remarks

Documents cited anywhere in the Information Disclosure Statement are enclosed unless otherwise indicated. It is respectfully requested that:

1. The Examiner consider completely the cited information, along with any other information, in reaching a determination concerning the patentability of the claims;

2. The enclosed form PTO-1449 (modified PTO/SB/08) be signed by the Examiner to evidence that the cited information has been fully considered by the United States Patent and Trademark Office during the examination of this application; and

3. The citations for the information be printed on any patent which issues from this application.

By submitting this Information Disclosure Statement, the undersigned makes no representation that a search has been performed, of the extent of any search performed, or that more relevant information does not exist.

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in this Statement is, or is considered to be, material to patentability as defined in 37 C.F.R. § 1.56(b).

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in this Statement is, or is considered to be, in fact, prior art as defined by 35 U.S.C. § 102, or an admission by Applicant as being prior art.

Notwithstanding any statements by the undersigned, the Examiner is urged to form an independent conclusion regarding the relevance of the cited information.

An early and favorable action is hereby requested.

The Director is hereby authorized to charge any deficiency or credit any overpayment in the fees occasioned by the filing of this Information Disclosure Statement to our Deposit Account No. 23/2825 under Docket No. M1567.70000US04 from which the undersigned is authorized to draw.

Respectfully submitted,

Electronic signature: /John A. Otterbein/
John A. Otterbein
Registration No.: 80,331
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

Docket No.: M1567.70000US04
Date: March 4, 2025

FEE TRANSMITTAL

(page 1 of 2)

		Complete if known	
☐ Applicant asserts small entity status. See 37 CFR 1.27.		Application Number	17/860,950-Conf. #9208
		Filing Date	July 8, 2022
☐ Applicant certifies micro entity status. See 37 CFR 1.29. Form PTO/SB/15A or B or equivalent must either be enclosed or have been submitted previously.		First Named Inventor	Corban I. Tillemann-Dick
		Examiner Name	L. W. Nouketcha
		Art Unit	3763
TOTAL AMOUNT OF PAYMENT	($) 112.00	Practitioner Docket No.	M1567.70000US04

METHOD OF PAYMENT (check all that apply)

☐ Check ☒ Credit Card ☐ Money Order ☐ None ☐ Other (please identify): _____

☒ Deposit Account Deposit Account Number: 23/2825 Deposit Account Name: Wolf, Greenfield & For the above-identified deposit account, the Director is hereby authorized to (check all that apply):

- ☐ Charge fee(s) indicated below
- ☐ Charge fee(s) indicated below, **except for the filing fee**
- ☒ Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17, **except for any excess claims fees or multiple dependent claims fees**
- ☐ Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17
- ☒ Credit any overpayment of fee(s)

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES (U = undiscounted fee; S = small entity fee; M = micro entity fee)

	FILING FEES			SEARCH FEES			EXAMINATION FEES			
Application Type	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**Fees Paid ($)**
Utility	350	140*	70	770	308	154	880	352	176	
Design	300	120	60	300	120	60	700	280	140	
Plant	240	96	48	485	194	97	725	290	145	
Reissue	350	140	70	770	308	154	2,550	1,020	510	
Provisional	325	130	65	0	0	0	0	0	0	

* The $140 small entity filing fee for a utility application is further reduced to $70 for a small entity applicant who files the application via Patent Center.

2. EXCESS CLAIM FEES

Fee Description	**Undiscounted Fee ($)**	**Small Entity Fee ($)**	**Micro Entity Fee ($)**
Each claim over 20 (including Reissues)	200	80	40
Each independent claim over 3 (including Reissues)	600	240	120
Multiple dependent claims	925	370	185

Total Claims **Extra Claims** **Fee ($)** **Fee Paid ($)**

_____ - 20 or HP = _____ x _____ = _____

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims **Extra Claims** **Fee ($)** **Fee Paid ($)**

_____ - 3 or HP = _____ x _____ = _____

paid for, if greater than 3.

Multiple Dependent Claims **Fee ($)** **Fee Paid ($)**

_____ _____

HP = highest number of independent claims

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $450 ($180 for small entity) ($90 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets **Extra Sheets** **Number of each additional 50 or fraction thereof** **Fee ($)** **Fee Paid ($)**

_____ - 100 = _____ /50 = _____ (round **up** to a whole number) x _____ = _____

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: March 6, 2025 Electronic Signature for Jamie L. Shepard: /Jamie L. Shepard/

13717472

FEE TRANSMITTAL

(page 2 of 2)

4. CONTINUING APPLICATION FEE

If the actual filing date of the application is more than six years after the earliest benefit date, a continuing application fee is due. The earliest benefit date is the earliest filing date for which benefit is claimed under 35 U.S.C. 120, 121, 365(c), or 386(c) and § 1.78(d).

Choose only one of the following:

If the actual filing date is more than six years, and is less than or equal to nine years, after the earliest benefit date, the continuing application fee is $2,700 ($1,080 for small entity or $540 for micro entity). See 37 CFR 1.17(w)(1).

or

If the actual filing date is more than nine years after the earliest benefit date, the continuing application fee is $4,000 ($1,600 for small entity or $800 for micro entity), less any amount previously paid under 37 CFR 1.17(w)(1). See 37 CFR 1.17(w)(2).

Fees Paid ($)

5. OTHER FEE(S) **Fees Paid ($)**

Non-English specification, $150 fee ($60 for small entity) ($30 for micro entity)

Non-electronic filing fee under 37 CFR 1.16(t) for a utility application, $400 fee ($200 small or micro entity)

Other (e.g., late filing surcharge): 2806 Submission of an Information Disclosure Statement 112.00

SUBMITTED BY					
Signature	/John A. Otterbein/	Registration No. (Attorney/Agent)	80,331	Telephone	617.646.8000
Name (Print/Type)	John A. Otterbein			Date	March 6, 2025

13717472

Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission	

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban I. Tillemann-Dick
Art Unit	3763
Examiner Name	L. W. Nouketcha
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

[X] Fee Transmittal Form	[ ] Drawing(s)	[ ] After Allowance Communication to TC
[ ] Fee Attached	[ ] Licensing-related Papers	[ ] Appeal Communication to Board of Appeals and Interferences
[ ] Amendment/Reply	[ ] Petition	[ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
[ ] After Final	[ ] Petition to Convert to a Provisional Application	[ ] Proprietary Information
[ ] Affidavits/declaration(s)	[ ] Power of Attorney, Revocation Change of Correspondence Address	[ ] Status Letter
[ ] Extension of Time Request	[ ] Terminal Disclaimer	[X] Other Enclosure(s) (please Identify below):
[ ] Express Abandonment Request	[ ] Request for Refund	Form PTO-1449
[X] Information Disclosure Statement	[ ] CD, Number of CD(s) _____	
[ ] Certified Copy of Priority Document(s)	[ ] Landscape Table on CD	
[ ] Reply to Missing Parts/ Incomplete Application	Remarks	
[ ] Reply to Missing Parts under 37 CFR 1.52 or 1.53		

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/John A. Otterbein/		
Printed name	John A. Otterbein		
Date	March 4, 2025	Reg. No.	80,331

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: March 6, 2025 Electronic Signature for Jamie L. Shepard: /Jamie L. Shepard/

13717548

Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission	

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban I. Tillemann-Dick
Art Unit	3763
Examiner Name	L. W. Nouketcha
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

- [X] Fee Transmittal Form
- [ ] Fee Attached
- [X] Amendment/Reply
- [ ] After Final
- [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [ ] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Reply to Missing Parts/ Incomplete Application
- [ ] Reply to Missing Parts under 37 CFR 1.52 or 1.53
- [X] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) _____
- [ ] Landscape Table on CD
- [ ] After Allowance Communication to TC
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- [ ] Proprietary Information
- [ ] Status Letter
- [ ] Other Enclosure(s) (please Identify below):

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Sarah C. C. Schlotter/		
Printed name	Sarah C.C. Schlotter, PhD		
Date	February 7, 2025	Reg. No.	79,027

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: February 7, 2025 Electronic Signature for Eileen M. MacKenzie: / Eileen M. MacKenzie /

13388297

UNITED STATES
PATENT AND TRADEMARK OFFICE

P.O. Box 1450
Alexandria, VA 22313 - 1450
www.uspto.gov

ELECTRONIC PAYMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**02/07/2025 07:18:11 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Eileen MacKenzie
PATENT CENTER #	69104843	AUTHORIZED BY	Sarah Schlotter
CUSTOMER #	23628	FILING DATE	07/08/2022
CORRESPONDENCE ADDRESS	-	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick

Payment Information

PAYMENT METHOD	PAYMENT TRANSACTION ID	PAYMENT AUTHORIZED BY
CARD / 8576	**E202527J18576507**	**Eileen MacKenzie**

PRE-AUTHORIZED ACCOUNT	PRE-AUTHORIZED CATEGORY
232825	**37 CFR 1.17 (Patent application and reexamination processing fees)**

FEE CODE	DESCRIPTION	ITEM PRICE($)	QUANTITY	ITEM TOTAL($)
2202	EACH CLAIM IN EXCESS OF 20	80.00	1	80.00
			TOTAL AMOUNT:	**$80.00**

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

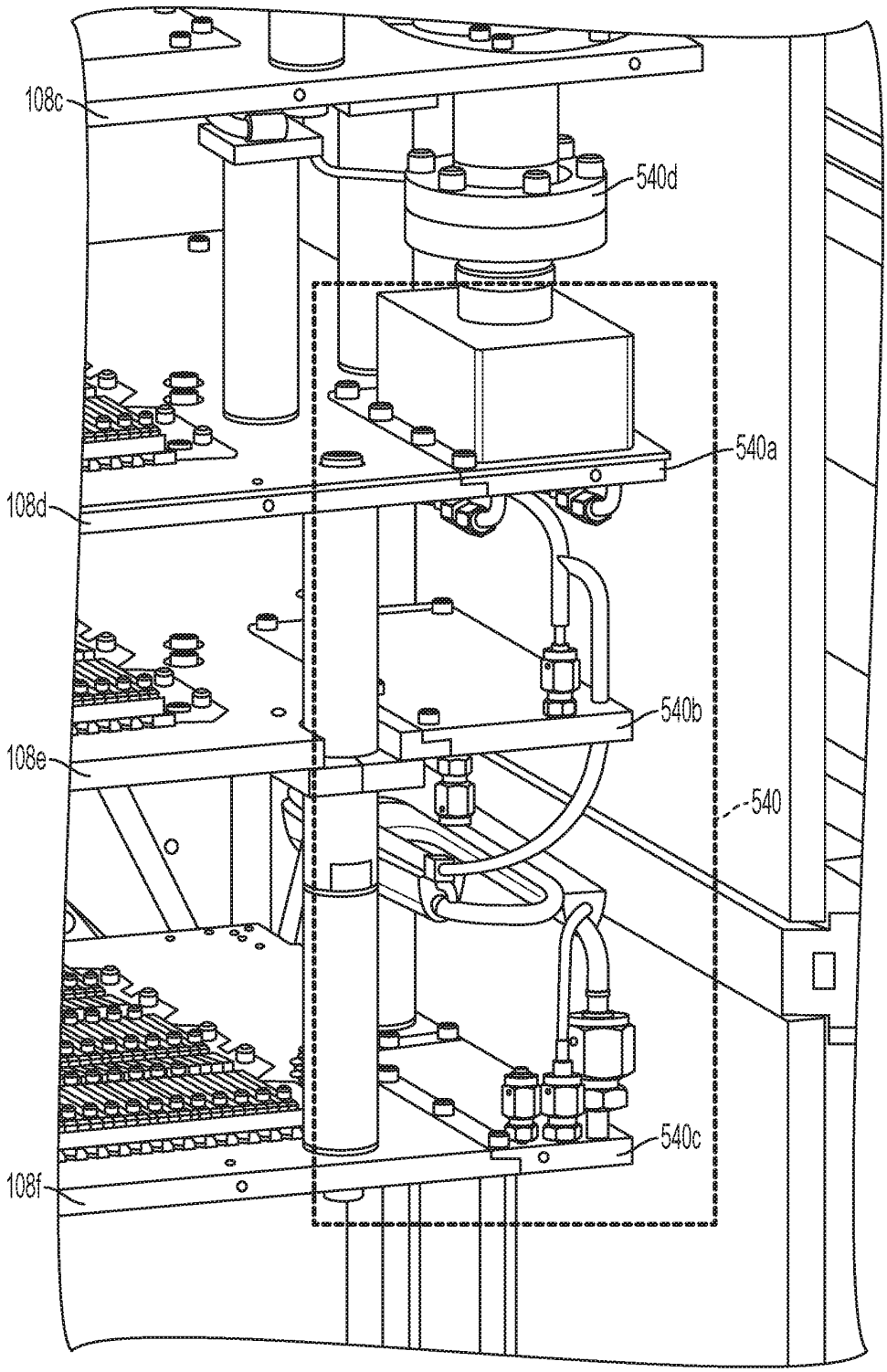


FIG. 5A

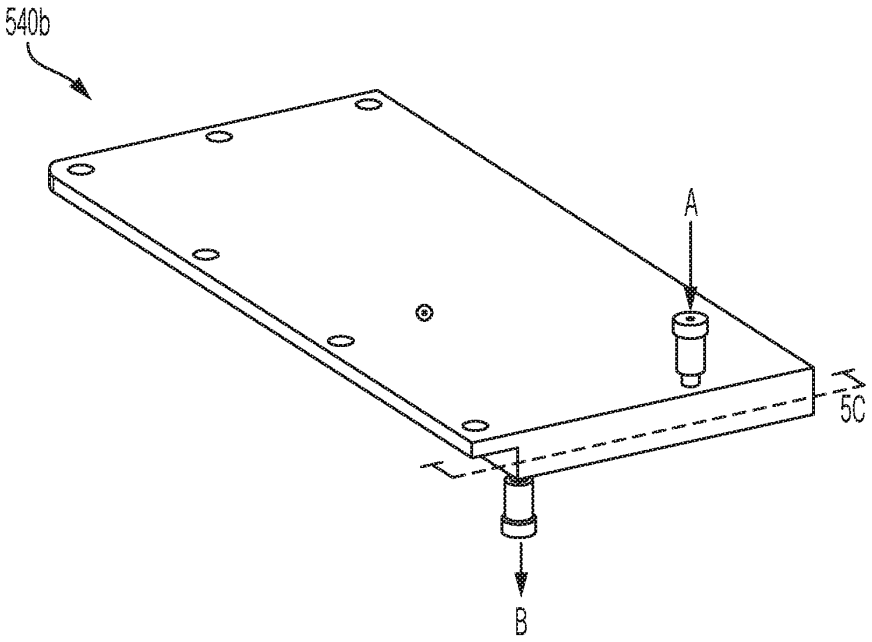


FIG. 5B

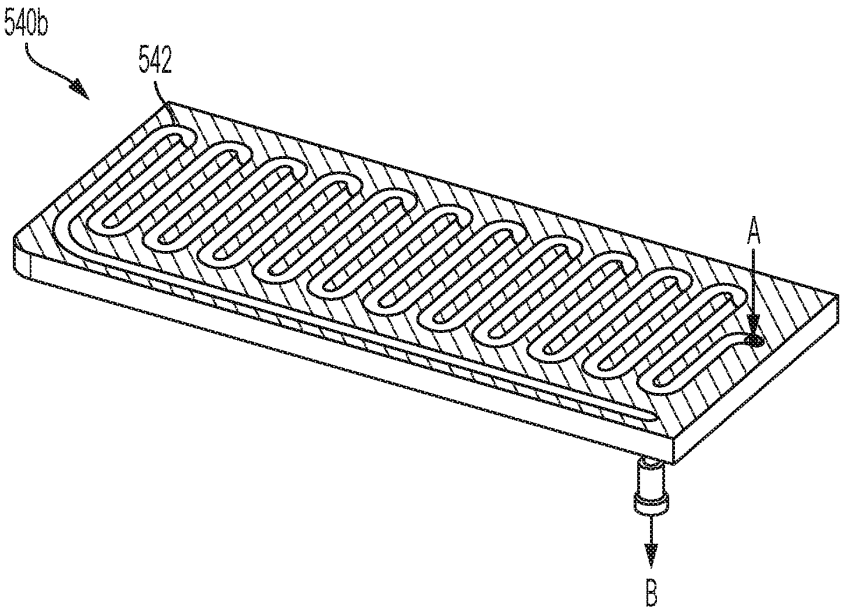


FIG. 5C

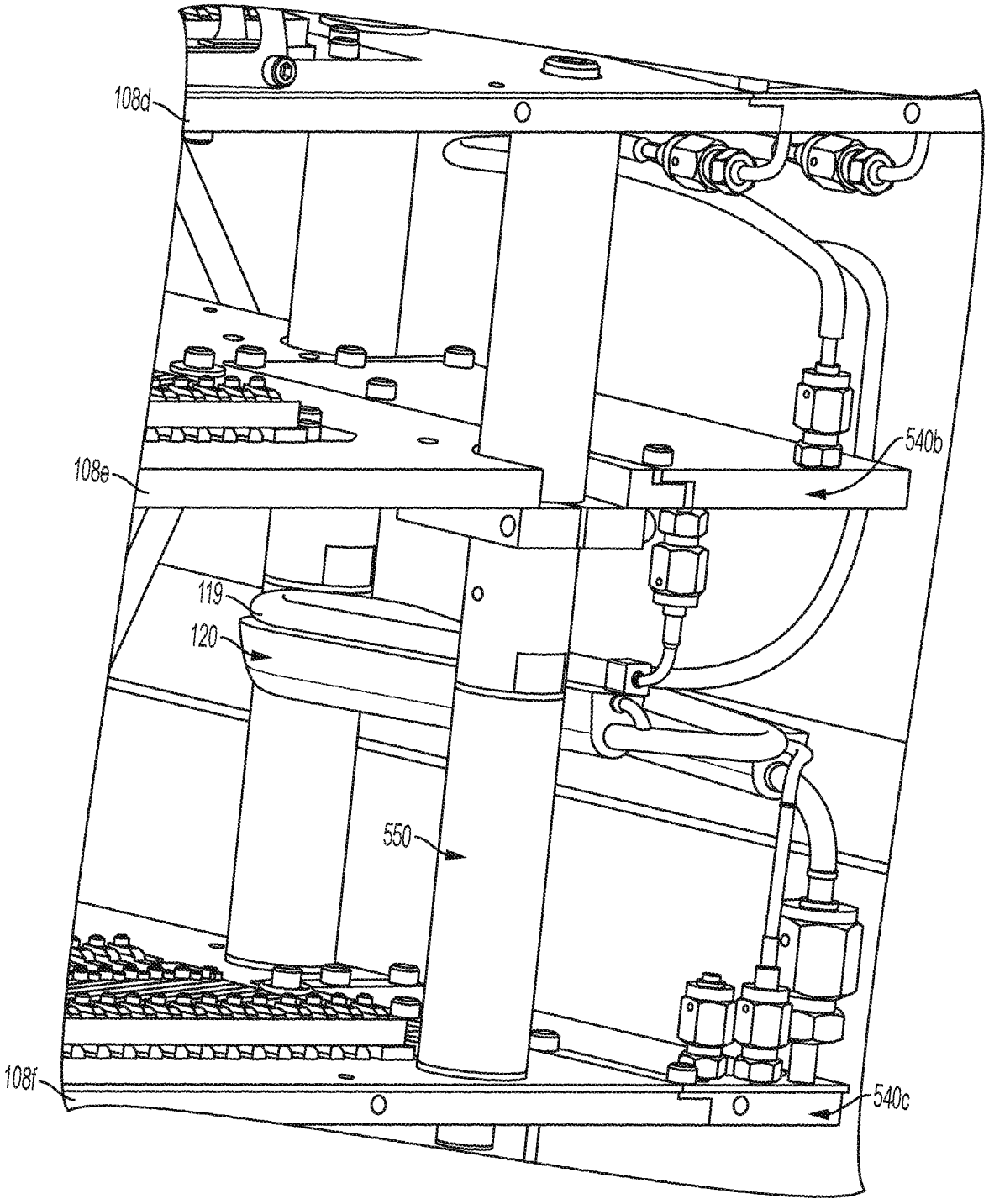


FIG. 5E

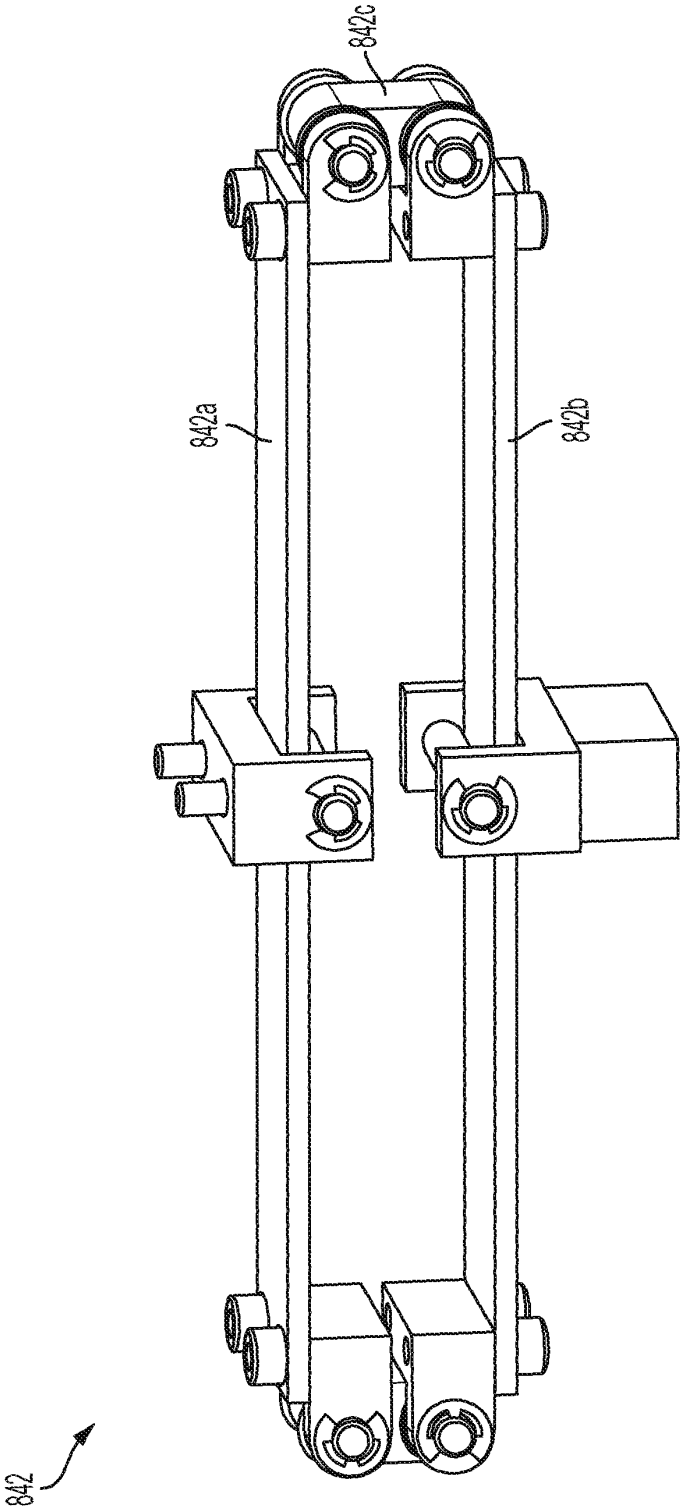


FIG. 8B

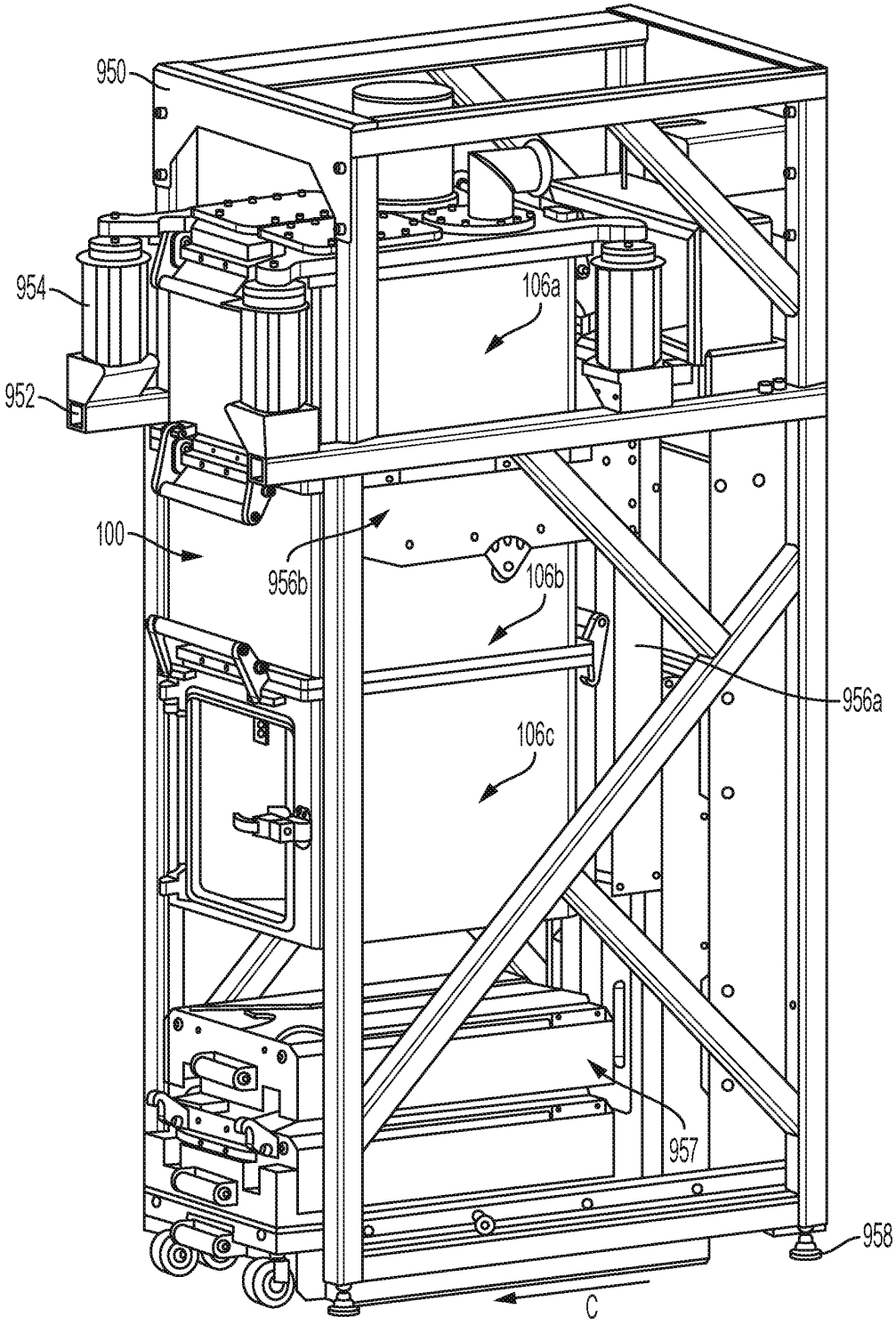


FIG. 9

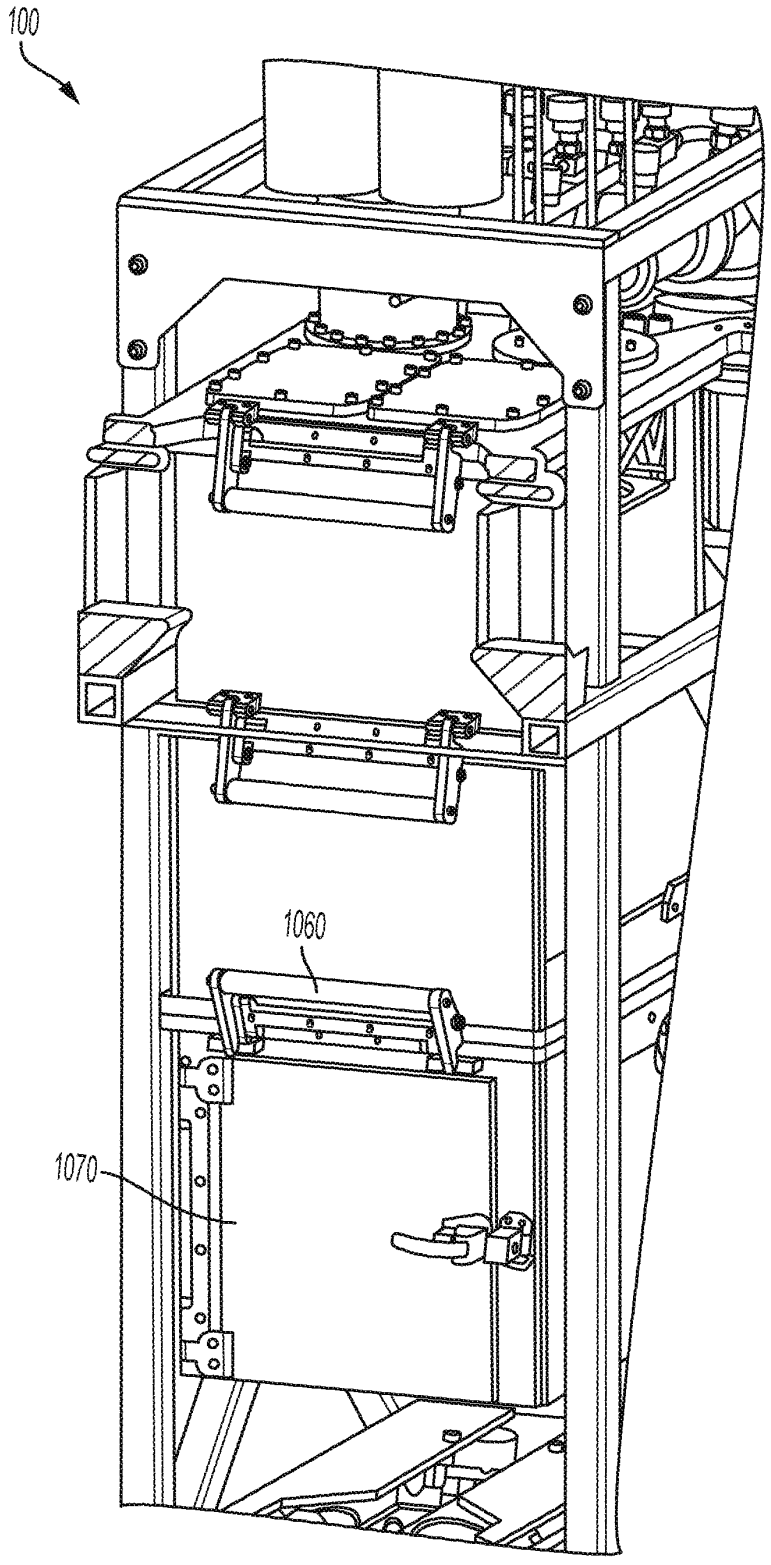


FIG. 10A

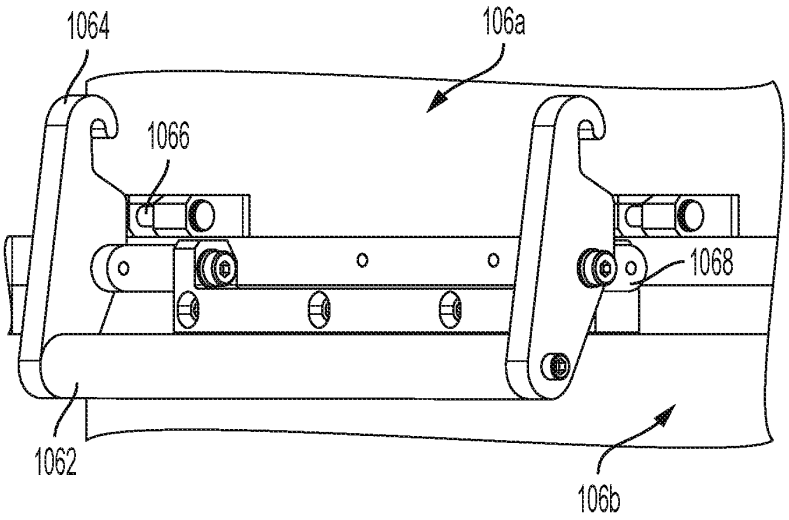


FIG. 10B

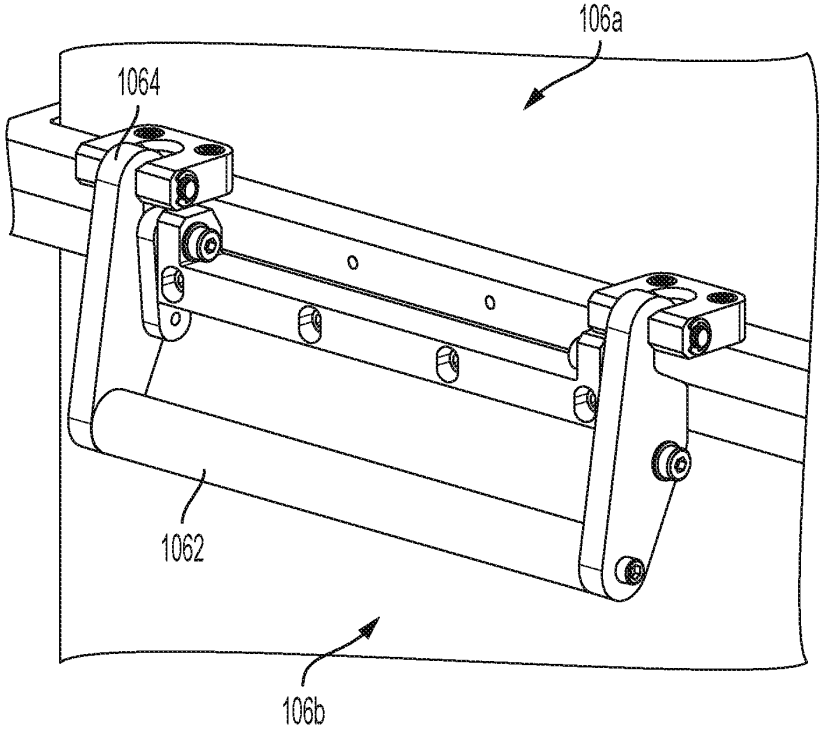


FIG. 10C

UNITED STATES
PATENT AND TRADEMARK OFFICE

P.O. Box 1450
Alexandria, VA 22313 - 1450
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ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**02/07/2025 07:18:11 PM Z ET**	**M1567.70000US04**

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INTEGRATED DILUTION REFRIGERATORS

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PATENT CENTER #	69104843	FILING DATE	07/08/2022
CUSTOMER #	23628	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	Sarah Schlotter

Documents

TOTAL DOCUMENTS: 7

DOCUMENT		PAGES	DESCRIPTION	SIZE (KB)
M156770000US04-TRN-SCS.pdf		1	Miscellaneous Incoming Letter	26 KB
M156770000US04-FEE-SCS.pdf		2	Fee Worksheet (SB06)	83 KB
M156770000US04-AMN-SCS.pdf		13	-	147 KB
M156770000US04-AMN-SCS-A....pdf	(1-1)	1	Amendment/Request for Reconsideration-After Non-Final Rejection	26 KB
M156770000US04-AMN-SCS-CLM.pdf	(2-5)	4	Claims	29 KB
M156770000US04-AMN-SCS-DRW.NONBW.pdf	(6-6)	1	Drawings-other than black and white line drawings	20 KB

M156770000US04-AMN-SCS-REM.pdf	(7-13)	7	Applicant Arguments/Remarks Made in an Amendment	120 KB
M156770000US04-RDRW-SCS.pdf		8	Drawings-other than black and white line drawings	209 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
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This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

FEE TRANSMITTAL

(page 1 of 2)

		Complete if known	
		Application Number	17/860,950-Conf. #9208
		Filing Date	July 8, 2022
[X]	Applicant asserts small entity status. See 37 CFR 1.27.	First Named Inventor	Corban I. Tillemann-Dick
[ ]	Applicant certifies micro entity status. See 37 CFR 1.29. Form PTO/SB/15A or B or equivalent must either be enclosed or have been submitted previously.	Examiner Name	L. W. Nouketcha
		Art Unit	3763
TOTAL AMOUNT OF PAYMENT	($) 80.00	Practitioner Docket No.	M1567.70000US04

METHOD OF PAYMENT (check all that apply)

[ ] Check [X] Credit Card [ ] Money Order [ ] None [ ] Other (please identify): _____

[X] Deposit Account Deposit Account Number: 23/2825 Deposit Account Name: Wolf, Greenfield & For the above-identified deposit account, the Director is hereby authorized to (check all that apply):

- [ ] Charge fee(s) indicated below
- [X] Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17, **except for any excess claims fees or multiple dependent claims fees**
- [X] Credit any overpayment of fee(s)
- [ ] Charge fee(s) indicated below, **except for the filing fee**
- [X] Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES (U = undiscounted fee; S = small entity fee; M = micro entity fee)

	FILING FEES			SEARCH FEES			EXAMINATION FEES			
Application Type	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**Fees Paid ($)**
Utility	350	140*	70	770	308	154	880	352	176	
Design	300	120	60	300	120	60	700	280	140	
Plant	240	96	48	485	194	97	725	290	145	
Reissue	350	140	70	770	308	154	2,550	1,020	510	
Provisional	325	130	65	0	0	0	0	0	0	

* The $140 small entity filing fee for a utility application is further reduced to $70 for a small entity applicant who files the application via Patent Center.

2. EXCESS CLAIM FEES

Fee Description	**Undiscounted Fee ($)**	**Small Entity Fee ($)**	**Micro Entity Fee ($)**
Each claim over 20 (including Reissues)	200	80	40
Each independent claim over 3 (including Reissues)	600	240	120
Multiple dependent claims	925	370	185

Total Claims		**Extra Claims**		**Fee ($)**		**Fee Paid ($)**
21	- 20 or HP =	1	x	80.00	=	80.00

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims		**Extra Claims**		**Fee ($)**		**Fee Paid ($)**
3	- 3 or HP =		x		=	

paid for, if greater than 3.

Multiple Dependent Claims	
Fee ($)	**Fee Paid ($)**

HP = highest number of independent claims

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $450 ($180 for small entity) ($90 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets		**Extra Sheets**		**Number of each additional 50 or fraction thereof**		**Fee ($)**		**Fee Paid ($)**
	- 100 =		/50 =		(round **up** to a whole number) x		=	

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: February 7, 2025 Electronic Signature for Eileen M. MacKenzie: / Eileen M. MacKenzie /

13629568

FEE TRANSMITTAL

(page 2 of 2)

4. CONTINUING APPLICATION FEE

If the actual filing date of the application is more than six years after the earliest benefit date, a continuing application fee is due. The earliest benefit date is the earliest filing date for which benefit is claimed under 35 U.S.C. 120, 121, 365(c), or 386(c) and § 1.78(d).

Choose only one of the following:

If the actual filing date is more than six years, and is less than or equal to nine years, after the earliest benefit date, the continuing application fee is $2,700 ($1,080 for small entity or $540 for micro entity). See 37 CFR 1.17(w)(1).

or

If the actual filing date is more than nine years after the earliest benefit date, the continuing application fee is $4,000 ($1,600 for small entity or $800 for micro entity), less any amount previously paid under 37 CFR 1.17(w)(1). See 37 CFR 1.17(w)(2).

Fees Paid ($)

_____

5. OTHER FEE(S) **Fees Paid ($)**

Non-English specification, $150 fee ($60 for small entity) ($30 for micro entity) _____

Non-electronic filing fee under 37 CFR 1.16(t) for a utility application, $400 fee ($200 small or micro entity) _____

Other (e.g., late filing surcharge): _____ _____

SUBMITTED BY					
Signature	/Sarah C. C. Schlotter/	Registration No. (Attorney/Agent)	79,027	Telephone	617.646.8000
Name (Print/Type)	Sarah C.C. Schlotter, PhD			Date	February 7, 2025

13629568

Docket No.: M1567.70000US04
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	L. W. Nouketcha
Art Unit:	3763

Certificate of Electronic Filing under 37 C.F.R. § 1.8
I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: February 7, 2025 Electronic Signature for Eileen M. MacKenzie: / Eileen M. MacKenzie /

RESPONSE TO NON-FINAL OFFICE ACTION UNDER 37 C.F.R. § 1.111

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Commissioner:

INTRODUCTORY COMMENTS

In response to the Office Action dated November 7, 2024, please amend the above-identified U.S. patent application as follows:

Amendments to the Claims begin on page 2 of this response.

Amendments to the Drawings begin on page 6 of this response and include attached replacement sheets.

Remarks/Arguments begin on page 7 of this response.

AMENDMENTS TO THE CLAIMS

Applicant submits below a complete listing of the current claims, including marked-up claim(s) with insertions indicated by underlining and deletions indicated by strikeouts and/or double bracketing. This listing of claims replaces all prior versions, and listings, of claims in the application:

1. (Currently Amended) A dilution refrigerator comprising:

an outer vacuum chamber comprising an outer housing having at least one substantially planar surface; and

an opening in the at least one substantially planar surface of the outer housing configured to provide access to an experimental volume disposed within an interior of the outer vacuum chamber.

2. (Currently Amended) The dilution refrigerator of claim 1, further comprising a sample stage housed within the experimental volume ~~outer vacuum chamber~~, wherein the opening is configured to provide access to the sample stage through the outer vacuum chamber.

3. (Original) The dilution refrigerator of claim 2, further comprising one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the sample stage are slidable and/or removable to provide access to the sample stage.

4. (Currently Amended) ~~The dilution refrigerator of claim 1,~~ A dilution refrigerator comprising:

an outer vacuum chamber comprising an outer housing having at least one substantially planar surface; and

an opening in the at least one substantially planar surface of the outer housing configured to provide access to an experimental volume disposed within an interior of the outer vacuum chamber, wherein:

the at least one substantially planar surface of the outer housing comprises a first surface disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator.

5. (Original) The dilution refrigerator of claim 1, wherein the at least one substantially planar surface comprises:

first surfaces disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator; and

second surfaces disposed within a plane parallel to the plane of the floor, wherein the first surfaces and the second surfaces are arranged as a rectangular prism.

6. (Original) The dilution refrigerator of claim 1, wherein the opening comprises a hermetic opening.

7. (Currently Amended) ~~The dilution refrigerator of claim 1,~~ A dilution refrigerator comprising:

an outer vacuum chamber comprising an outer housing having at least one substantially planar surface; and

an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber, wherein the opening comprises a hinged door.

8. (Original) The dilution refrigerator of claim 7,

further comprising one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the hinged door are slidable and/or removable to provide access to the interior of the outer vacuum chamber.

9. (Original) The dilution refrigerator of claim 7, wherein the opening further comprises a load lock.

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10. (Original) The dilution refrigerator of claim 1, wherein the outer vacuum chamber comprises:

a first section; and

a second section suspended from the first section.

11. (Original) The dilution refrigerator of claim 10, wherein the first section is coupled to the second section by integrated clamps and/or cams.

12. (Original) The dilution refrigerator of claim 10, wherein the first and/or second section of the outer vacuum chamber are configured to be at least partially removed from the dilution refrigerator to provide access to an interior of the outer vacuum chamber.

13. (Original) The dilution refrigerator of claim 10, further comprising an external system configured to lift and/or lower the first and/or second section of the outer vacuum chamber.

14. (Original) The dilution refrigerator of claim 13, wherein the external system comprises pneumatic and/or hydraulic devices configured to lift and/or lower the first and/or second sections.

15. (Original) The dilution refrigerator of claim 13, wherein the external system comprises a screw mechanism configured to lift and/or lower the first and/or second sections.

16. (Currently Amended) The dilution refrigerator of claim 1, wherein the outer vacuum chamber is configured to fit within a server rack ~~rack-type~~ container.

17. (Currently Amended) The dilution refrigerator of claim 16, wherein the server rack ~~rack-type~~ container is configured to integrate with commercial server rack infrastructure.

18. (Currently Amended) The dilution refrigerator of claim 16, wherein the server rack ~~rack-type~~ container is a 19-inch server rack.

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19. (Currently Amended) The dilution refrigerator of claim 17, wherein the server rack ~~rack-type~~ container comprises an external housing comprising an integrated horizontal surface.

20. (Original) The dilution refrigerator of claim 19, wherein the integrated horizontal surface is configured to be stowed when not in use.

21. (New) The dilution refrigerator of claim 8, wherein:

the portions of the one or more radiation shields that are slidable and/or removable are coupled to the hinged door.

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AMENDMENTS TO THE DRAWINGS

Replacement Sheets are submitted herewith. Please replace the original sheets showing FIGs. 5A-5C, 5E, and 8B-10C with the Replacement Sheets. FIGs. 5A-5C, 5E, and 8B-10C have been redrawn as black-and-white line drawings.

By this amendment, no new matter is added.

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REMARKS

In response to the Office Action dated November 7, 2024, Applicant respectfully requests reconsideration. Claims 1-20 were previously pending in this application. By this amendment, claims 1-2, 4, 7, and 16-19 have been amended. New claim 21 has been added and is supported by at least FIGS. 10A and further described on p. 26, lines 17-24 of the application as filed. No claims have been canceled. As a result, claims 1-21 are pending for examination with claims 1, 4, and 7 being independent claims. No new matter has been added.

Interview Summary

Applicant would like to thank the Examiner for the courtesy of a telephone interview conducted on January 28, 2025. The substance of the interview is summarized as follows.

The Applicant's representative, Sarah Schlotter (Reg. No. 79,027), and first-named inventor Corban Tillemann-Dick (CEO, Maybell Quantum Industries, Inc.) provided the Examiner with a background of the industrial importance of the claimed technology. The Applicant's representative further provided the Examiner with an explanation of the technical distinctions between the cited references, Hart and Mikheev, and the language of the claims. The Examiner explained his interpretation of the claim language and suggested claim amendments that could overcome the current 35 U.S.C. § 102 rejections, which are reflected in the amendments to claims 1, 4, and 7 filed herein.

The Applicant's representative and the Examiner also discussed the objections to the drawings. The Applicant's representative explained that FIG. 5D is a microscopy image of a material structure and could therefore be presented as a photograph under 37 C.F.R. § 1.84(b)(1). The Examiner agreed to waive the objection to FIG. 5D. Replacement sheets showing amended FIGs. 5A-5C, 5E and 8B-10C are filed herewith.

Finally, the Applicant's representative and the Examiner discussed the rejections of claims 16-20 under 35 U.S.C. § 112(b). The Applicant's representative proposed claim amendments to claims 16-19 to recite a "server rack" rather than a "server rack-type container" in order to overcome the rejections. The Examiner agreed that the proposed claim language overcomes the rejections under 35 U.S.C. § 112(b). Claims 16-19 have accordingly been amended herein.

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Allowable Subject Matter

Applicant notes with appreciation that the Office Action states that claims 8, 12, and 14-15 are objected to as being dependent upon a rejected base claim but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.

Objections to the Drawings

The Office Action objects to the drawings because Fig. 5A-5E and 8B-10C purportedly appear to be annotated black and white photographs. The replacement sheets provided herewith include revised versions of FIGs. 5A-5C, 5E, and 8B-10C and black-and-white line drawings, in compliance with 37 C.F.R. § 1.84(a). Further, and as agreed during the interview, FIG. 5D depicts a microscopy image for which a photograph is the only practicable medium for illustration and can be presented under 37 C.F.R. § 1.84(b)(1).

Accordingly, withdrawal of these objections is respectfully requested.

Rejections under 35 U.S.C. § 112

The Office Action rejects claim 16-20 under 35 U.S.C. § 112(b) as purportedly being indefinite. As agreed during the interview, claims 16-19 have been amended herein to recite "server rack container." The rejections are rendered moot in light of the foregoing amendments.

Accordingly, withdrawal of the rejections of claim 16-20 under 35 U.S.C. § 112 is respectfully requested.

Rejections Under 35 U.S.C. § 102

The Office Action rejects claims 1 and 4 under 35 U.S.C. § 102(a)(1) as purportedly being anticipated by U.S. Publication No. 2021/0076530 to Hart ("Hart"). The Office Action further rejects claim 1 under 35 U.S.C. § 102(a)(1) as purportedly being anticipated by U.S. Patent No. 6,202,439 to Mikheev ("Mikheev"). Without conceding the rejections are proper, Applicant has elected to amend the claims based on the telephone interview. Support for the amendments can be throughout the

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specification as filed, for example, in FIGS. 1 and 11 and further described on p. 17, lines 27-31 and p. 27, lines 7-16. Reconsideration is respectfully requested.

I. Independent claim 1

Independent claim 1, as amended herein, recites:

> A dilution refrigerator comprising:
>
> an outer vacuum chamber ***comprising an outer housing*** having at least one substantially planar surface; and
>
> ***an opening in the at least one substantially planar surface of the outer housing configured to provide access to an experimental volume disposed within an interior of the outer vacuum chamber***. (Emphasis supplied).

As discussed during the interview, Hart and Mikheev do not describe at least the above emphasized language of independent claim 1.

As shown in FIG. 4 reproduced below, Hart describes an enclosure 320 for thermalizing and securing a quantum computing device directly to the mixing chamber plate 210 on the interior of a cryogenic device (Hart, Abstract, ¶ 34). While enclosure 320 includes an opening covered by cover 425, enclosure 320 is fully internal to the cryogenic device 400, and would be fully enclosed by the outer vacuum chamber, as conceded by the Office Action (Hart, FIG. 4, ¶ 44; Office Action, p. 5). Because the enclosure is fully internal to the cryogenic device, Hart fails to describe any "opening in the at least one substantially planar surface of the outer housing," as required by amended claim 1.

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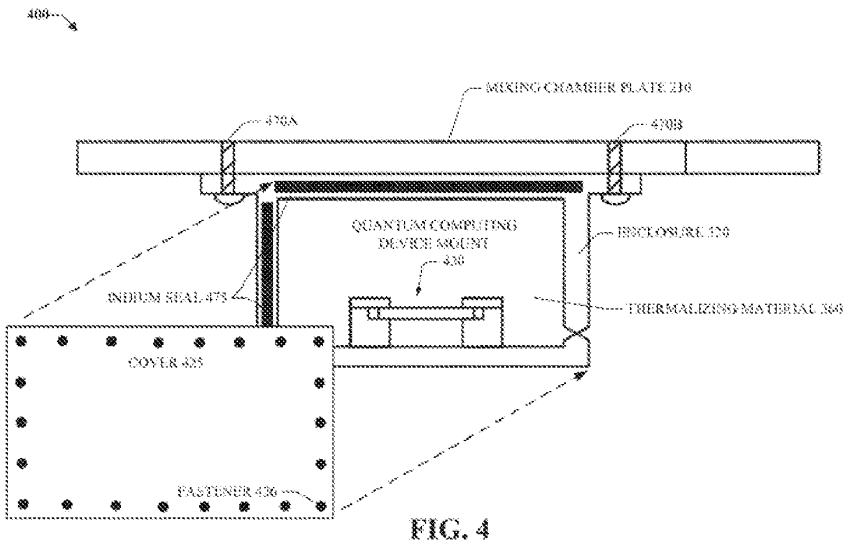


FIG. 4

Mikheev describes a cryogenic device including a cryostat 1 and a dilution refrigerator inserted along the central axis of the cryostat (Mikheev, see FIGs. 1 and 2 (reproduced below) and Col. 5, Lines. 14-33). When the dilution refrigerator is inserted into an opening on the top of the cryostat 1 (Col. 5, Lines 29-30), the cited opening (through plate adjacent the port 8A) fails to "provide access to an experimental volume disposed within the interior of the outer vacuum chamber" as required by claim 1. Rather, the experimental volume of Mikheev, depicted in FIGs. 2 and 3 as extension tail 27, is accessible only through bore 11 "which defines a probe access path" (Col. 5, Line 34). See also FIG. 3, in which a probe 30 with sample 35 is disposed in the extension tail 27 (Col. 6, Lines 12-22). The bore 11 is connected to tube 60 via metal tube 13 and 1K pot 12 (Col. 5, Lines 32-40) such that during operation the sample 35 is introduced to the extension tail 27 within the dilution refrigerator by being inserted through tube 60 (see Col. 5, Lines 48-50 of EP 0675330A1, referenced at Col. 7, line 19 of Mikheev). However, as shown in FIG. 1, tube 60 is not an opening in outer wall 2 or an opening in the cited plate adjacent port 8A. Mikheev therefore does not describe an "opening in the at least one substantially planar surface of the outer housing" as required by amended claim 1.

For at least the reasons described above and discussed during the interview, Hart and Mikheev both fail to describe at least the above-emphasized language of independent claim 1. Thus, independent claim 1 patentably distinguishes over Hart and Mikheev. Accordingly, withdrawal of the

rejections of independent claim 1 and the claims that depend therefrom under 35 U.S.C. § 102 is respectfully requested.

Fig.1.

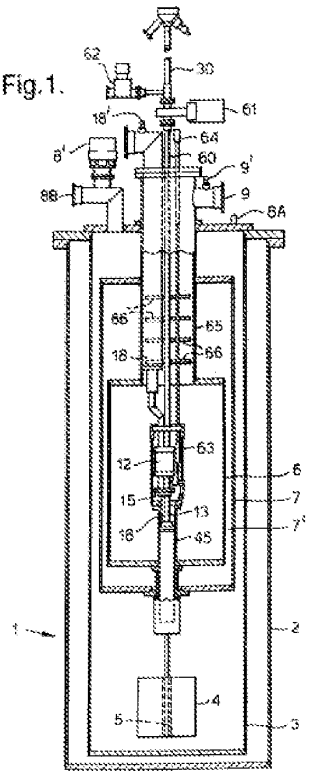
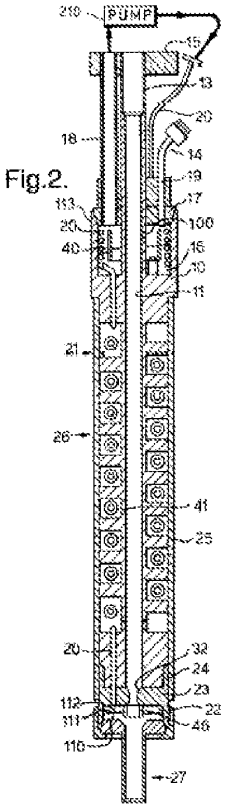


Fig.2.



II. Independent claim 4

Claim 4 has been amended herein to be written in independent form and includes the same limitations emphasized above with respect to independent claim 1. For at least the reasons described above, independent claim 4 patentably distinguishes over Hart. Accordingly, withdrawal of the rejection of independent claim 4 and the claims that depend therefrom under 35 U.S.C. § 102 is respectfully requested.

Rejections Under 35 U.S.C. § 103

The Office Action rejects claim 7 under 35 U.S.C. § 103 as purportedly being obvious over U.S. Publication No. 2021/0076530 to Hart (hereinafter "Hart"). Without conceding the rejection is

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proper, Applicant has elected to amend claim 7 to be in independent form including all of the limitations of independent claim 1 as amended herein. As should be appreciated from the foregoing, Hart does not describe each and every limitation of independent claim 7. Thus, independent claim 7 patentably distinguishes over Hart.

Applicant further traverses the Office Action's official notice that "going from a door closed by fasteners to a door closed by hinge[s] would have been obvious to an ordinary skill[ed] artisan" (p. 7). MPEP § 2144.03(A) states that "it would not be appropriate for the examiner to take official notice of facts without citing a prior art reference where the facts asserted to be well known are not beyond dispute, or are not capable of instant and unquestionable demonstration as being well-known." See *In re Ahlert,* 424 F.2d 1088, 1091 (CCPA 1970). The outer vacuum chamber for a dry dilution refrigerator is a specialized device designed to maintain an internal pressure several orders of magnitude below typical atmospheric pressure. Proper sealing of the outer vacuum chamber is needed to maintain the low internal pressure within the vacuum chamber, to prevent atomic and molecular contaminants from entering the vacuum chamber, and to prevent valuable purified ^{3}He or ^{4}He from leaking out of the vacuum chamber. It cannot be said that the use of hinged doors rather than fasteners is beyond dispute or "capable of instant and unquestionable demonstration as being well-known" within the specialized technical area of cryogenic vacuum devices. As such, the Office's reliance on taking official notice of this purported fact is improper, and Applicant respectfully requests citation to evidentiary support in the record if the rejection under 35 U.S.C. § 103 is to be maintained, as required. See *In re Zurko*, 258 F.3d 1379, 1385 (Fed. Cir. 2001).

Accordingly, withdrawal of the rejection of independent claim 7 under 35 U.S.C. § 103 is respectfully requested.

General Comments on Dependent Claims

Since each of the dependent claims depends from a base claim that is believed to be in condition for allowance, for the sake of brevity, Applicant believes that it is unnecessary at this time to argue the further distinguishing features of the dependent claims. However, Applicant does not necessarily concur with the interpretation of the previously presented dependent claims as set forth in the Office Action, nor does Applicant concur that the basis for rejection of any of the previously

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presented dependent claims is proper. Therefore, Applicant reserves the right to specifically address the further patentability of the dependent claims in the future.

CONCLUSION

In view of the foregoing, this application should now be in condition for allowance. A notice to this effect is respectfully requested. If the Examiner believes, after this response, the application is not in condition for allowance, the Examiner is requested to call the undersigned at the telephone number indicated below to discuss any outstanding issues.

If this response is not considered timely filed and if a request for an extension of time is otherwise absent, Applicant hereby requests any necessary extension of time.

The Director is hereby authorized to charge any additional fees which may be required with this Amendment, or credit any overpayment, to Deposit Account No. 23/2825, under Docket No. M1567.70000US04.

Dated: February 7, 2025

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
John A. Otterbein
Registration No.: 80,331
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

Attachments

13388298

DocCode - SCORE

Placeholder Sheet for Supplemental Content

Application Number: 17860950 Document Date: 02/07/2025

The presence of this form indicates that the following document type was received in electronic format on the date identified above. This document is stored separately from the typical case contents which are stored in image format.

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Form Revision Date: March 1, 2024

PTO/SB/06 (09-11)
Approved for use through 1/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 17/860,950	Filing Date 07/08/2022	☐ To be Mailed

ENTITY: ☐ LARGE ☑ SMALL ☐ MICRO

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA		RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A		N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A		N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*		x $50 =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*		x $240 =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).				
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))					
* If the difference in column 1 is less than zero, enter "0" in column 2.				TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1)		(Column 2)	(Column 3)			
AMENDMENT	02/07/2025	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA		RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 21	Minus	** 20	= 1		x $80 =	80
	Independent (37 CFR 1.16(h))	* 3	Minus	*** 3	= 0		x $240 =	0
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	80

		(Column 1)		(Column 2)	(Column 3)			
AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA		RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=		x $0 =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=		x $0 =	
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.	PROGRAM SUPPORT SPECIALIST
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".	/FIKIRTE A GEREMEW/
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".	
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.	

This collection of information is required by 37 CFR 1.16. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
17/860,950	07/08/2022	Corban I. Tillemann-Dick	M1567.70000US04	9208

23628 7590 02/03/2025

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BOSTON, MA 02210-2206

EXAMINER	
NOUKETCHA, LIONEL W	

ART UNIT	PAPER NUMBER
3763	

NOTIFICATION DATE	DELIVERY MODE
02/03/2025	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

Patents_eOfficeAction@WolfGreenfield.com
WGS_eOfficeAction@WolfGreenfield.com

Applicant-Initiated Interview Summary	Application No. 17/860,950	Applicant(s) Tillemann-Dick et al.		
	Examiner LIONEL W NOUKETCHA	Art Unit 3763	AIA (First Inventor to File) Status Yes	Page 1 of 1

All Participants (applicant, applicants representative, PTO personnel)	Title	Type
LIONEL W NOUKETCHA	Examiner	Telephonic
Sarah Schlotter	Attorney of Record	
Corban I. Tillemann-Dick	Inventor	

Date of Interview: 28 January 2025

Issues Discussed:

Proposed Amendment(s)

Agreement was reached that the drawing objection of Fig. 5D will be withdrawn.
Agreement was reached that replacing "server rack-type" by "server rack" will be alleviate the 112 rejection of at least claims 17-19.
Agreement appeared to be reached that reciting that "the opening is provided on the housing of the vacuum chamber", "the planar surface is part of the outer housing of the vacuum chamber", or similar language would over the rejection by Hart.
Agreement appeared to be reached that reciting that "the opening extending through the vacuum chamber", or "the opening operable to open and close so as to provide access to the vacuum chamber", or similar language would overcome the rejection by Mikheev.

☑ Attachment

/LIONEL NOUKETCHA/ Primary Examiner, Art Unit 3763	

Applicant is reminded that a complete written statement as to the substance of the interview must be made of record in the application file. It is the applicants responsibility to provide the written statement, unless the interview was initiated by the Examiner and the Examiner has indicated that a written summary will be provided. See MPEP 713.04
Please further see:
MPEP 713.04
Title 37 Code of Federal Regulations (CFR) § 1.133 Interviews, paragraph (b)
37 CFR § 1.2 Business to be transacted in writing

Applicant recordation instructions: The formal written reply to the last Office action must include the substance of the interview. (See MPEP section 713.04). If a reply to the last Office action has already been filed, applicant is given a non-extendable period of the longer of one month or thirty days from this interview date, or the mailing date of this interview summary form, whichever is later, to file a statement of the substance of the interview.

Examiner recordation instructions: Examiners must summarize the substance of any interview of record. A complete and proper recordation of the substance of an interview should include the items listed in MPEP 713.04 for complete and proper recordation including the identification of the general thrust of each argument or issue discussed, a general indication of any other pertinent matters discussed regarding patentability and the general results or outcome of the interview, to include an indication as to whether or not agreement was reached on the issues raised.

Docket No.: M1567.70000US04
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	L. W. Nouketcha
Art Unit:	3763

INTERVIEW AGENDA

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Commissioner:

The Applicant's representatives, John A. Otterbein (Reg. No. 80,331) and Sarah Schlotter (Reg. No. 79,027) and named inventor Corban Tillemann-Dick (CEO, Maybell Quantum Industries, Inc.), thank Examiner Nouketcha for their courtesy in agreeing to conduct a telephone interview scheduled for January 28, 2025, at 3:30 PM (EST) in connection with the above-identified matter. The Applicant's representative will call the Examiner at 571-272-8438 at the scheduled time.

Applicant's representatives would like to discuss some embodiments of the technology described in the application and the Non-Final Office Action of November 7, 2024. In particular, Applicant's representatives would like to discuss the rejection of independent claim 1 under 35 U.S.C. § 102 over cited reference Hart and how the Office is reading Hart to disclose "an opening in the at least one substantially planar surface" of the outer vacuum chamber when Hart fails to describe any vacuum chamber, as conceded in the Office Action (p. 4). Rather, the enclosure 320 described in Hart is mounted directly to mixing chamber plate 210 internal to the cryogenic device to thermalize enclosure 320 and the quantum computing devices housed therein, and thus, does not relate to an opening through an outer vacuum chamber of the cryogenic device (Hart, ¶ 35). Applicant's representatives would further like to discuss the language of the independent claim in view of the

differences between the present technology and Hart. The goal of the interview is to come to a common understanding of the language of the claims in the context of distinguishing the claims over Hart.

Applicant's representatives would further like to discuss the rejection of dependent claims 16-20 under 35 U.S.C. § 112(b) with respect to the "server rack-type container" language in dependent claims 16-19. In particular, Applicant's representatives would like to discuss that language in view of the description on page 26, lines 25-30 of the application as filed.

Finally, Applicant's representatives would like to discuss the objections to FIGS. 5A-5E and 8B-10C for including black and white photographs. Specifically, Applicant believes at least FIG. 5D to be permissible under 37 CFR 1.84(b)(1) for depicting a crystalline structure of the material.

If the Examiner has any questions concerning the Interview Agenda, the Examiner is invited to contact the undersigned at the telephone number listed below.

Dated: January 27, 2025

Respectfully submitted,

By /John A. Otterbein/

John A. Otterbein
Registration No.: 80,331
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
WOLF, GREENFIELD & SACKS,
P.C. 600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

EXHIBIT 1004 – Page 80 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

FORM PTO-1449/A and B (modified PTO/SB/08)				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet	1	of	1	GROUP ART UNIT: 3763	EXAMINER: L. W. Nouketcha

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document		Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		Number	Kind Code		
		6,202,439	B1	Mikheev et al.	03-20-2001
		2013-0014518	A1	Aigouy et al.	01-17-2013
		2014-0202179	A1	Batey et al.	07-24-2014
		2017-0167475	A1	MORI et al.	06-15-2017
		2018-0216684	A1	GRUSS et al.	08-02-2018
		2020-0262013	A1	NISHIO et al.	08-20-2020

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document			Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		Office/ Country	Number	Kind Code			
		JP	2006-138851	A	Bruker Biospin AG	06-01-2006	Y; Abstract Only
		JP	2007-048973	A	Sumitomo Heavy Industries	02-22-2007	Y; Abstract Only

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)
		Korean Notice of Preliminary Rejection dated November 26, 2024, in connection with Korean Application No. 10-2024-7004190, with English translation. (M1567.70000KR00).	Y

[NOTE – No copies of U.S. patents, published U.S. patent applications, or pending, unpublished patent applications stored in the USPTO's Image File Wrapper (IFW) system, are included. See 37 CFR § 1.98 and 1287OG163. Copies of all other patent(s), publication(s), unpublished, pending U.S. patent applications, or other information listed are provided as required by 37 CFR § 1.98 unless 1) such copies were provided in an IDS in an earlier application that complies with 37 CFR § 1.98, and 2) the earlier application is relied upon for an earlier filing date under 35 U.S.C. § 120.]

EXAMINER:	DATE CONSIDERED:

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

UNITED STATES
PATENT AND TRADEMARK OFFICE

P.O. Box 1450
Alexandria, VA 22313 - 1450
www.uspto.gov

ELECTRONIC PAYMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**01/17/2025 08:34:24 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Jennifer Weaver
PATENT CENTER #	68816396	AUTHORIZED BY	Sarah Schlotter
CUSTOMER #	23628	FILING DATE	07/08/2022
CORRESPONDENCE ADDRESS	-	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick

Payment Information

PAYMENT METHOD	PAYMENT TRANSACTION ID	PAYMENT AUTHORIZED BY
DA / 232825	**E20251GK37138068**	**Jennifer Weaver**

PRE-AUTHORIZED ACCOUNT	PRE-AUTHORIZED CATEGORY
232825	**37 CFR 1.17 (Patent application and reexamination processing fees)**

FEE CODE	DESCRIPTION	ITEM PRICE($)	QUANTITY	ITEM TOTAL($)
2806	SUBMISSION OF AN INFORMATION DISCLOSURE STATEMENT	104.00	1	104.00
			TOTAL AMOUNT:	**$104.00**

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban I. Tillemann-Dick
Art Unit	3763
Examiner Name	L. W. Nouketcha
Total Number of Pages in This Submission	
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

- [X] Fee Transmittal Form
- [ ] Fee Attached
- [ ] Amendment/Reply
- [ ] After Final
- [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [X] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Reply to Missing Parts/ Incomplete Application
- [ ] Reply to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) _____
- [ ] Landscape Table on CD
- [ ] After Allowance Communication to TC
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- [ ] Proprietary Information
- [ ] Status Letter
- [X] Other Enclosure(s) (please Identify below):

Form PTO-1449
Copies of cited references

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Sarah C. C. Schlotter/		
Printed name	Sarah C.C. Schlotter, PhD		
Date	January 17, 2025	Reg. No.	79,027

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: January 17, 2025 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

13544424

FEE TRANSMITTAL

Complete if known	
Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban I. Tillemann-Dick
Examiner Name	L. W. Nouketcha
Art Unit	3763
Practitioner Docket No.	M1567.70000US04

[X] Applicant asserts small entity status. See 37 CFR 1.27.

[ ] Applicant certifies micro entity status. See 37 CFR 1.29. Form PTO/SB/15A or B or equivalent must either be enclosed or have been submitted previously.

TOTAL AMOUNT OF PAYMENT ($)104.00

METHOD OF PAYMENT (check all that apply)

[ ] Check [X] Credit Card [ ] Money Order [ ] None [ ] Other (please identify): _____

[X] Deposit Account Deposit Account Number: 23/2825 Deposit Account Name: Wolf, Greenfield & Sacks, P.C.

For the above-identified deposit account, the Director is hereby authorized to (check all that apply):

[ ] Charge fee(s) indicated below

[ ] Charge fee(s) indicated below, **except for the filing fee**

[X] Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17, **except for any excess claims fees or multiple dependent claim fee**

[ ] Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17

[X] Credit any overpayment of fee(s)

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES (U = undiscounted fee; S = small entity fee; M = micro entity fee)

	FILING FEES			SEARCH FEES			EXAMINATION FEES			
Application Type	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**Fees Paid ($)**
Utility	320	128*	64	700	280	140	800	320	160	
Design	220	88	44	160	64	32	640	256	128	
Plant	220	88	44	440	176	88	660	264	132	
Reissue	320	128	64	700	280	140	2,320	928	464	
Provisional	300	120	60	0	0	0	0	0	0	

* The $128 small entity status filing fee for a utility application is further reduced to $64 for a small entity applicant who files the application via Patent Center or EFS-Web.

2. EXCESS CLAIM FEES

Fee Description	**Undiscounted Fee ($)**	**Small Entity Fee ($)**	**Micro Entity Fee ($)**
Each claim over 20 (including Reissues)	100	40	20
Each independent claim over 3 (including Reissues)	480	192	96
Multiple dependent claims	860	344	172

Total Claims		**Extra Claims**	**Fee ($)**		**Fee Paid ($)**
_____	- 20 or HP =	_____	x _____	=	_____

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims		**Extra Claims**	**Fee ($)**		**Fee Paid ($)**
_____	- 3 or HP =	_____	x _____	=	_____

HP = highest number of independent claims paid for, if greater than 3.

Multiple Dependent Claims	
Fee ($)	**Fee Paid ($)**

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $420 ($168 for small entity) ($84 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets		**Extra Sheets**		**Number of each additional 50 or fraction thereof**	**Fee ($)**	**Fee Paid ($)**
_____	- 100 =	_____	/50 =	_____ (round **up** to a whole number) x	_____	= _____

4. OTHER FEE(S)

	Fees Paid ($)
Non-English specification, $140 fee ($56 small entity) ($28 for micro entity)	
Non-electronic filing fee under 37 CFR 1.16(t) for a utility application, $400 fee ($200 small or micro entity)	
Other (e.g., late filing surcharge): 2806 Submission of an Information Disclosure Statement	104.00

SUBMITTED BY

Signature	/Sarah C. C. Schlotter/	Registration No. (Attorney/Agent)	79,027	Telephone	617.646.8000
Name (Print/Type)	Sarah C.C. Schlotter, PhD			Date	January 17, 2025

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: January 17, 2025 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

13544423

Espacenet

Bibliographic data: JP2007048973 (A) — 2007-02-22

REFRIGERATOR COOLING TYPE SUPER-CONDUCTIVE MAGNET DEVICE

Inventor(s): MITSUBORI HITOSHI ± (MITSUBORI HITOSHI)

Applicant(s): SUMITOMO HEAVY INDUSTRIES ± (SUMITOMO HEAVY IND LTD)

Classification: **- international:** ***H01F6/04***
- cooperative: F25B2400/06 (EP)

Application number: JP20050232330 20050810 Global Dossier

Priority number(s): JP20050232330 20050810

Also published as: JP4563281 (B2)

Abstract of JP2007048973 (A)

PROBLEM TO BE SOLVED: To surely support a troubled refrigerator by another refrigerator even in a case wherein a plurality of refrigerators are arranged so as to be apart from each other, in reference to the refrigerator cooling type superconductive magnet device which generates a strong magnetic field by cooling a superconductive coil by the plurality of refrigerators. ;SOLUTION: The refrigerator cooling type super conductive magnet device has a plurality of superconductive coils 18A-18D for generating magnetic field, and a plurality of GM (get memory) refrigerators 13A-13D for cooling the superconductive coils 18A-18D. The plurality of GM refrigerators 13A-13D are connected by employing heat pipes 25A-25D to constitute, so that a part of chill generated by one GM refrigerator is conducted to the other refrigerators. ;COPYRIGHT: (C)2007,JPO&INPIT

(19)日本国特許庁(JP)　(12)公開特許公報(A)　(11)特許出願公開番号
特開2007-48973
(P2007-48973A)
(43)公開日　平成19年2月22日(2007.2.22)

(51)Int.Cl.	F I	テーマコード（参考）
H01F 6/04 (2006.01)	H01F 7/22 ZAAG	

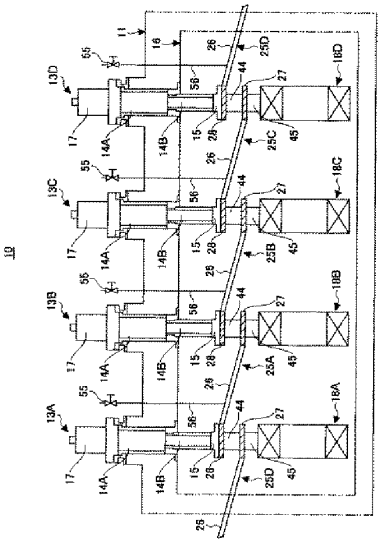
審査請求 未請求　請求項の数 4　OL　（全 11 頁）

(21)出願番号　特願2005-232330 (P2005-232330)
(22)出願日　平成17年8月10日 (2005.8.10)

(71)出願人　000002107
住友重機械工業株式会社
東京都品川区北品川五丁目９番１１号
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(54)【発明の名称】冷凍機冷却型超電導磁石装置

(57)【要約】
【課題】　本発明は複数の冷凍機により超電導コイルを冷却することにより強い磁場を発生する冷凍機冷却型超電導磁石装置に関し、複数の冷凍機が離れて配置されている場合においても、故障した冷凍機を他の冷凍機で確実に支援することを課題とする。
【解決手段】　磁場を発生する複数の超電導コイル１８Ａ～１８Ｄと、この超電導コイル１８Ａ～１８Ｄを冷却する複数のＧＭ冷凍機１３Ａ～１３Ｄとを有する冷凍機冷却型超電導磁石装置において、前記複数のＧＭ冷凍機１３Ａ～１３Ｄをヒートパイプ２５Ａ～２５Ｄを用いて連結し、一のＧＭ冷凍機で発生する寒冷の一部が他の冷凍機に伝導されるよう構成する。
【選択図】　図４



【特許請求の範囲】
【請求項1】
磁場を発生する複数の超電導コイルと、該超電導コイルを冷却する複数の冷凍機とを有する冷凍機冷却型超電導磁石装置において、
前記複数の冷凍機間をヒートパイプを用いて連結し、一の前記冷凍機で発生する寒冷の一部が他の冷凍機に伝導されるよう構成したことを特徴とする冷凍機冷却型超電導磁石装置。
【請求項2】
前記冷凍機の冷却シリンダには２本の前記ヒートパイプが接続され、
かつ、一方の前記ヒートパイプの放熱部と、他方の前記ヒートパイプの吸熱部とが前記冷却シリンダに直列に接続されていることを特徴とする請求項１記載の冷凍機冷却型超電導磁石装置。
【請求項3】
前記一対の冷凍機間に配設された前記ヒートパイプは、内設される作動液を充填するための配管と、該配管を開閉する弁装置とを有することを特徴とする請求項１または２記載の冷凍機冷却型超電導磁石装置。
【請求項4】
前記冷凍機は、前記冷却シリンダと前記ヒートパイプとの熱的な接続を解除しうる構成で真空容器に取り付けられることを特徴とする請求項１乃至３のいずれか１項に記載の冷凍機冷却型超電導磁石装置。

【発明の詳細な説明】
【技術分野】
【0001】
本発明は冷凍機冷却型超電導磁石装置に係り、特に複数の冷凍機により超電導コイルを冷却することにより強い磁場を発生する冷凍機冷却型超電導磁石装置に関する。
【背景技術】
【0002】
例えば、シリコン単結晶を磁界印加式チョクラルスキー法（ＭＣＺ法）を用いて成長させる際、シリコン単結晶製造装置に磁界を印加しつつシリコン単結晶を成長させることが行われている。このシリコン単結晶製造装置に対する磁界の印加は、冷凍機冷却型超電導磁石装置を用いて行われている。
【0003】
図１及び図２は、従来の一例である冷凍機冷却型超電導磁石装置１００（以下、超電導磁石装置という）を示している。この超電導磁石装置１００は、後述するようにＭＣＺ法を用いてシリコン単結晶を成長させる際に用いられるものである。
【0004】
超電導磁石装置１００は、大略すると真空容器１１１，ギフォード・マクマホン式冷凍機１１３（以下、ＧＭ冷凍機という），熱シールド１１６，及び超電導コイル１１８等により構成されている。
【0005】
熱シールド１１６は真空容器１１１に内設されており、この真空容器１１１にはＧＭ冷凍機１１３が配設されている。ＧＭ冷凍機１１３は、冷媒（例えば、ヘリウムガス）を圧縮する冷凍機コンプレッサ（図示せず）に接続されており、この冷凍機コンプレッサから高圧に圧縮された冷媒が供給される。
【0006】
この高圧冷媒は、ＧＭ冷凍機１１３内でモータ１１７により駆動されるディスプレーサ（図示せず）により膨張され、これによりＧＭ冷凍機１１３に内設された蓄冷材は冷却される。また、膨張することにより低圧となった冷媒は、冷凍機コンプレッサに戻されて再び高圧化される。
【0007】

このＧＭ冷凍機１１３は、１段目冷却シリンダ１１４Ａと２段目冷却シリンダ１１４Ｂを有している。１段目冷却シリンダ１１４Ａは熱シールド１１６に熱的に接続され、２段目冷却シリンダ１１４Ｂは冷却ステージ１１５と熱的に接続されている。

【0008】

よって、ＧＭ冷凍機１１３の１段目冷却シリンダ１１４Ａが熱シールド１１６を冷却することにより外部の熱が熱シールド１１６内に侵入するのを防止し、かつ２段目冷却シリンダ１１４Ｂは冷却ステージ１１５を介して超電導コイル１１８を臨界温度以下（例えば、４Ｋ～６Ｋ程度）に冷却する。これにより超電導コイル１１８は、超電導状態を実現する。

【0009】

真空容器１１１は、その中央に円筒状の中空円筒１２２を形成している。超電導コイル１１８は、この中空円筒１２２の回りに配設されている。よって、超電導コイル１１８が励磁されると、真空容器本体１２１に形成された中空円筒１２２には水平磁界が発生し、よってこの中空円筒１２２は常温磁場空間１２３として機能する。ＭＣＺ法によるシリコン単結晶を製造するシリコン単結晶製造装置１３０は、この常温磁場空間１２３内に配設され、超電導コイル１１８が発生する磁界内でシリコン単結晶が製造される。

【0010】

ところで、この種の超電導磁石装置１００は、通常1万時間毎に計画的メンテナンスを行い、安定した運転を確保することとしている（特許文献１参照）。しかしメンテナンスを迎える前に故障する冷凍機も存在する。このような場合は超電導磁石装置１００の故障により超電導コイル１１８を維持する臨界温度を越えてしまい必要な磁場を発生できなくなり、結晶引き上げ中の製造物が不良品となり大きな損害に繋がることになる。

【0011】

そこで、仮に一台のＧＭ冷凍機１１３が結晶引き上げ中に故障しても、他のＧＭ冷凍機１１３の余裕冷凍能力を効率よく支援させ、結晶引き上げ完了まで超電導コイル１１８を超電導状態に維持するため、臨界温度を越えてしまわないようにしたシステムが考案されている。具体的には、隣接するＧＭ冷凍機１１３を熱的に接続し、一台のＧＭ冷凍機１１３が故障しても、これと隣接するＧＭ冷凍機１１３の寒冷を故障したＧＭ冷凍機１１３に対応する超電導コイル１１８に伝導し、これにより当該超電導コイル１１８が臨界温度を越えないように構成していた。また、隣接するＧＭ冷凍機１１３を熱的に接続する手段としては、従来では銅等の熱伝導性の良好な金属材料が用いられていた。

【特許文献1】特開２００５－１２３３１３号公報

【発明の開示】

【発明が解決しようとする課題】

【0012】

上記のようにＧＭ冷凍機１１３の故障に対処するため、複数も受けられたＧＭ冷凍機１１３は、その冷凍性能は能力の約７０％程度を設計値として考慮し、残り３０％は余力とすることが考えられる。仮にＧＭ冷凍機１１３が４台設けられている場合、この構成とすることにより一台のＧＭ冷凍機１１３が故障した場合でも、他のＧＭ冷凍機１１３を１００の能力で駆動することにより、故障したＧＭ冷凍機１１３の冷却を他のＧＭ冷凍機１１３の余力分で支援することが可能となる。

【0013】

しかしながら、図２に示されるように、ＧＭ冷凍機１１３が離間して配置される場合がある。このように各ＧＭ冷凍機１１３が長い離間距離を有して配置されている場合には、従来のように隣接するＧＭ冷凍機１１３間を銅等の熱伝導性金属を用いて熱的に接続した構成では熱損失が大きいため、故障したＧＭ冷凍機１１３を効率よく支援することができないという問題点があった。

【0014】

尚、上記のように1台のＧＭ冷凍機１１３が故障した際、結晶引き上げ作業の持続条件を安定して確保することが不十分となるが、結晶引き上げ作業は通常約３～４日間連続し

て行われるため、その間は超電導コイル１１８としての機能を失ってはならない。従って1台のＧＭ冷凍機１１３が故障した場合、他のＧＭ冷凍機１１３が冷却を支援し超電導コイル１１８を超電導状態として持続しなければならない最大時間は4日（９６時間）となる。

【0015】

本発明は上記の点に鑑みてなされたものであり、複数の冷凍機が長い離間距離を有して配置されている場合においても、故障した冷凍機を他の冷凍機で確実に支援しうる冷凍機冷却型超電導磁石装置を提供することを目的とする。

【課題を解決するための手段】

【0016】

上記の課題を解決するために本発明では、次に述べる各手段を講じたことを特徴とするものである。

【0017】

請求項１記載の発明は、

磁場を発生する複数の超電導コイルと、該超電導コイルを冷却する複数の冷凍機とを有する冷凍機冷却型超電導磁石装置において、

前記複数の冷凍機間をヒートパイプを用いて連結し、一の前記冷凍機で発生する寒冷の一部が他の冷凍機に伝導されるよう構成したことを特徴とするものである。

【0018】

上記発明によれば、ヒートパイプを用いて複数の冷凍機間を連結したため、冷凍機間が離れていても、一の冷凍機で発生する寒冷の一部を他の冷凍機に伝導することができる。よって、複数の内の一台の冷凍機が故障したとしても、離れた位置にある他の冷凍機により故障した冷凍機を支援することが可能となる。

【0019】

また、請求項２記載の発明は、

請求項１記載の冷凍機冷却型超電導磁石装置において、

前記冷凍機の冷却シリンダには２本の前記ヒートパイプが接続され、

かつ、一方の前記ヒートパイプの放熱部と、他方の前記ヒートパイプの吸熱部とが前記冷却シリンダに直列に接続されていることを特徴とするものである。

【0020】

上記発明によれば、冷凍機に接続される２本のヒートパイプの内、その放熱部と吸熱部とが冷却シリンダに直列に接続されるため、コンパクトな構造で放熱部と吸熱部とを配置でき、ヒートパイプを設けても装置が大型化するのを防止することができる。

【0021】

また、請求項３記載の発明は、

請求項１または２記載の冷凍機冷却型超電導磁石装置において、

前記一対の冷凍機間に配設された前記ヒートパイプは、内設される作動液を充填するための配管と、該配管を開閉する弁装置とを有することを特徴とするものである。

【0022】

上記発明によれば、ヒートパイプに対する作動液の充填処理を容易に行うことができる。

【0023】

また、請求項４記載の発明は、

請求項１乃至３のいずれか１項に記載の冷凍機冷却型超電導磁石装置において、

前記冷凍機は、前記冷却シリンダと前記ヒートパイプとの熱的な接続を解除しうる構成で真空容器に取り付けられることを特徴とするものである。

【0024】

上記発明によれば、シリンダとヒートパイプとの熱的な接続を解除できるため、故障した冷凍機のシリンダを介して外部の熱が超電導コイルに伝導することを防止できる。

【発明の効果】

【0025】
本発明によれば、冷凍機間が離れていても、複数の内の一台の冷凍機が故障したとしても、離れた位置にある他の冷凍機により故障した冷凍機を支援することが可能となる。
【発明を実施するための最良の形態】
【0026】
次に、本発明を実施するための最良の形態について図面と共に説明する。
【0027】
図３及び図４は、本発明の一実施例である冷凍機冷却型超電導磁石装置１０（以下、超電導磁石装置という）を示している。この超電導磁石装置１０は、後述するようにシリコン単結晶を磁界印加式チョクラルスキー法（ＭＣＺ法）を用いて成長させる際に用いられるものである。
【0028】
超電導磁石装置１０は、大略すると真空容器１１，ギフォード・マクマホン式冷凍機１３（以下、GM冷凍機という），熱シールド１６，超電導コイル１８Ａ～１８Ｄ，及びヒートパイプ２５Ａ～２５Ｄ等により構成されている。
【0029】
熱シールド１６は熱伝導率のよい銅やアルミニウムにより形成されており、真空容器１１に内設されている。この真空容器１１は、複数（本実施例では４台）のＧＭ冷凍機１３Ａ～１３Ｄが配設されている。ＧＭ冷凍機１３Ａ～１３Ｄは、それぞれ冷媒を圧縮する冷凍機コンプレッサ（図示せず）に接続されている。冷凍機コンプレッサで高圧に圧縮された冷媒（例えば、ヘリウムガス）は、ＧＭ冷凍機１３Ａ～１３Ｄに供給される。
【0030】
この高圧冷媒は、ＧＭ冷凍機１３Ａ～１３Ｄに配設されているモータ１７により駆動されるディスプレーサ（図示せず）により１段目冷却シリンダ１４Ａ及び２段目冷却シリンダ１４Ｂ内で膨張され、これにより各ＧＭ冷凍機１３Ａ～１３Ｄに内設された蓄冷材は冷却される。また、膨張することにより低圧となった冷媒は、ＧＭ冷凍機１３Ａ～１３Ｄから冷凍機コンプレッサに戻され再び高圧化される。
【0031】
このＧＭ冷凍機１３Ａ～１３Ｄは、１段目冷却シリンダ１４Ａと２段目冷却シリンダ１４Ｂを有している。１段目冷却シリンダ１４Ａは熱シールド１６の天板部分と熱的に接続され、２段目冷却シリンダ１４Ｂは冷却ステージ１５と熱的に接続されている。また、冷却ステージ１５の下方には、超電導コイル１８Ａ～１８Ｄが熱的に接続された状態で配設される。更に、冷却ステージ１５の下端と超電導コイル１８Ａ～１８Ｄとの間には、後述するヒートパイプ２５Ａ～２５Ｄを構成する放熱部２８及び吸熱部２７が伝熱体４４，４５を介して配設されている。
【0032】
よって、ＧＭ冷凍機１３が駆動すると、１段目冷却シリンダ１４Ａが熱シールド１６を冷却することにより外部の熱が熱シールド１６内に侵入するのを防止する。また、超電導コイル１８は、冷却ステージ１５，放熱部２８，伝熱体４４，吸熱部２７，伝熱体４５を介してＧＭ冷凍機１３（２段目冷却シリンダ１４Ｂ）により臨界温度以下（例えば、４Ｋ～６Ｋ程度）に冷却される。これにより超電導コイル１８は、超電導状態を実現する。
【0033】
真空容器１１はステンレス鋼等により形成されており、その中央に円筒状の中空円筒２２を形成している。超電導コイル１８Ａ～１８Ｄは、この中空円筒２２を囲繞するよう複数個配置されている（本実施例ではＧＭ冷凍機１３Ａ～１３Ｄの台数に合わせて４個配置されている）。
【0034】
また、４個の超電導コイル１８Ａ～１８Ｄの配置（当社式）は既定の角度で配置され、その内の2個ずつ（例えば、超電導コイル１８Ａと超電導コイル１８Ｃ、超電導コイル１８Ｂと超電導コイル１８Ｄ）がペアとなるよう構成されている。よって、電源から各超電

導コイル１８Ａ～１８Ｄに電流が供給されて励磁が行われると、真空容器本体２１に形成された中空円筒２２には所定の水平磁界が発生し、この中空円筒２２は常温磁場空間２３として機能する。

【0035】

一方、ＭＣＺ法によるシリコン単結晶を製造するシリコン単結晶製造装置３０は、この常温磁場空間２３内に配設され、超電導コイル１８Ａ～１８Ｃが発生する磁界内でシリコン単結晶３６（インゴッド）が製造される。ここで、シリコン単結晶製造装置３０について簡単に説明しておく。

【0036】

本実施例に係る超電導磁石装置１０は、常温強磁場空間２３にシリコン単結晶製造装置３０を設けた構成としている。この超電導磁石装置１０は、加熱炉３１内にルツボ３２，ヒータ３３，引き上げワイヤー３５等を設けた構成とされている。

【0037】

この超電導磁石装置１０を用いてシリコン単結晶３６のインゴットを製造するには、先ずシリコン単結晶の原料となる他結晶シリコン片（ナゲット）をルツボ３２に装填し、ヒータ３３により加熱溶融させる。そして、引き上げワイヤー３５の先端に予め種結晶３４を設けておき、これを溶融した他結晶シリコンに接触させ、回転させながら引き上げワイヤー３５を引き上げる。これにより、種結晶３４の下部にはシリコン単結晶３６が形成される。

【0038】

この際、ＭＣＺ法では、ルツボ３２内の融液に対して強磁界を印加することが行なわれる。これは、ルツボ３２内の融液に磁界を印加することにより、ルツボ３２内での融液の対流を抑制し、これによりシリコン単結晶３６に溶け込む酸素量を低減させるためである。超電導磁石装置１０は、このルツボ３２内の融液に印加する磁界を生成するのに用いられている。

【0039】

続いて、本発明の要部となるヒートパイプ２５について説明する。本実施例では、４ホンのヒートパイプ２５が設けられているが、個々のヒートパイプを指す場合にはヒートパイプ２５Ａ～２５Ｄと符号を付し、総称する場合にはヒートパイプ２５と符号を付すものとする。

【0040】

図４は、説明の便宜上、円筒状の真空容器１１を展開した状態を示した図である。よって、同図に示されるように４台のＧＭ冷凍機１３Ａ～１３Ｄが並設された図となっている。また、図４では図示の便宜上、隣接する各ＧＭ冷凍機１３Ａ～１３Ｄは等間隔のように図示されているが、実際はＧＭ冷凍機１３ＡとＧＭ冷凍機１３Ｄとの間、及びＧＭ冷凍機１３ＢとＧＭ冷凍機１３Ｃとの間は大きく離間している（配置例として、図２参照）。

【0041】

このため、仮に一台のＧＭ冷凍機（例えばＧＭ冷凍機１３Ａ）が結晶引き上げ中に故障し、他のＧＭ冷凍機ＧＭ冷凍機１３Ｂ，１３Ｄの余裕冷凍能力を利用して支援しようとしても、従来のように銅等の熱伝導材料を用いた構成では熱伝導効率が悪く、故障したＧＭ冷凍機１３Ａを確実に支援することが困難であったことは前述した通りである。

【0042】

そこで本実施例では、従来用いていた銅等の熱伝導材料に代えて、ヒートパイプ２５Ａ～２５Ｄを用いて複数のＧＭ冷凍機１３Ａ～１３Ｄを熱的に連結し、一の冷凍機で発生する寒冷の一部が他の冷凍機にヒートパイプ２５Ａ～２５Ｄを介して熱伝導されるよう構成したことを特徴とするものである。よって、各ＧＭ冷凍機１３Ａ～１３Ｄは、ヒートパイプ２５Ａ～２５Ｄにより環状に手を繋いだような状態となる。

【0043】

ヒートパイプ２５（２５Ａ～２５Ｄ）は、図５（Ａ）に拡大して示すように、パイプ本体２６，吸熱部２７，放熱部２８，及び作動液３７等により構成されている。このヒート

パイプ２５は、離れた場所に熱を高速に伝達する機能を奏するものである。

【0044】

吸熱部２７は、例えば銅材料などの高熱伝導材により形成されている。また、放熱部２８は、銅材料などの高熱伝導材により形成されている。また、吸熱部２７と放熱部２８とを繋ぐパイプ本体２６は、ステンレス，銅，アルミ等により形成されている。更に、パイプ本体２６内に充填される作動液３７は、本実施例では液体ヘリウムを用いている。

【0045】

ヒートパイプ２５の動作原理は、次の通りである。即ち、吸熱部２７では作動液３７の蒸発が起こり、その蒸気は放熱部２８に移動し凝縮する。ここで蒸発潜熱の受け渡しが行われ、凝縮した作動液３７は吸熱部２７に還流する。この繰り返しで吸熱部２７から放熱部２８への熱伝達が行われる。このヒートパイプ２５は、従来において高熱伝導材料として一般に使用されていた銅材料と熱を運ぶ能力を比較した場合、等価な断面積にてヒートパイプは銅材料の約10～100倍の能力を有する。

【0046】

図５（Ｂ），（Ｃ）は、図５（Ａ）に示すヒートパイプ２５の変形例を示している。図５（Ｂ）に示すヒートパイプ４０は、図５（Ａ）に示すヒートパイプ２５ではパイプ本体２６が単管式であったものを、二重管式のパイプ本体４２としたものである。また、図５（Ｃ）に示すヒートパイプ４１は、パイプ本体４３を復管式としたものである。

【0047】

再び図４に戻り、説明を続ける。ヒートパイプ２５Ａの放熱部２８はＧＭ冷凍機１３Ａに接続され、吸熱部２７はＧＭ冷凍機１３Ｂに接続されている。同様に、ヒートパイプ２５Ｂの放熱部２８はＧＭ冷凍機１３Ｂに接続されると共に吸熱部２７はＧＭ冷凍機１３Ｃに接続され、ヒートパイプ２５Ｃの放熱部２８はＧＭ冷凍機１３Ｃに接続されると共に吸熱部２７はＧＭ冷凍機１３Ｄに接続され、ヒートパイプ２５Ｄの放熱部２８はＧＭ冷凍機１３Ｄに接続されると共に吸熱部２７はＧＭ冷凍機１３Ａに接続される。

【0048】

更に、個々のＧＭ冷凍機１３Ａ～１３Ｄにおける吸熱部２７と放熱部２８との配設位置に注目すると、放熱部２８は冷却ステージ１５の直下位置に配設され、吸熱部２７は放熱部２８より下部に配設されている。また、放熱部２８と吸熱部２７との間には、銅等の熱伝導材料からなる伝熱体４４が設けられている。更に、吸熱部２７の下部には、銅等の熱伝導材料からなる伝熱体４５が配設されており、伝熱体４５の下端部は超電導コイル１８Ａ～１８Ｄと熱的に接続されている。

【0049】

ヒートパイプ２５Ａ～２５Ｄを上記構成とすることにより、放熱部２８は吸熱部２７よりも高い位置に配置されることとなる。また、このように放熱部２８を吸熱部２７よりも高い位置に配置することにより、パイプ本体２６は傾斜した構成となる。

【0050】

このようにヒートパイプ２５Ａ～２５Ｄを構成するのは、作動液３７の蒸発と凝縮で起こる循環移動を重力により効果的に作用させるためである。即ち、吸熱部２７が放熱部２８よりも高い位置に配置される場合は作動液３７の循環は行われず、熱の伝達を行うことができなくなってしまうからである。

【0051】

また、上記構成とすることにより、各ＧＭ冷凍機１３Ａ～１３Ｄの冷却シリンダ１４Ａ，１４Ｂに対し、吸熱部２７と放熱部２８は直列に接続された構成となる。これにより、ヒートパイプ２５Ａ～２５Ｄを設けても、吸熱部２７と放熱部２８がコンパクトな構造で各ＧＭ冷凍機１３Ａ～１３Ｄに接続されるため、ヒートパイプ２５Ａ～２５Ｄを設けても超電導磁石装置１０が徒に大型化するのを防止することができる。

【0052】

更に、本実施例では各ヒートパイプ２５Ａ～２５Ｄに、引き出し配管５６を設けると共に、この各引き出し配管５６に封じ切り弁５５を配設した構成としている。このように、

各ヒートパイプ２５Ａ～２５Ｄに封じ切り弁５５および引き出し配管５６を設けることにより、パイプ本体２６に対する作動液３７の充填を容易に行うことができる。

【0053】

上記のように本実施例に係る超電導磁石装置１０によれば、ヒートパイプ２５Ａ～２５Ｄを用いて複数のＧＭ冷凍機１３Ａ～１３Ｄを連結したため、各ＧＭ冷凍機１３Ａ～１３Ｄの間が遠く離間している場合であっても、故障したＧＭ冷凍機に対して他のＧＭ冷凍機が発生する寒冷の一部を効率よく伝導することができ、確実に支援することが可能となる。

【0054】

本実施例における、具体的な支援の一例について説明する。いま、４台あるＧＭ冷凍機１３Ａ～１３Ｄの内の一台（例えば、ＧＭ冷凍機１３Ａ）が故障を想定すると、そのＧＭ冷凍機１３Ａ自身は冷却能力を失い、常温部（装置外部）からの入熱が当該ＧＭ冷凍機１３Ａを通り抜け超電導コイル１８Ａに熱伝導し、超電導コイル１８Ａを昇温させることになる。

【0055】

ここで、故障したＧＭ冷凍機１３Ａより超電導コイル１８Ａの冷却部（故障がなければ４Ｋで冷却される箇所）に侵入する入熱量は、例えば約0．6～0．9Ｗとなる。従って、この熱量を故障の起きていない他の3台のＧＭ冷凍機１３Ｂ～１３Ｄで効率よく吸収することが必要となる。

【0056】

正常時における各ＧＭ冷凍機１３Ａ～１３Ｄは、一台当たりの冷凍能力（４Ｋとする冷却能力）は約1Ｗであり、前述した通り各々の約0．3Ｗ分は余力としている。従って、故障の起きていない他の3台のＧＭ冷凍機１３Ｂ～１３Ｄの全体年の余力の合計は、0．3Ｗ×３台＝0．9Ｗとなる。よって、ヒートパイプヒートパイプ２５Ａ～２５Ｄを用い、この余力となる寒冷を効率よく支援側のＧＭ冷凍機１３Ａに熱移動させる。これにより、ＧＭ冷凍機１３Ａに故障が発生しても、他のＧＭ冷凍機１３Ｂ～１３Ｄにより支援が行われるため、超電導磁石装置１０を停止させる必要はなく、結晶引き上げに支障が発生することを防止できる。尚、通常時においては、ヒートパイプヒートパイプ２５Ａ～２５Ｄは、各ＧＭ冷凍機１３Ａ～１３Ｄ間における温度バラつきを均熱化する機能を奏するため、安定した冷却運転を行うことが可能となる。

【0057】

尚、上記したように、ＧＭ冷凍機１３Ａ～１３Ｄのいずれか（例えば、ＧＭ冷凍機１３Ａ）に故障が発生した場合、ＧＭ冷凍機１３Ａ自身は冷却能力を失うため、常温部（装置外部）からの入熱が当該ＧＭ冷凍機１３Ａを通り抜け超電導コイル１８Ａに熱伝導し、超電導コイル１８Ａを昇温させることになる。

【0058】

そこで、図6に示すように、真空容器１１に各ＧＭ冷凍機１３Ａ～１３Ｄを着脱可能に収納する副真空容器５０を設けておき、この副真空容器５０内にＧＭ冷凍機１３Ａ～１３Ｄを装着する構成としてもよい。

【0059】

図６（Ａ）は、通常時（以上が発生していない状態）を示している。この状態では、ＧＭ冷凍機１３Ａ～１３Ｄの２段目冷却シリンダ１４Ｂの先端は、冷却ステージ１５に接触した構成となっている。このため、２段目冷却シリンダ１４Ｂと冷却ステージ１５は熱的に接続され、２段目冷却シリンダ１４Ｂの寒冷は冷却ステージ１５に伝導する。

【0060】

これに対し、図６（Ｂ）は、ＧＭ冷凍機１３Ａ～１３Ｄに異常が発生した状態を示している。ＧＭ冷凍機１３Ａ～１３Ｄに異常が発生した場合には、ＧＭ冷凍機１３Ａ～１３Ｄを副真空容器５０から矢印Ｚ方向に所定量（本実施例では、ΔＨで示す量）だけ引き抜く処理を行う。これにより、２段目冷却シリンダ１４Ｂの先端は、冷却ステージ１５から離間した状態、即ち熱的に分離された構成となる。

【0061】
よって、２段目冷却シリンダ１４Ｂとヒートパイプ２５との熱的な接続を解除できるため、故障したＧＭ冷凍機１３Ａ～１３Ｄを介して外部の熱が超電導コイル１８Ａ～１８Ｄに伝導することを低減できる。

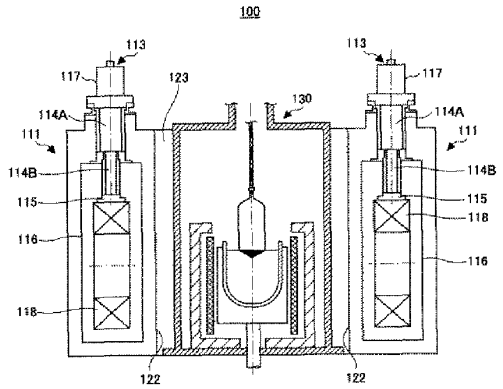
【図面の簡単な説明】

【0062】
【図1】図１は、従来の一例である超電導磁石装置の断面図である。
【図2】図２は、従来の一例である超電導磁石装置の平面図である。
【図3】図３は、本発明の一実施例である超電導磁石装置の断面図である。
【図4】図４は、本発明の一実施例である超電導磁石装置の展開図である。
【図5】図５は、ヒートパイプを説明するための図である。
【図6】図６は、ＧＭ冷凍機を副真空容器に対して離脱可能とした構成を説明するための図である。

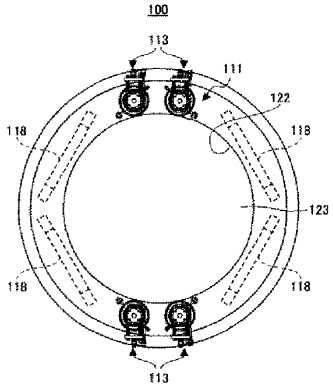
【符号の説明】

【0063】
１０　超電導磁石装置
１１　真空容器本体
１３Ａ～１３Ｄ　ＧＭ冷凍機
１４Ａ　１段目冷却シリンダ
１４Ｂ　２段目冷却シリンダ
１５　冷却ステージ
１６　熱シールド
１８Ａ～１８Ｄ　超電導コイル
２３　常温強磁場空間
２５，２５Ａ～２５Ｄ，４０，４１　ヒートパイプ
２６，４２，４３　パイプ本体
２７　吸熱部
２８　放熱部
３０　シリコン単結晶製造装置
４４，４５　伝熱体

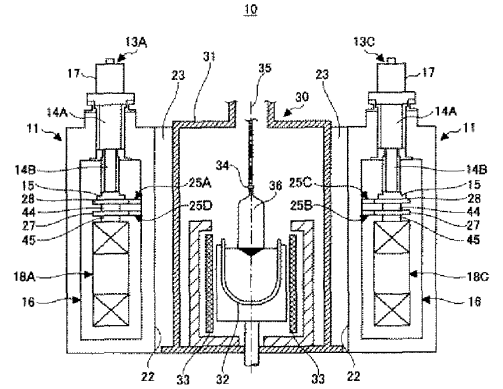
【図1】


100
113
117
123
130
114A
111
114B
115
116
118
122

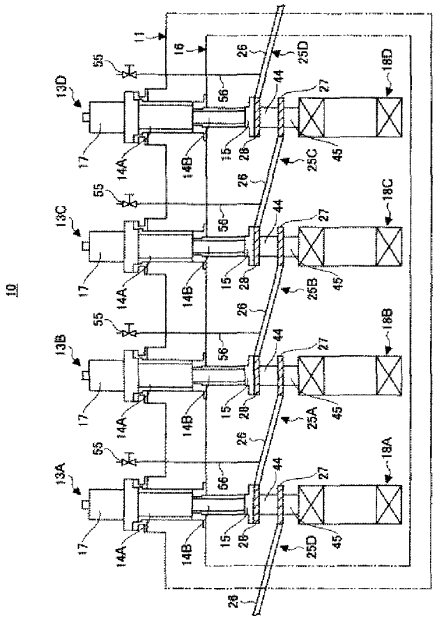
【図2】


100
113
111
122
118
123

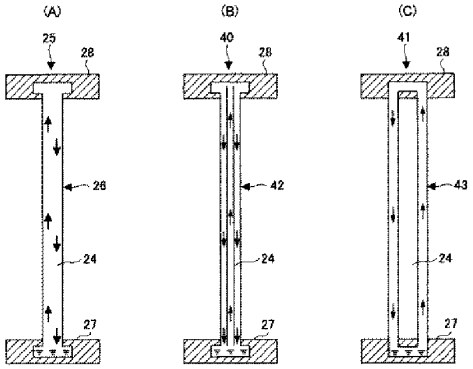
【図3】


10
13A
13C
17
31
23
35
30
14A
11
14B
15
28
44
27
45
34
36
25A
25D
25C
25B
18A
18C
16
22
33
32

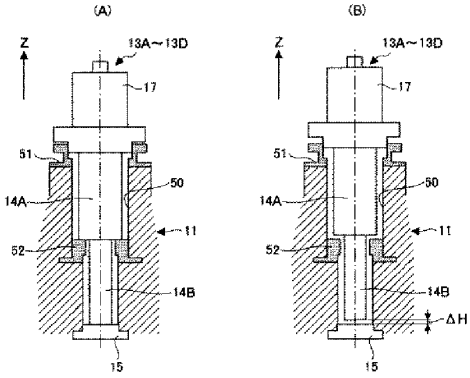
【図4】


10
11
16
26
25D
18D
13D
55
56
44
27
17
14A
14B
15
28
45
25C
18C
13C
25B
18B
13B
25A
18A
13A

【図5】


(A)
25
28
26
24
27
(B)
40
28
42
24
27
(C)
41
28
43
24
27

【図6】


(A)
Z
13A～13D
17
51
50
14A
11
52
14B
15
(B)
Z
13A～13D
17
51
50
14A
11
52
14B
ΔH
15

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PATENT AND TRADEMARK OFFICE

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APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**01/17/2025 08:34:24 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Jennifer Weaver
PATENT CENTER #	68816396	FILING DATE	07/08/2022
CUSTOMER #	23628	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	Sarah Schlotter

Documents

TOTAL DOCUMENTS: 7

DOCUMENT	PAGES	DESCRIPTION	SIZE (KB)
M156770000US04-TRN-SCS.pdf	1	Miscellaneous Incoming Letter	26 KB
M156770000US04-IDS1449-SCS.pdf	1	Information Disclosure Statement (IDS) Form (SB08)	23 KB
Warning: This is not a USPTO supplied IDS fillable form. Data in the form cannot be automatically loaded to other USPTO systems.			
M156770000US04-IDSBODY-SCS.pdf	3	Letter specifying the conditions for filing under 37 CFR 1.97	32 KB
M156770000US04-FEE-SCS.pdf	1	Fee Worksheet (SB06)	34 KB
M156770000KR00_KROA_11-26-2024.pdf	11	Other reference-Patent/Application/Search Documents	608 KB

JP2007048973A_w_engabs_FOR.pdf	13	Foreign Reference	767 KB
JP2006138851A_w_engabs_FOR.pdf	12	Foreign Reference	738 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
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This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

DOCKET NO.: M1567.70000US04

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	L. W. Nouketcha
Art Unit:	3763

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: January 17, 2025 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

MAIL STOP AMENDMENT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

STATEMENT FILED PURSUANT TO THE DUTY OF DISCLOSURE UNDER 37 C.F.R. §§ 1.56, 1.97 AND 1.98

Commissioner:

Pursuant to the duty of disclosure under 37 C.F.R. §§ 1.56, 1.97 and 1.98, the undersigned requests consideration of this Information Disclosure Statement.

PART I: Compliance with 37 C.F.R. § 1.97

This Information Disclosure Statement has been filed more than three months after the filing date of this application and after the mailing date of a first Office Action, but before the mailing date of any of a Final Action under 37 C.F.R. § 1.113, a Notice of Allowance under 37 C.F.R. § 1.311, or an action that otherwise closes prosecution in this application.

Please charge our Credit Card in the amount of $104.00 covering the fee set forth in 37 C.F.R. § 1.17(p).

PART II: Information Cited

The undersigned hereby makes of record in the above-identified application the information listed on the attached form PTO-1449 (modified PTO/SB/08). The order of presentation of the references should not be construed as an indication of the importance of the references.

The undersigned hereby makes the following additional information of record in the above-identified application.

The undersigned would like to bring to the Examiner's attention the enclosed search report or other communication from a corresponding or related International or Foreign National Application:

Serial No.	Date of Mailing	Type(s) of Communication	Docket No.
KR 10-2024-7004190	11-26-2024	Korean Notice of Preliminary Rejection	M1567.70000KR00

PART III: Remarks

Documents cited anywhere in the Information Disclosure Statement are enclosed unless otherwise indicated. It is respectfully requested that:

1. The Examiner consider completely the cited information, along with any other information, in reaching a determination concerning the patentability of the present claims;

2. The enclosed form PTO-1449 (modified PTO/SB/08) be signed by the Examiner to evidence that the cited information has been fully considered by the United States Patent and Trademark Office during the examination of this application;

3. The citations for the information be printed on any patent which issues from this application.

By submitting this Information Disclosure Statement, the undersigned makes no representation that a search has been performed, of the extent of any search performed, or that more relevant information does not exist.

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, material to patentability as defined in 37 C.F.R. § 1.56(b).

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, in fact, prior art as defined by 35 U.S.C. § 102, or an admission by Applicant as prior art.

Notwithstanding any statements by the undersigned, the Examiner is urged to form his or her own conclusion regarding the relevance of the cited information.

An early and favorable action is hereby requested.

The Director is hereby authorized to charge any deficiency or credit any overpayment in the fees occasioned by the filing of this Information Disclosure Statement to our Deposit Account No. 23/2825 under Docket No. M1567.70000US04 from which the undersigned is authorized to draw.

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

Docket No.: M1567.70000US04
Date: January 17, 2025

United States Patent and Trademark Office

Office of the Commissioner for Patents

Dear Applicant,

You recently received an Office action from your examiner. Review of your patent application is under way! You can continue to advertise or mark any products covered by your application for your invention as "Patent Pending" for as long as this application is pending. This letter provides information about how to continue through the patent application process and the help available to you on your journey.

Where are you in the patent application process? Your patent application is now in step 3, Application Prosecution (www.uspto.gov/UtilityPatentGuide.) Though the Office action includes a "rejection," that does not mean that you don't have a good idea you can patent. It means your examiner believes your application is not yet ready for allowance.

Ready to respond? Responding to the Office action is your opportunity to address the issues raised by your examiner. Responses must be timely, complete, and in writing. In your response, you may want to consider amending your application (www.uspto.gov/patents/maintain/responding-office-actions).

We provide Pro Se Assistance, support specifically geared for independent inventors without an agent or attorney. Visit www.uspto.gov/ProSePatents for a consolidated list of resources, including a sample amendment format. Full description of amendment formatting can be found at www.uspto.gov/web/offices/pac/mpep/s714.html. Call us at 866-767-3848, or email proseassistancecenter@uspto.gov.

Have questions about the Office action? Contact your examiner! A conversation with your examiner (called an "interview") may help clarify and resolve any issues and possibly identify what you can patent. While an interview does not stop the clock for your official response or substitute for a response, there is no fee for an interview. To schedule a call or video, you can:

1. use the USPTO's Automated Interview Request (AIR) form (www.uspto.gov/patents/uspto-automated-interview-request-air-form);
2. file the Applicant Initiated Interview Request form (PTOL-413A) (www.uspto.gov/sites/default/files/documents/PTOL413A.pdf); or
3. contact your examiner directly via telephone (contact information is provided at the end of your Office action).

Need help near you? We have regional offices across the country (www.uspto.gov/locations), as well as Patent and Trademark Resource Centers in libraries in nearly every state (www.uspto.gov/ptrc), with specialists standing by to help you at no cost.

Become a *registered* electronic filer (registered eFiler). As a registered eFiler, you can electronically view your submission, track progress of your application, and respond to USPTO correspondence. (www.uspto.gov/NewPatentFilers)

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- General information: USPTO Contact Center — 800-786-9199 • TTY/TDD 800-877-8339 • www.uspto.gov/help
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Want to learn more?

- Hear about resources for startups, inventors, and entrepreneurs, as well as our initiatives engaging women, the military community, and others. These programs offer helpful tips and tricks on identifying and managing your IP, finding options for funding, and expanding your network to support your business.
  - www.uspto.gov/startups
  - www.uspto.gov/inventors
  - www.uspto.gov/initiatives
- Access our free services all in one spot. Find all of our contact centers, nationwide services, events, education and training. (www.uspto.gov/FreeServices)
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Best,

Vaishali Udupa
Commissioner for Patents
United States Patent and Trademark Office

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
17/860,950	07/08/2022	Corban I. Tillemann-Dick	M1567.70000US04	9208

23628 7590 11/07/2024

WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

EXAMINER	
NOUKETCHA, LIONEL W	

ART UNIT	PAPER NUMBER
3763	

NOTIFICATION DATE	DELIVERY MODE
11/07/2024	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

Patents_eOfficeAction@WolfGreenfield.com
WGS_eOfficeAction@WolfGreenfield.com

EXHIBIT 1004 – Page 106 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Office Action Summary	**Application No.** 17/860,950	**Applicant(s)** Tillemann-Dick et al.	
	Examiner LIONEL W NOUKETCHA	**Art Unit** 3763	**AIA (FITF) Status** Yes

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTHS FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☑ Responsive to communication(s) filed on 07/08/2022.

☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2a)☐ This action is **FINAL.** 2b) ☑ This action is non-final.

3)☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

4)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims*

5) ☑ Claim(s) 1-20 is/are pending in the application.

5a) Of the above claim(s) _____ is/are withdrawn from consideration.

6) ☐ Claim(s) _____ is/are allowed.

7) ☑ Claim(s) 1-2,4,6-7 and 16-20 is/are rejected.

8) ☑ Claim(s) 8,12 and 14-15 is/are objected to.

9) ☐ Claim(s) _____ are subject to restriction and/or election requirement

* If any claims have been determined allowable, you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to **PPHfeedback@uspto.gov.**

Application Papers

10)☐ The specification is objected to by the Examiner.

11)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

Priority under 35 U.S.C. § 119

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

Certified copies:

a)☐ All b)☐ Some** c)☐ None of the:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

** See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☑ Notice of References Cited (PTO-892)

2) ☑ Information Disclosure Statement(s) (PTO/SB/08a and/or PTO/SB/08b) Paper No(s)/Mail Date _____.

3) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date _____.

4) ☐ Other: _____.

DETAILED ACTION

Notice of Pre-AIA or AIA Status

1. The present application, filed on or after March 16, 2013, is being examined under the first inventor to file provisions of the AIA.

Status of Claims

2. Claims 1-20 are currently pending in the application.

Information Disclosure Statement

3. All the information disclosure statements (IDS) submitted on herein so far are in compliance with the provisions of 37 CFR 1.97. Accordingly, the information disclosure statements have been considered by the examiner.

Drawings

4. The drawings are objected to because Fig. 5A-5E and 8B-10C appears to be annotated black and white photographs. Photographs, including photocopies of photographs, are not ordinarily permitted in utility and design patent applications. If the subject matter of the application admits of illustration by a drawing, the examiner may require a drawing in place of the photograph. The photographs must be of sufficient quality so that all details in the photographs are reproducible in the printed patent. India ink, or its equivalent that secures solid black lines, must be used for drawings. See MPEP 1.84.

Corrected drawing sheets in compliance with 37 CFR 1.121(d) are required in reply to the Office action to avoid abandonment of the application. Any amended replacement drawing sheet should include all of the figures appearing on the immediate prior version of the sheet, even if only one figure is being amended. The figure or figure number of an amended drawing should not be labeled as “amended.” If a drawing figure is to be canceled, the appropriate figure must be removed from the replacement sheet, and where necessary, the remaining figures must be renumbered and appropriate changes made to the

brief description of the several views of the drawings for consistency. Additional replacement sheets may be necessary to show the renumbering of the remaining figures. Each drawing sheet submitted after the filing date of an application must be labeled in the top margin as either "Replacement Sheet" or "New Sheet" pursuant to 37 CFR 1.121(d). If the changes are not accepted by the examiner, the applicant will be notified and informed of any required corrective action in the next Office action. The objection to the drawings will not be held in abeyance.

Claim Rejections - 35 USC § 112

5. The following is a quotation of 35 U.S.C. 112(b):

> (b) CONCLUSION.—The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the inventor or a joint inventor regards as the invention.

> The following is a quotation of 35 U.S.C. 112 (pre-AIA), second paragraph:
> The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention.

6. Claim(s) 16-20 is/are rejected under 35 U.S.C. 112(b) or 35 U.S.C. 112 (pre-AIA), second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which the inventor or a joint inventor, or for pre-AIA the applicant regards as the invention.

Claim 16 calls for the limitation "wherein the outer vacuum chamber is configured to fit within a server rack-type container" in lines 1-2, which limitation is indefinite for the following reasons:

I. it is unclear what the term "server rack-type container" is intended to convey. The scope of the word "type" is not understood when read in light of the specification. Is "server rack-type container" referring only to server rack container? Or does it encompass other structures different than server rack container? It is uncertain. See Ex parte Copenhaver, 109 USPQ 118 (Bd. Pat. App. & Inter. 1955) and MPEP 2173.05(b).

II. the limitation is defined by reference to an object (server rack-type container) and the relationship between the limitation (the outer vacuum chamber) and the object is not sufficiently defined. That is, the examiner cannot readily ascertain proportional relationship that will allow for the outer vacuum

chamber to fit within a server rack-type container. The relationship of parts is not based on any known standard for determining a fit between the outer vacuum chamber and the server rack-type container; but on a device and a server rack-type container of unspecified build. See 2173.05(b) II; Ex parte Miyazaki, 89 USPQ2d 1207 (Bd. Pat. App. & Inter. 2008) (precedential) and Ex parte Brummer, 12 USPQ2d 1653 (Bd. Pat. App. & Inter. 1989).

Claim(s) 17-20 is/are indefinite for their dependency on an indefinite base claim.

Claim Rejections - 35 USC § 102

7. In the event the determination of the status of the application as subject to AIA 35 U.S.C. 102 and 103 (or as subject to pre-AIA 35 U.S.C. 102 and 103) is incorrect, any correction of the statutory basis for the rejection will not be considered a new ground of rejection if the prior art relied upon, and the rationale supporting the rejection, would be the same under either status.

8. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (a)(1) the claimed invention was patented, described in a printed publication, or in public use, on sale or otherwise available to the public before the effective filing date of the claimed invention.

9. Claim(s) 1-2 and 4-6 is/are rejected under 35 U.S.C. 102(a)(1) as being anticipated by Hart (US 20210076530 A1).

Regarding claim 1:

Hart discloses a dilution refrigerator #105 ([0032]) comprising:

an outer vacuum chamber (not discussed by Hart, but inherently present in dilution refrigerator) comprising at least one substantially planar surface (see planar front surface #210 and #310, best seen in Fig. 4);

and

an opening (opening covered by cover #425) in the at least one substantially planar surface configured to provide access to an interior (interior of #320) of the outer vacuum chamber (note: interior of #320 is an interior of the outer vacuum chamber; as in the typical arrangement, the vacuum chamber will be surrounding the whole of #400).

Regarding claim 2:

Hart further discloses further comprising a sample stage #430 housed within the outer vacuum chamber, wherein the opening is configured to provide access to the sample stage through the outer vacuum chamber (see Fig. 4).

Regarding claim 4:

Hart further discloses wherein the at least one substantially planar surface comprises a first surface disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator (see Fig. 4).

Regarding claim 6:

Hart further discloses wherein the opening comprises a hermetic opening ([0053]).

10. Claim(s) 1-2 is/are rejected under 35 U.S.C. 102(a)(1) as being anticipated by Mikheev (US 6202439 B1).

Regarding claim 1:

Mikheev discloses dilution refrigerator comprising:

an outer vacuum chamber (chamber defined by #2 and #3; col. 5, L 14-17) comprising at least one substantially planar surface (see surface of plate comprising #8A); and

an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber (see opening covered by the aforementioned plate; covering the top edge of body #1).

Regarding claim 2:

Mikheev further discloses a sample stage housed within the outer vacuum chamber, wherein the opening is configured to provide access to the sample stage through the outer vacuum chamber (col. 5, L 29-42).

Claim Rejections - 35 USC § 103

11. In the event the determination of the status of the application as subject to AIA 35 U.S.C. 102 and 103 (or as subject to pre-AIA 35 U.S.C. 102 and 103) is incorrect, any correction of the statutory basis for the rejection will not be considered a new ground of rejection if the prior art relied upon, and the rationale supporting the rejection, would be the same under either status.

12. The following is a quotation of 35 U.S.C. 103 which forms the basis for all obviousness rejections set forth in this Office action:

> A patent for a claimed invention may not be obtained, notwithstanding that the claimed invention is not identically disclosed as set forth in section 102, if the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art to which the claimed invention pertains. Patentability shall not be negated by the manner in which the invention was made.

13. The factual inquiries set forth in *Graham v. John Deere Co.*, 383 U.S. 1, 148 USPQ 459 (1966), that are applied for establishing a background for determining obviousness under 35 U.S.C. 103 are summarized as follows:

1. Determining the scope and contents of the prior art.

2. Ascertaining the differences between the prior art and the claims at issue.

3. Resolving the level of ordinary skill in the pertinent art.

4. Considering objective evidence present in the application indicating obviousness or nonobviousness.

14. Claim(s) 7 is/are rejected under 35 U.S.C. 103 as being unpatentable over Hart (US 20210076530 A1).

Regarding claim 7:

Although Hart discloses wherein the opening comprises a door #425, Hart does not disclose wherein said door is a hinged door.

Nonetheless, going from a door closed by fasteners to a door closed by hinged would have been obvious to an ordinary skill artisan, as hinged doors are well known in the art (official notice).

Thus, it would have been obvious for one of ordinary skills in the art before the effective filing date to have provided the apparatus of Hart with the opening comprising a hinged door.

One of ordinary skills would have recognized that hinged doors are easy to open and close because of their simple rotating hinges; and employing them would have facilitated operation of the device.

Allowable Subject Matter

15. Claims 8, 12, and 14-15 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.

16. The following is a statement of reasons for the indication of allowable subject matter:

The combination of elements as set forth in each of claims 8, 12, and 14-15 is not disclosed or made obvious by the prior art of record.

Conclusion

17. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure.

Nishio (US 20200262013 A1) teaches a pertinent cryogenic device.

18. Any inquiry concerning this communication or earlier communications from the examiner should be directed to LIONEL W NOUKETCHA whose telephone number is (571)272-8438. The examiner can normally be reached on Mon - Fri: 08:00 AM - 04:00 PM.

Examiner interviews are available via telephone, in-person, and video conferencing using a USPTO supplied web-based collaboration tool. To schedule an interview, applicant is encouraged to use the USPTO Automated Interview Request (AIR) at http://www.uspto.gov/interviewpractice.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Frantz Jules can be reached on 571-272-6681. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/LIONEL NOUKETCHA/
Primary Examiner, Art Unit 3763

Notice of References Cited	Application/Control No. 17/860,950	Applicant(s)/Patent Under Reexamination Tillemann-Dick et al.	
	Examiner LIONEL W NOUKETCHA	Art Unit 3763	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date YYYY-MM-DD	Name	CPC Classification	US Classification
*	A	US-20210076530-A1	2021-03-11	Hart; Sean	G06F1/20	1/1
*	B	US-6202439-B1	2001-03-20	Mikheev; Vladimir Andreyevich	F25B9/12	62/51.1
*	C	US-20200262013-A1	2020-08-20	NISHIO; Tatsuki	F25B9/14	1/1
	D					
	E					
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date YYYY-MM-DD	Country	Name	CPC Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in YYYY-MM-DD format are publication dates. Classifications may be US or foreign.

EXHIBIT 1004 – Page 115 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	17/860,950	Tillemann-Dick et al.
	Examiner	Art Unit
	LIONEL W NOUKETCHA	3763

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

CLAIMS

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
Final	Original	11/04/2024								
	1	✓								
	2	✓								
	3									
	4	✓								
	5									
	6	✓								
	7	✓								
	8	O								
	9									
	10									
	11									
	12	O								
	13									
	14	O								
	15	O								
	16	✓								
	17	✓								
	18	✓								
	19	✓								
	20	✓								

EXHIBIT 1004 – Page 116 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	17/860,950	Tillemann-Dick et al.
	Examiner	Art Unit
	LIONEL W NOUKETCHA	3763

CPC - Searched*		
Symbol	Date	Examiner
F25B9/12 F25B9/145 F25D2317/043 F25B9/14	11/04/2024	LN

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	Date	Examiner
F25B9/12 F25B9/145 F25D2317/043 F25B9/14	11/04/2024	LN
CPC combined with text	11/04/2024	LN
Inventors and applicant names searched	11/04/2024	LN
Concept searched in IP.com	11/04/2024	LN
Search history attached	11/04/2024	LN

Interference Search			
US Class/CPC Symbol	US Subclass/CPC Group	Date	Examiner

/LIONEL NOUKETCHA/ Primary Examiner, Art Unit 3763	

EXHIBIT 1004 – Page 117 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

FORM PTO-1449/A and B (modified PTO/SB/08)				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet	1	of	2	GROUP ART UNIT: Not Yet Assigned	EXAMINER: Not Yet Assigned

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	U.S. Patent Document Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		4,296,609		Severijns et al.	10-27-1981
		4,672,823		Benoit et al.	06-16-1987
		4,986,077	A	Shao et al.	01-22-1991
		5,172,554	A	Swift et al.	12-22-1992
		5,207,674	A	Hamilton	05-04-1993
		2004-0223300	A1	Fink et al.	11-11-2004
		2005-0223714	A1	Li et al.	10-13-2015
		2009-0275476	A1	Atrey	11-05-2009
		2015-0160702	A1	Franz	06-11-2015
		2018-0051937	A1	Thiers et al.	02-22-2018
		2019-0226724	A1	Kotsubo et al.	07-25-2019
		2020-0370792	A1	Matthews	11-26-2020
		2021-0076530	A1	Hart et al.	03-11-2021
		2021-0402407	A1	Hoehne	12-30-2021
		2021-0402407	A1	Hoehne	12-30-2021
		2022-0221108	A1	Corcoles-Gonzalez et al.	07-14-2022

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Foreign Patent Document Number	Foreign Patent Document Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		CN	111089436	A	Csic Pride Nanjing Cryogenic Tech Co., Ltd .	05-01-2020	Y; Abstract Only
		FR	2 184 536	A1	Anvar	12-28-1973	Y; Abstract Only
		GB	2 282 437	A	Hitachi Europe Limited	04-05-1995	
		WO	2015-004904	A1	Denso Corp.	01-15-2015	Y; Abstract Only

EXAMINER:	DATE CONSIDERED:

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

11455735.1

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

FORM PTO-1449/A and B (modified PTO/SB/08) **INFORMATION DISCLOSURE STATEMENT BY APPLICANT**				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet	2	of	2	GROUP ART UNIT: Not Yet Assigned	EXAMINER: Not Yet Assigned

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)
		SMITH et al., Flexible Coaxial Ribbon Cable for High-Density Superconducting Microwave Device Arrays. arXiv. 2020 July 13:6 pages.	

[NOTE – No copies of U.S. patents, published U.S. patent applications, or pending, unpublished patent applications stored in the USPTO's Image File Wrapper (IFW) system, are included. See 37 CFR § 1.98 and 1287OG163. Copies of all other patent(s), publication(s), unpublished, pending U.S. patent applications, or other information listed are provided as required by 37 CFR § 1.98 unless 1) such copies were provided in an IDS in an earlier application that complies with 37 CFR § 1.98, and 2) the earlier application is relied upon for an earlier filing date under 35 U.S.C. § 120.]

EXAMINER:	DATE CONSIDERED:
/LIONEL NOUKETCHA/	11/03/2024

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

11455735.1

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

PE2E SEARCH - Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	British Equivalents	Time Stamp
L1	1	"20210402407".pn.	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 09:33 AM
L2	3	jp-2012182176$.did.	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/03 10:26 AM
L3	4	"17860950"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/03 10:30 AM
L4	1	"20220279927".pn.	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:06 AM
L5	144	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment)	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:43 AM
L6	74	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:43 AM
L7	0	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment) AND opening near3	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:46 AM

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

		(hermetic OR door) AND @pd<="20210708"					
L8	74	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:46 AM
L9	8	dilution near3 refrigerator AND vacuum ADJ (chamber OR compartment) AND (hermetic OR door) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 11:52 AM
L10	6	("2014/0007596").urpn. AND (PGPB | USPT | USOC).dbnm.	(US-PGPUB; USPAT; USOCR)	OR	ON	ON	2024/11/03 12:04 PM
L11	10	("4432216" | "5323112" | "5611207" | "5744959" | "20030122543" | "20050202976" | "20080098752" | "20100109666").pn. OR ("9458969").urpn. AND (PGPB | USPT | USOC).dbnm.	(US-PGPUB; USPAT; USOCR)	OR	ON	ON	2024/11/03 12:04 PM
L12	9	(F25B9/12).cpc. AND (F25D2317/043).cpc.	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/03 12:13 PM
L13	1	(F25B9/12).cpc. AND (hermetic OR door) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/03 03:49 PM
L14	12	("20140137571"|"20180112928"|"20190042968"|"9779360"|"20140137571"|"20140326001"|"20180112928"|"20190042968"|"20090007573"|"20110120147"|"20170284725"|"4136526"|"4300360"|"4485640"|"5347819"|"20140137571").PN.	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 04:05 PM
L15	21	(F25B9/12).cpc. AND cover AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/03 04:07 PM
L16	74	dilution ADJ refrigerator AND vacuum ADJ (chamber) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 10:04 PM
L17	178	((("TILLEMANN-DICK") near3 ("Corban")) OR (("THOMPSON") near3	(US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT)	OR	ON	ON	2024/11/03 10:13 PM

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

		("Kyle")) OR (("CHOO") near3 ("Bryan")) OR (("OGANDO") near3 ("DOS") near3 ("SANTOS") near3 ("ALLAN") near3 ("John")) OR (("BYARS") near3 ("Jonathan"))).INV.					
L18	10	((("MAYBELL") near3 ("QUANTUM") near3 ("INDUSTRIES") near3 ("INC"))).AS,AANM.	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/03 10:13 PM
L19	515	L18 L17	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/03 10:13 PM
L20	0	L19 dilution ADJ refrigerator AND vacuum ADJ (chamber) AND @pd<="20210708"	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:14 PM
L21	9	L19 dilution ADJ refrigerator AND vacuum ADJ (chamber)	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:14 PM
L22	1	L19 dilution ADJ refrigerator AND (sample ADJ stage).clm.	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:17 PM
L23	8	dilution ADJ refrigerator AND (sample ADJ stage).clm.	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:18 PM
L24	15	("20040223300" OR "20050223714" OR "20090275476" OR "20150160702" OR "20180051937" OR "20190226724" OR "20200370792" OR "20210076530" OR "20210402407" OR "20220221108" OR	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 10:27 PM

		"4296609" OR "4672823" OR "4986077" OR "5172554" OR "5207674").pn.					
L25	1	("6202439").pn.	(US-PGPUB; USPAT)	AND	ON	ON	2024/11/03 11:24 PM
L26	6	("5542256" | "5816071").pn. OR ("6202439").urpn. AND (PGPB | USPT | USOC).dbnm.	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/03 11:33 PM
L27	2	dilution ADJ refrigerator AND (lid OR cover) near10 (hinged OR easy OR access) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 08:46 AM
L28	2	dilution ADJ refrigerator AND (lid OR cover OR panel) near10 (hinged OR easy OR access$3) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 08:47 AM
L29	54	dilution ADJ refrigerator AND (lid OR cover OR panel OR opening) near10 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:07 AM
L30	1409	cryostat AND (lid OR cover OR panel OR opening) near10 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:51 AM
L31	1176	cryostat AND (lid OR cover OR panel OR opening) near6 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:51 AM
L32	919	cryostat AND (lid OR cover OR panel OR opening) near6 (vacuum OR shell OR chamber) AND vacuum AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:52 AM
L33	305	cryostat AND (lid OR cover OR panel OR opening) near6 (vacuum OR shell OR chamber) AND vacuum AND shield AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:52 AM

L34	517	cryostat AND (lid OR cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND vacuum AND shield AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:53 AM
L35	380	cryostat AND (lid OR cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND vacuum near5 (shell OR chamber OR housing OR casing) AND shield AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:53 AM
L36	21	cryostat AND ((lid OR cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND vacuum near5 (shell OR chamber OR housing OR casing) AND shield).clm. AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:54 AM
L37	23	cryostat AND ((cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND (vacuum OR seal$3 OR hermetic) near5 (shell OR chamber OR housing OR casing) AND shield).clm. AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR)	AND	ON	ON	2024/11/04 09:57 AM
L38	1255	cryostat AND ((cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND (vacuum OR seal$3 OR hermetic) near5 (shell OR chamber OR housing OR casing) AND shield) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA,	AND	ON	ON	2024/11/04 09:58 AM

			VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)				
L39	2091	(cryostat OR (dilution ADJ refrigerator)) AND (cover OR panel OR opening OR plate) near3 (vacuum OR shell OR chamber OR housing OR casing) AND (vacuum OR seal$3 OR hermetic) near3 (shell OR chamber OR housing OR casing) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	AND	ON	ON	2024/11/04 09:59 AM
L40	134	(cryostat OR (dilution ADJ refrigerator)) AND (cover OR panel OR opening OR plate OR door) near3 (vacuum OR shell OR chamber OR housing OR casing) AND (vacuum OR seal$3 OR hermetic) near3 (shell OR chamber OR housing OR casing) AND (cover OR panel OR opening OR plate OR door) near6 (srew OR hinged OR fasten$4) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO, RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)	AND	ON	ON	2024/11/04 10:02 AM
L41	346	(F25B9/12 OR F25B9/145 OR F25D2317/043 OR F25B9/14).cpc. AND (lid OR cover OR panel OR opening) near6 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT)	OR	ON	ON	2024/11/04 02:46 PM
L42	1565	(F25B9/12 OR F25B9/145 OR F25D2317/043 OR F25B9/14).cpc. AND (lid OR cover OR panel OR opening) near3 (vacuum OR shell OR chamber) AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AU, AP, AT, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, OA, RU, SU, WO, MC, MD, MY, NL, NO, NZ, PH, PL, PT, RO,	OR	ON	ON	2024/11/04 02:46 PM

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IPR2026-00291 - U.S. Patent No. 12,313,320

			RS, SE, SG, SI, SK, TH, TN, TR, TW, UA, VN); FPRS; EPO; JPO; DERWENT; IBM_TDB)				
L43	387	(F25B9/12 OR F25B9/145 OR F25D2317/043 OR F25B9/14).cpc. AND (lid OR cover OR panel OR opening OR plate) near4 (vacuum OR shell OR chamber OR housing OR casing) AND vacuum near5 (shell OR chamber OR housing OR casing) AND shield AND @pd<="20210708"	(US-PGPUB; USPAT; USOCR; FIT (AP, AT, AU, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, MC, MD, MY, NL, NO, NZ, OA, PH, PL, PT, RO, RS, RU, SE, SG, SI, SK, SU, TH, TN, TR, TW, UA, VN, WO); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/04 02:48 PM
L44	24	L43 AND dilution ADJ refrigerator	(US-PGPUB; USPAT; USOCR; FIT (AP, AT, AU, BE, BG, BR, BY, CA, CH, CN, CS, CU, CZ, DD, DE, DK, EA, EE, EP, ES, FI, FR, GB, HR, HU, ID, IE, IL, IS, IT, JP, KR, LT, LU, LV, MA, MC, MD, MY, NL, NO, NZ, OA, PH, PL, PT, RO, RS, RU, SE, SG, SI, SK, SU, TH, TN, TR, TW, UA, VN, WO); FPRS; EPO; JPO; DERWENT; IBM_TDB)	OR	ON	ON	2024/11/04 02:48 PM

PE2E SEARCH - Search History (Interference)

There are no Interference searches to show.

DOCKET NO.: M1567.70000US04

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	Not Yet Assigned
Art Unit:	Not Yet Assigned

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: March 8, 2023 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

MAIL STOP AMENDMENT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

STATEMENT FILED PURSUANT TO THE DUTY OF DISCLOSURE UNDER 37 C.F.R. §§ 1.56, 1.97 AND 1.98

Examiner:

Pursuant to the duty of disclosure under 37 C.F.R. §§ 1.56, 1.97 and 1.98, the undersigned requests consideration of this Information Disclosure Statement.

PART I: Compliance with 37 C.F.R. § 1.97

This Information Disclosure Statement has been filed before the mailing of a first Office Action on the merits.

No fee or certification is required.

PART II: Information Cited

The undersigned hereby makes of record in the above-identified application the information listed on the attached form PTO-1449 (modified PTO/SB/08). The order of presentation of the references should not be construed as an indication of the importance of the references.

The undersigned hereby makes the following additional information of record in the above-identified application.

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

EXHIBIT 1004 – Page 127 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

The undersigned would like to bring to the Examiner's attention the following applications that may contain subject matter related to this application:

Serial No.	Filing Date	Inventor(s)	Docket No.
*17/860,909	07-08-2022	Tillemann-Dick et al.	M1567.70000US02
*17/860,923	07-08-2022	Tillemann-Dick et al.	M1567.70000US03
*17/861,026	07-08-2022	Tillemann-Dick et al.	M1567.70000US05
*17/861,044	07-08-2022	Tillemann-Dick et al.	M1567.70000US06

*A copy of this reference is not provided as the Office has waived the requirement under 37 C.F.R. § 1.98(a)(2)(iii) for submitting a copy of a cited U.S. patent application if it is scanned to the Image File Wrapper system and is available on Private PAIR .

The undersigned would like to bring to the Examiner's attention the enclosed search reports or other communications from a corresponding or related International or Foreign National Application:

Serial No.	Date of Mailing	Type(s) of Communication	Docket No.
PCT/US2022/036531	**11-23-2023**	**International Search Report and Written Opinion**	**M1567.70000WO00**
PCT/US2022/036531	**09-16-2022**	**Invitation to Pay Additional Fees**	**M1567.70000WO00**

PART III: Remarks

Documents cited anywhere in the Information Disclosure Statement are enclosed unless otherwise indicated. It is respectfully requested that:

1. The Examiner consider completely the cited information, along with any other information, in reaching a determination concerning the patentability of the present claims;

2. The enclosed form PTO-1449 (modified PTO/SB/08) be signed by the Examiner to evidence that the cited information has been fully considered by the United States Patent and Trademark Office during the examination of this application;

3. The citations for the information be printed on any patent which issues from this application.

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

By submitting this Information Disclosure Statement, the undersigned makes no representation that a search has been performed, of the extent of any search performed, or that more relevant information does not exist.

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, material to patentability as defined in 37 C.F.R. § 1.56(b).

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, in fact, prior art as defined by 35 U.S.C. § 102, or an admission by Applicant as prior art.

Notwithstanding any statements by the undersigned, the Examiner is urged to form his or her own conclusion regarding the relevance of the cited information.

An early and favorable action is hereby requested.

The Director is hereby authorized to charge any deficiency or credit any overpayment in the fees occasioned by the filing of this Information Disclosure Statement to our Deposit Account No. 23/2825 under Docket No. M1567.70000US04 from which the undersigned is authorized to draw.

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
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Docket No.: M1567.70000US04
Date: March 7, 2023

/LIONEL NOUKETCHA/ 11/03/2024

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

FORM PTO-1449/A and B (modified PTO/SB/08)				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet	1	of	1	GROUP ART UNIT: 3763	EXAMINER: L. W. Nouketcha

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		6,788,386	B2	Cox et al.	09-07-2004
		11,946,680		Tillemann-Dick et al.	04-02-2024
		12,000,640		Tillemann-Dick et al.	06-04-2024
		2005-0268641	A1	Dekiya	12-08-2005
		2009-0206229	A1	Nesch	08-20-2009
		2007-0273074	A1	Mizuno et al.	11-29-2007
		2019-0383525	A1	Matthews et al.	12-19-2019
		2024-0295347	A1	Tillemann-Dick et al.	09-05-2024
		2024-0295348	A1	Tillemann-Dick et al.	09-05-2024

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		WO	2022/200761	A1	Oxford Instruments Nanotechnology Tools, Ltd	09-29-2022	

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)
		International Search Report and Written Opinion mailed August 6, 2024, in connection with International Application No. PCT/US2024/018062 (M1567.70003WO00).	
		Invitation to Pay Additional Fees mailed May 28, 2024, in connection with International Application No. PCT/US2024/018062 (M1567.70003WO00).	
		International Preliminary Report on Patentability dated December 14, 2023, in connection with International Application No. PCT/US2022/036531 (M1567.70000WO00).	

[NOTE – No copies of U.S. patents, published U.S. patent applications, or pending, unpublished patent applications stored in the USPTO's Image File Wrapper (IFW) system, are included. See 37 CFR § 1.98 and 1287OG163. Copies of all other patent(s), publication(s), unpublished, pending U.S. patent applications, or other information listed are provided as required by 37 CFR § 1.98 unless 1) such copies were provided in an IDS in an earlier application that complies with 37 CFR § 1.98, and 2) the earlier application is relied upon for an earlier filing date under 35 U.S.C. § 120.]

EXAMINER:	DATE CONSIDERED:
/LIONEL NOUKETCHA/	11/03/2024

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

12792505.1

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

Bibliographic Data

Application No: 17/860,950

Foreign Priority claimed: ○ Yes ◉ No

35 USC 119 (a-d) conditions met: ☐ Yes ☐ No ☐ Met After Allowance

Verified and Acknowledged: /LIONEL NOUKETCHA/ Examiner's Signature | Initials

Title: INTEGRATED DILUTION REFRIGERATORS

FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
07/08/2022	062	3763	
RULE			

APPLICANTS

Maybell Quantum Industries, Inc., Denver, CO,

INVENTORS

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Kyle J. Thompson, Boulder, CO, UNITED STATES

Bryan J. Choo, New York, NY, UNITED STATES

John Ogando Dos Santos Allan, Boulder, CO, UNITED STATES

Jonathan Michael Byars, Golden, CO, UNITED STATES

CONTINUING DATA

This application has PRO of 63319248 03/11/2022

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FOREIGN APPLICATIONS

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FORM PTO-1449/A and B (modified PTO/SB/08)				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban Tillemann-Dick	
Sheet	1	of	1	GROUP ART UNIT: Not Yet Assigned	EXAMINER: Not Yet Assigned

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		2015-0196221	A1	Garside	07-16-2015
		2018-0045471	A1	Dietrich	02-15-2018
		2023-0008279	A1	Tillemann-Dick et al.	01-12-2023
		2023-0009670	A1	Tillemann-Dick et al.	01-12-2023
		2023-0010758	A1	Tillemann-Dick et al.	01-12-2023
		2023-0010920	A1	Tillemann-Dick et al.	01-12-2023
		2023-0012324	A1	Tillemann-Dick et al.	01-12-2023

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		JP	2012-182176	A	Fujikura Ltd	09-20-2012	Y

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)
		International Search Report and Written Opinion mailed November 23, 202, in connection with International Application No. PCT/US2022/036531 (M1567.70000WO00).	
		Invitation to Pay Additional Fees mailed September 16, 2022, in connection with Application No. PCT/US2022/036531 (M1567.70000WO00)	
		POBELL, Matter and Methods at Low Temperatures. Springer Berlin. 15 Feb. 2007:468 pages.	

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EXAMINER:	DATE CONSIDERED:
/LIONEL NOUKETCHA/	11/03/2024

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

11050118.1

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DOCKET NO.: M1567.70000US04

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	Not Yet Assigned
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Dated: July 13, 2023 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

MAIL STOP AMENDMENT
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Alexandria, VA 22313-1450

STATEMENT FILED PURSUANT TO THE DUTY OF DISCLOSURE UNDER 37 C.F.R. §§ 1.56, 1.97 AND 1.98

Commissioner:

Pursuant to the duty of disclosure under 37 C.F.R. §§ 1.56, 1.97 and 1.98, the undersigned requests consideration of this Information Disclosure Statement.

PART I: Compliance with 37 C.F.R. § 1.97

This Information Disclosure Statement has been filed before the mailing of a first Office Action on the merits.

No fee or certification is required.

PART II: Information Cited

The undersigned hereby makes of record in the above-identified application the information listed on the attached form PTO-1449 (modified PTO/SB/08). The order of presentation of the references should not be construed as an indication of the importance of the references.

11455733.1

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The undersigned hereby makes the following additional information of record in the above identified application.

The undersigned would like to bring to the Examiner's attention the following application that may contain subject matter related to this application:

Serial No.	Filing Date	Inventor(s)	Docket No.
*18/182,244	03-10-2023	Tillemann-Dick et al.	M1567.70001US01

*A copy of this reference is not provided as the Office has waived the requirement under 37 C.F.R. § 1.98(a)(2)(iii) for submitting a copy of a cited U.S. patent application if it is scanned to the Image File Wrapper system and is available on Private PAIR .

PART III: Remarks

Documents cited anywhere in the Information Disclosure Statement are enclosed unless otherwise indicated. It is respectfully requested that:

1. The Examiner consider completely the cited information, along with any other information, in reaching a determination concerning the patentability of the present claims;

2. The enclosed form PTO-1449 (modified PTO/SB/08) be signed by the Examiner to evidence that the cited information has been fully considered by the United States Patent and Trademark Office during the examination of this application;

3. The citations for the information be printed on any patent which issues from this application.

By submitting this Information Disclosure Statement, the undersigned makes no representation that a search has been performed, of the extent of any search performed, or that more relevant information does not exist.

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, material to patentability as defined in 37 C.F.R. § 1.56(b).

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.N./

EXHIBIT 1004 – Page 134 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, in fact, prior art as defined by 35 U.S.C. § 102, or an admission by Applicant as prior art.

Notwithstanding any statements by the undersigned, the Examiner is urged to form his or her own conclusion regarding the relevance of the cited information.

An early and favorable action is hereby requested.

The Director is hereby authorized to charge any deficiency or credit any overpayment in the fees occasioned by the filing of this Information Disclosure Statement to our Deposit Account No. 23/2825 under Docket No. M1567.70000US04 from which the undersigned is authorized to draw.

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
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Date: July 13, 2023

/LIONEL NOUKETCHA/ 11/03/2024

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ENCLOSURES (*Check all that apply*)

- [ ] Fee Transmittal Form
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Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Sarah C. C. Schlotter/		
Printed name	Sarah C.C. Schlotter, PhD		
Date	October 23, 2024	Reg. No.	79,027

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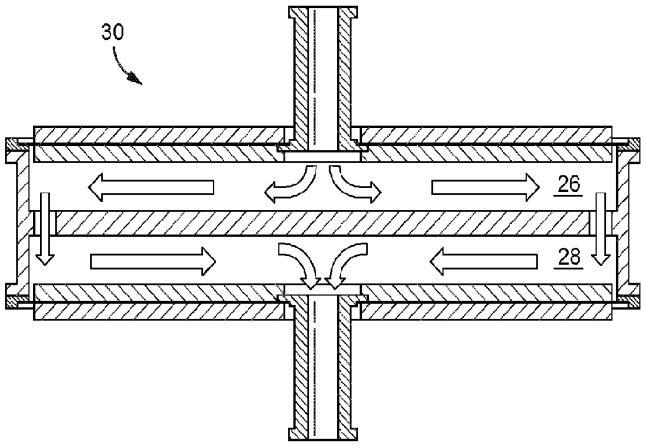
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(54) Title: HEAT EXCHANGER FOR CRYOGENIC COOLING APPARATUS

Fig. 8



(57) Abstract: A heat exchanger for a cryogenic cooling apparatus is provided. The heat exchanger has a first conduit, a second conduit and a chamber, wherein the chamber is arranged to receive a fluid from the first conduit, and wherein second conduit is thermally coupled to the outside of the chamber. The chamber has a first region and a second region, the first region separated from the second region by a plate extending through the chamber, the plate comprising one or more apertures for allowing a flow of the fluid from the first region to the second region.

[Continued on next page]

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HEAT EXCHANGER FOR CRYOGENIC COOLING APPARATUS

FIELD OF THE INVENTION

The invention relates to a heat exchanger for a cryogenic cooling apparatus. In a particularly advantageous implementation, the heat exchanger forms part of a dilution refrigerator.

BACKGROUND

There are a number of applications that require cooling to millikelvin temperatures. Such temperatures can be obtained by operation of a dilution refrigerator. A dilution unit will form part of the dilution refrigerator, the dilution unit comprising a still and a mixing chamber, connected by a set of heat exchangers. An operational fluid formed of a helium-3/helium-4 mixture is circulated around the dilution unit during operation. Cooling is obtained at the mixing chamber from the enthalpy of mixing as helium-3 is diluted into helium-4. The mixing chamber is thereby operable so as to obtain the lowest temperature of any part of the dilution refrigerator. Helium-3 is boiled at the still, which removes energy due to the latent heat of vaporisation. A cold plate is arranged between the still and the mixing chamber and generally obtains a temperature between these two components during use.

The heat exchangers are an important aspect of dilution refrigerator design and are used to couple 'cold' helium-3 leaving the mixing chamber to the 'warm' helium-3 returning to it. The quality of this exchange determines, for example, the minimum temperature attainable. There are essentially two types of heat exchanger in use (on all dilution refrigerators) today, the so called 'continuous' exchanger and the 'step' exchangers.

An example of a prior art dilution unit is shown by Figure 1. Operational fluid flows between the still 102 and the mixing chamber 105 through two counter-flow paths in a heat exchanging unit. The heat exchanging unit comprises a continuous heat exchanger 101 arranged between the still 102 and a cold plate 103. The continuous heat exchanger 101 comprises a coaxial unit arranged in a

spiral, through which the two paths proceed in opposite directions, with the inner path surrounded by the outer path in a coiled arrangement (not shown). Continuous heat exchangers can generally be used to obtain temperatures down to around 30 millikelvin. Dilution refrigerators with only continuous heat exchangers are limited to operate at around 30 millikelvin due to the increasing Kapitza (thermal boundary) resistance between liquid helium and metals at low temperatures. At lower temperatures continuous heat exchangers do not provide sufficient surface area to defeat the increasing thermal boundary resistance. Step heat exchangers may be used to obtain yet lower temperatures by using large-surface-area sinters to overcome the Kapitza resistance. Two step heat exchangers 104 are arranged in a stack between the cold plate 103 and the mixing chamber 105. Each step heat exchanger forms a substantially disc-like structure, in which the two paths are separated by a foil. The number of step heat exchangers provided may be selected to suit the application.

In common use there are effectively two geometries of step heat exchanger, the 'counterflow block' and the 'semi-continuous'. For the counterflow block, there are two counterflowing streams of helium-3, thermally coupled by sinters through a supporting medium, which can be a thin membrane. Semi-continuous heat exchangers generally have a coiled geometry similar to that of a continuous heat exchangers. However, the inner conduit is constructed from a set of discrete sintered elements that are jointed together and enclosed within an outer tube. If the outer tube is exposed then the semi-continuous heat exchanger may provide the appearance of a continuous heat exchanger. Alternatively, the outer tube may be housed within welded boxes that provide the appearance of a step heat exchanger.

The assembly of a dilution unit, and in particular the step heat exchangers described above, is typically an intricate and labour-intensive procedure that takes highly trained technicians hundreds of hours to complete. The performance of the dilution refrigerator is sensitive to minor differences in the assembly process, and the high reliance on manual assembly techniques means that the final performance of the dilution refrigerator cannot always be precisely

guaranteed in advance. It is desirable to reduce the standard deviation between the performance of heat exchangers and dilution refrigerators manufactured according to a particular process. It is also desirable to provide a simpler method of constructing these devices that is more amenable to automation. The invention is set in the context of solving these problems.

SUMMARY OF THE INVENTION

A first aspect of the invention provides a heat exchanger for a cryogenic cooling apparatus, comprising: a first conduit, a second conduit and a chamber, wherein the chamber is arranged to receive a fluid from the first conduit, and wherein second conduit is thermally coupled to the outside of the chamber, the chamber having a first region and a second region, the first region separated from the second region by a plate extending through the chamber, the plate comprising one or more apertures for allowing a flow of the fluid from the first region to the second region.

The configuration of the heat exchanger lends itself to simpler assembly processes that can be semi or fully automated. The repeatability of the performance of the heat exchanger is therefore improved in comparison with some prior art heat exchangers. The plate is preferably arranged to obstruct a flow of fluid through the chamber. The apertures may hence be arranged with respect to the first conduit so that the fluid follows a non-linear path through the chamber. The second conduit is thermally coupled to the outside of the chamber and so the non-linear path increases the thermal coupling between the fluid from the first conduit that is in the chamber and the fluid in the second conduit.

The chamber may be arranged along the first conduit. In other words, the chamber may be arranged to receive fluid directly from a first portion of the first conduit, and a second portion of the first conduit may be arranged to receive fluid directly from the chamber. The first conduit is typically fluidly coupled to the inside of the chamber at a first position within the first region and a second position within the second region, wherein the one or more apertures are laterally offset from the first position and/or the second position in a direction

along the plate. This improves the thermal coupling between the fluid in the chamber and any fluid in the second conduit. The heat exchanger typically comprises a central axis extending through the centre of the chamber, wherein the first conduit is coupled to the chamber at two positions arranged along the central axis. The one or more apertures may therefore be radially dispersed from the central axis. Extending the first conduit along the central axis ensures that the heat exchanger is properly supported and facilitates simpler assembly. The heat exchanger is preferably rotationally symmetric about the central axis. This further simplifies the method of assembly because, for example, if any joints need to be made using a welding process, it may be possible to rotate the heat exchanger about the central axis during this welding process.

The purpose of the heat exchanger is to thermally couple fluid in the first conduit with fluid in the second conduit in use. In order to ensure these two conduits are effectively thermally engaged, the first conduit is preferably arranged inside the second conduit. Similarly, the chamber is preferably arranged inside the second conduit. A fluid inside the second conduit would then be in direct contact with the outside of the first conduit and the chamber.

The chamber preferably comprises a first end piece and a second end piece forming opposing sides of the chamber respectively, the first end piece coupled to the second end piece by a flow deflector, the flow deflector comprising a collar separating the first end piece from the second end piece, wherein the plate extends across the collar to form part of the flow deflector. These components may be fused together, as will be described. Typically, one or both of the first end piece and the second end piece comprises a first face arranged inside the chamber, a second face arranged outside the chamber and a foil member arranged between the first face and the second face, wherein the first face and the second face each comprise a sintered material applied to the foil member. The sintered material may be a metal powder such as silver, copper or titanium and is typically the metal as used in the foil member. The sintered body is porous and increases the effective surface area for adequate heat exchange between the fluid in the chamber and the fluid in the second conduit. However,

sintered material is generally not compatible with high temperatures, such as can result from welding or fusing processes. A peripheral support member is therefore preferably arranged around the perimeter of each said foil member, the peripheral support member being fused to the collar, for example by a localised heating process such as laser or electron beam welding.

The first face and/or the second face may be profiled so that the thickness of the sinter on the foil member increases with the radial separation from the central axis. This is particularly advantageous wherein the heat exchanger comprises a central axis extending through the centre of the chamber, and wherein the first conduit is coupled to the chamber at two positions arranged along the central axis. Profiling the sinter in this way typically reduces the viscous heating within the heat exchanger. Typically both of the first and second end pieces are profiled in a similar manner. Any shape or profile that can be machined into a press tool can be used to apply the profiled sinter. For example, the sinter on the first and second end pieces may be profiled so that the separation between the first faces and the plate decreases, , with the radial offset from the central axis, typically in a linear manner. Similarly, the sinter on the first and second end pieces may be profiled so that the separation between the second faces and the second conduit decreases, with the radial offset from the central axis, typically in a linear manner. The thickness of sinter applied to the foil members will typically range from 0.1 – 3.0 mm, preferably 0.2 – 2.0 mm thickness at any position along the first and second faces on which sinter is applied. For example, the sinter thickness may vary from a minimum of 0.5 mm near the centre of the foil member to 1 mm near the edge. The specific values may be chosen depending on the operational temperature for the heat exchanger. The maximum separation between the sinter on the first faces and the plate is typically from 0.1 – 5.0 mm, preferably 0.1 – 3.0 mm, preferably still 0.2 – 1.50 mm (as measured along the central axis of the chamber). This corresponds to the "depth of the chamber" or the "flow channel depth" inside the chamber.

The same material is typically used for forming the collar and the peripheral support member(s). For example, the collar and the peripheral support

member(s) may each be formed of stainless steel. The sintered material and the foil member are preferably formed of the same material, for example silver, copper or titanium. The thermal conductivity of the foil member and/or the sintered material is preferably substantially higher than that of the peripheral support member and/or the collar. For example, thermal conductivity of the foil member and/or the sintered material may be at least twenty times larger than that of the peripheral support member and/or the collar when at a temperature of 300 K. The thermal conductivity of a material is generally dependent on its temperature however in this case the manufacturing processes are typically carried out at a notional 'room temperature'. At 300 K, the thermal conductivity of copper is around 392 W / m / K compared with around 15 W / m / K for stainless steel. The lower thermal conductivity of the peripheral support member(s) ensures that the heat input from fusing the end piece(s) to the collar is not effectively conducted to the sintered material so as to cause unwanted liquefaction of the sinter. The first end piece may be constructed similarly to the second end piece and fused to the collar to form the chamber to form a simple and effective heat exchanger suitable for low-temperature applications.

The chamber may define a flow channel for conveying the fluid through the first region and the second region. For example, the fluid may flow from an inlet of the chamber to an outlet of the chamber through an internal volume defined by a separation between the first face of the end pieces and the plate. Alternatively, the flow channel may be partially or fully formed within a sinter applied to the first end piece and the second end piece, and in particular within the sinter applied to the respective "first faces" of the end pieces (facing the plate). The flow channel may comprise one or more flow paths through the chamber, the one or more flow paths shaped by the sinter applied to the first end piece and the second end piece. The flow channel may therefore be imprinted onto the sintered material to define one or more pathways for the fluid to flow through the first region and the second region. The direction of flow of the operational fluid is thereby controlled, which can enable better heat dispersion through the chamber and improved thermal performance of the heat exchanger. One or more flow channels may also be imprinted to the sinter applied to the "second faces" of the end pieces

forming part of the second conduit. This improves the thermal coupling across the heat exchanger. The depth of the flow channel(s) may decrease with the radial separation from the central axis in order to balance the impact of viscous heating against helium-3 requirement.

Further aspects of the invention will now be described that share similar advantages as discussed above. Any feature described in connection with one aspect is equally applicable to the remaining aspects.

Although the heat exchanger of the first aspect is particularly well suited to replacing prior art step heat exchanger using liquid helium, it may have applications in a variety of different cryogenic cooling systems. A second aspect of the invention provides a cryogenic cooling apparatus comprising: a target refrigerator; and a heat exchanger according to the first aspect, wherein the first conduit is arranged to convey an operational fluid to the target refrigerator and the second conduit arranged to convey the operational fluid from the target refrigerator. The operational fluid conveyed along the first conduit is typically in a different state from the operational fluid conveyed along the second conduit and typically also at a different temperature.

A third aspect of the invention provides a dilution refrigerator comprising: a still, a mixing chamber and a heat exchanger according to the first aspect, wherein the first conduit is arranged to flow an operational fluid from the still to the mixing chamber and the second conduit is arranged to flow the operational fluid from the mixing chamber to the still, the heat exchanger configured to thermally couple the operational fluid in the first conduit with the operational fluid in the second conduit.

The mixing chamber typically comprises a mass of sinter, and the first conduit comprises an end portion that is open and extends around a portion of the mass of sinter so as to bring said portion of the mass of sinter into contact with the operational fluid, the second conduit extending around the end portion and the mass of sinter so as to convey the operational fluid in a direction away from the mass of sinter. The dilution refrigerator is preferably configured such that

operation of the dilution refrigerator causes a phase boundary to arise in the operational fluid at a position inside the end portion of the first conduit. This phase boundary refers to the boundary between the concentrated and dilute phases of helium-3 that typically arises within the mixing chamber of a dilution refrigerator. The incoming concentrated phase is typically conveyed by the first conduit from the position of the still to the mixing chamber such that it is in thermal contact with the outgoing dilute phase conveyed by the second conduit at the still and along the first conduit. It will be understood that the concentrated and dilute phases do not typically mix at the still.

The heat exchanger is typically simpler to construct than prior art step heat exchangers and so is well suited for low-temperature applications. A particular benefit is therefore achieved when the heat exchanger is arranged to obtain a temperature below 30mK during operation of the dilution refrigerator. For example, the dilution refrigerator may further comprise a cold plate arranged between the still and the mixing chamber, the cold plate arranged to obtain a base temperature between that of the still and the mixing during operation of the dilution refrigerator, the dilution refrigerator further comprising a chamber assembly comprising one or more said chambers arranged along a portion of the first conduit extending between the cold plate and the mixing chamber, each said chamber being arranged to receive the operational fluid from the first conduit, and wherein second conduit is thermally coupled to the outside of each said chamber.

In steady state operation, the total fluid flow rate through all the chambers will be equal. The temperature of the fluid from the first conduit will typically lower as it progresses further through the chamber assembly into the lower temperature region. In many cases, the viscosity of a fluid may increase as the temperature is reduced and the flow of a viscous fluid can lead to unwanted heating, reducing the efficiency of the heat exchanger. To mitigate against this, so called 'flow channels' can be introduced to provide a low-impedance path through which the fluid can flow. The size of these flow channels is generally controlled to provide the required fluid flow rates whilst reducing the total amount of fluid in the

chamber (thereby lowering the amount of helium-3 required for operation, which is a scarce and expensive resource). Many existing dilution refrigerators are reliant on custom-built, unique sized or shaped parts however volume manufacture and automation favours part commonality. Preferably, therefore, each said chamber comprises one or more flow channels for conveying the fluid through the respective first region and the respective second region, wherein each said flow channel is formed within a sinter, wherein the chamber assembly is arranged along a thermal gradient during operation of the dilution refrigerator so that a first said chamber is arranged to obtain a higher base temperature than a second said chamber, and wherein the diameter of the one or more flow channels in the first chamber is lower than the diameter of the one or more flow channels in the second chamber. The diameter of any flow channels may thereby be controlled to achieve a desired balance between flow rates and total fluid volume. This improves the thermal performance of the heat exchanger. The second conduit may also comprise flow channels that are formed within a sinter on the outside of the chamber to further improve the thermal performance of the heat exchanger. Imprinting the flow channels into the sinter also allows the flow channels to be mass produced in an efficient and repeatable manner.

The chamber assembly may form a step heat exchanger, with each heat exchanger corresponding to a respective step and configured to obtain a respective temperature during operation of the dilution refrigerator. The chamber assembly may comprise a first said heat exchanger and a second said heat exchanger, the first said heat exchanger being arranged between the cold plate and the second heat exchanger chamber, wherein the depth of the chamber for the second said heat exchanger and/or the number/size of apertures through the plate of the second said heat exchanger is higher than that of the first said heat exchanger. This optimises the flow of the fluid through the chamber assembly to improve performance of the system, as previously described.

In order to further simplify the method of assembly, the chamber assembly and the mixing chamber are preferably rotationally symmetric about an axis

extending through the first conduit. Furthermore, the second conduit preferably forms the exterior of the heat exchanger and comprises a plurality of modules that are fused together. Similarly, the first conduit is preferably formed from a plurality of modules that are fused together. This fusing process can be formed by electron-beam welding or laser beam welding and produces reliable joints without the need for intricate and time-consuming manual processes.

A fourth aspect of the invention is a method of forming a heat exchanger for a cryogenic refrigerator, the method comprising: providing a first conduit, a second conduit, a first end piece, a second end piece and a flow deflector, the flow deflector comprising a collar and a plate, the plate extending across the collar; wherein providing the first end piece comprises: fusing a first peripheral support member around the perimeter of a first foil member, and then applying a sintered material to opposing faces of the first foil member, the thermal conductivity of the first peripheral support member being at least twenty times lower than that of the first foil member when at a temperature of 300 K; fusing the first peripheral support member to the collar so as to form a chamber, the chamber having a first region separated from a second region by the plate, the plate arranged between the first end piece and the second end piece; wherein the first conduit is arranged to convey a fluid into the first region and out from the second region, and wherein the plate comprises one or more apertures for allowing a flow of the fluid from the first region to the second region; and wherein second conduit is thermally coupled to the outside of the chamber.

The method is practically easier to perform than the intricate jointing processes typically required for assembling prior art step heat exchangers. The method is also more amenable for automation. Consequently, the heat exchanger takes less time to assemble and the standard deviation in the performance of different heat exchangers produced according to the same technique is reduced. Sintered material (typically formed from a metal powder such as silver or copper) is applied to the foil member for increasing the surface area for heat exchange between the fluid in the chamber and any fluid in the second conduit in use. The sintered material is liable to melt if exposed to high temperatures. The

peripheral support member is therefore fused to the foil member prior to applying the sintered material. Furthermore, the peripheral support member is selected to have a lower thermal conductivity than the sintered material and preferably also the foil member. Once the sintered material is applied, the peripheral support member can then be fused to the collar to form the chamber without risk of melting the sintered material.

A first portion of the first conduit is preferably fused to the first foil member so as to facilitate a flow of the fluid through the first foil member. This typically occurs prior to applying the sintered material and may occur at the same time as when the first peripheral support member is fused to the first foil member. The first portion of the first conduit, and preferably also the first peripheral support member, are preferably fused to the first foil member by welding or vacuum brazing. For example, the parts may be assembled together and then baked in a vacuum chamber to fuse. A similar process may then be followed for forming the second end piece. For example, providing the second end piece may comprise: fusing a second peripheral support member around the perimeter of a second foil member, and then applying a sintered material to opposing faces of the second foil member, the thermal conductivity of the second peripheral support member being at least twenty times lower than that of the second foil member when at a temperature of 300 K, wherein forming the chamber further comprises fusing the second peripheral support member to the collar. The method may further comprise: fusing a second portion of the first conduit to the second foil member so as to facilitate a flow of the fluid through the second foil member, wherein the second portion of the first conduit is preferably fused to the second foil member by welding or vacuum brazing. Typically, the second portion of the first conduit is fused to the second foil member before the sintered material is applied to the second foil member and preferably at the same time as the second peripheral support member is fused to the second foil member. The second portion of the first conduit, and preferably also the second peripheral support member, are preferably fused to the second foil member by welding or vacuum brazing. The second peripheral support member is preferably fused to the collar at the same time as the first peripheral support member. Each said

peripheral support member is preferably fused to the respective foil member by vacuum brazing. In contrast, each said support member is preferably fused to the collar by a localised heat source, such as laser or electron beam welding. A localised heating process is preferable because the sintered material has already been applied to the foil member at this stage and so it is desirable to reduce the amount of heat conducted to the sinter.

A fifth aspect of the invention is a method of forming a dilution refrigerator, comprising: providing a still and a mixing chamber, and forming a heat exchanger according to any of the preceding aspects, wherein the first conduit is arranged to flow an operational fluid from the still to the mixing chamber, and wherein the second conduit is arranged to flow the operational fluid from the mixing chamber to the still.

The first conduit preferably comprises an end portion arranged to receive the operational fluid from the chamber, and providing the mixing chamber then comprises: arranging the end portion around a portion of a mass of sinter so as to bring said portion of the mass of sinter into contact with the operational fluid; and arranging the second conduit around the end portion and the mass of sinter so as to convey the operational fluid in a direction away from the mass of sinter. The mass of sinter may be formed of a sintered material or from several smaller sintered masses, and is shaped to be received by the end portion of the first conduit. The method may then further comprise sealing the second conduit to a support on which the sintered mass is mounted. This closes a distal end of the second conduit on the support, which may be the lowest-temperature thermal stage for the dilution refrigerator.

A particular benefit may be achieved when the first conduit and the second conduit are formed from a plurality of modules for assembly, the method further comprising fusing a first module of the first conduit together with a second module of the first conduit at a position between the chamber and the end portion, and/or fusing a first module of the second conduit together with a second module of the second conduit at a position between the chamber and the end portion. The resulting assembly has a fully welded construction, which

ensures that the joints are reliably formed according to a fast and highly repeatable process.

The heat exchange of the first aspect is particularly well suited for use in low temperatures, including those below 30 millikelvin. The cold plate of a dilution refrigerator typically has an base temperature from 40 to 150 millikelvin, more preferably from 40 to 60 millikelvin, whereas the mixing chamber typically has a base temperature that is less than 25 millikelvin, and preferably less than 10 millikelvin in use. The method may therefore further comprise: arranging a cold plate between the still and the mixing chamber so as to obtain a base temperature between that of the still and the mixing during operation of the dilution refrigerator; providing a plurality of said chambers arranged along a portion of the first conduit extending between the cold plate and the mixing chamber, each said chamber arranged to receive the operational fluid from the first conduit, and wherein second conduit is thermally coupled to the outside of each said chamber. As before, the first conduit and the second conduit are preferably formed from a plurality of modules for assembly, the method further comprising fusing a first module of the first conduit together with a second module of the first conduit at a position between two said chambers, and/or fusing a first module of the second conduit together with a second module of the second conduit at a position between two said chambers. These chambers will typically be similarly formed and comprise the features discussed in connection with the first aspect. The modules are preferably fused together using a localised heat source, and preferably by electron beam welding, which reduces the heat input to the sinters. Furthermore, in order to ensure effective heat transfer between the operational fluid in the first conduit and the second conduit, a portion of the first conduit extending from the cold plate to the mixing chamber is preferably arranged inside the second conduit. The chambers are also preferably arranged substantially inside the second conduit.

A sixth aspect of the invention is a dilution refrigerator comprising: a still and a mixing chamber; a first conduit arranged to convey an operational fluid from the still to the mixing chamber; a second conduit arranged to convey the operational

fluid from the mixing chamber to the still; a heat exchanger arranged to thermally couple the operational fluid in the first conduit with the operational fluid in the second conduit at a position between the still and the mixing chamber; characterised in that the heat exchanger comprises one or more chambers arranged along a portion of the first conduit, each said chamber having a first region and a second region, the first region separated from the second region by a plate extending through the chamber, the plate comprising one or more apertures for allowing a flow of the operational fluid from the first region to the second region, and wherein second conduit is arranged around the outside of each said chamber.

A plurality of chambers is preferably provided, the second conduit being formed of a plurality of modules that are welded together between each said chamber, and the first conduit is preferably formed of a plurality of modules that are welded together between each said chamber. Each said chamber preferably comprises a first end piece and a second end piece forming opposing sides of the chamber respectively, the first end piece coupled to the second end piece by a flow deflector, the flow deflector comprising a collar separating the first end piece from the second end piece, wherein the plate extends across the collar, wherein each of the first end piece and the second end piece has a first face arranged inside the chamber and a second face arranged outside the chamber, the first face and the second face being formed from a sintered material applied to a foil member arranged between the first face and the second face, wherein each of the first and second end pieces further comprise a respective outer support member extending around the perimeter of the respective foil member, the outer support member fused to the collar. The thermal conductivity of the foil members is typically at least twenty times larger than that of the outer support members when at a temperature of 300 K.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be discussed with reference to the accompanying drawings in which:

Figure 1 is an illustration of a prior art dilution unit;

Figure 2 is an illustration of a perspective view of a foil member forming part of a first embodiment of the invention;

Figure 3 is an illustration of a perspective view of a first portion of a first conduit forming part of the first embodiment of the invention;

Figure 4 is an illustration of a perspective view of a peripheral support member forming part of the first embodiment of the invention;

Figure 5 is an illustration of a perspective view of a first end piece forming part of the first embodiment of the invention prior to applying a sintered material;

Figure 6 is an illustration of a perspective view of a flow deflector forming part of the first embodiment of the invention;

Figure 7 is a first cross-sectional illustration of a chamber forming part of the first embodiment of the invention;

Figure 8 is a second cross-sectional illustration of a chamber forming part of the first embodiment of the invention;

Figure 9 is a first cross-sectional illustration of a mixing chamber forming part of the first embodiment of the invention;

Figure 10 is a second cross-sectional illustration of a mixing chamber forming part of the first embodiment of the invention;

Figure 11 is a schematic illustration of a dilution refrigerator according to the first embodiment;

Figure 12 is a flow chart illustrating a method according to an embodiment of the invention;

Figure 13 is a cross-sectional illustration of a chamber forming part of a second embodiment of the invention;

Figure 14 is an illustration of a foil member forming part of the second embodiment;

Figure 15 is a cross-sectional illustration of a chamber forming part of a third embodiment of the invention; and

Figure 16 is a cross-sectional illustration of a chamber forming part of a fourth embodiment of the invention.

DETAILED DESCRIPTION

A method for assembling a heat exchanger and a dilution refrigerator according to a first embodiment of the invention will now be discussed. The method begins at step 201 (Figure 12), at which point first and second end pieces are produced for forming part of a heat exchanger. A first foil member 10 (Figure 2) is provided that is formed from a high thermal conductivity material such as silver or copper, typically with a thermal conductivity greater than 300 W / m / K at 300 K. In this case, the first foil member 10 is a substantially planar silver disc having a central aperture for receiving an inlet tube 12 forming a first portion of a first conduit (to be discussed) that conveys an operational fluid in use. The first foil member 10 has diameter of around 45 mm but more generally is usually between 20-100 mm depending on the application. A first peripheral support member 14 (Figure 4) is provided, formed from a relatively low thermal conductivity material such as stainless steel, typically with a thermal conductivity below 15 W / m / K at 300 K. The first peripheral support member 14 is ring-shaped and configured to support the first foil member 10. The first peripheral support member 14 extends around the outside of the first foil member 10, contacting the perimeter of the first foil member 10 and an outer portion of one of the opposing faces of the first foil member 10. The first foil member 10, inlet tube 12 and peripheral support member are assembled, as shown in Figure 5, and then fused together, for example by welding or vacuum brazing.

A material to be sintered is next applied as a powder to the major faces of the first foil member 10. The sinter material is a high thermal conductivity material and typically the same material as used as the first foil member 10. Pressure is applied to form a sinter 15 on the two opposing faces of the first foil member 10. In the case of a silver powder pressure alone is sufficient for this operation, however copper powders typically also need to be baked during this operation. With the appropriate tooling, the powder can be pressed onto both sides of the first foil member 10 in one operation. The sinter 15 is typically applied to the entire surface of the two major faces of the first foil member 10 but not to the peripheral support member 14. A first end piece 22 for a heat exchanger is

thereby produced. This process is then repeated with a second foil member 11, second peripheral support member and an outlet tube 32 to form a second end piece 24.

The first end piece 22 and the second end piece 24 are configured to fit against opposing ends of a flow deflector 16, which is shown by Figure 6. The flow deflector 16 comprises a collar 17, which is an annular element having approximately the same circumference as the peripheral support members. A plate 18 extends across the flow deflector 16 in a radial direction. The plate 18 is arranged approximately centrally within the collar 17, subdividing the flow deflector 16 into an upper portion and a lower portion that are provided on opposite sides of the plate 18, inside the collar 17. The plate 18 comprises a plurality of apertures 20 to fluidly couple the upper and lower portions. In Figure 6 these apertures are dispersed at a constant radius around the plate 18, with approximately a constant separation kept between each neighbouring aperture. In the present embodiment the flow deflector 16 is formed as a unitary member. In particular, the flow deflector 16 is a "machined body" and the apertures may be added by a process such as electrical discharge machining. Alternatively, the flow deflector 16 can be formed from a foil element with apertures formed in the foil element, for example by etching. This foil element would then be welded between two annular supports to form the flow deflector 16.

The method proceeds to step 202, at which point the heat exchanger chamber 30 is formed. The first and second end pieces 22, 24 are arranged against opposing ends of the flow deflector 16, as shown in Figure 7, with the sinter material 15 applied to the distal face of each end piece arranged inside the collar 17, and the peripheral support members contacting opposing ends of the collar 17. A highly controlled, localised heating process, such as electron-beam welding, laser beam welding or Tungsten Inert Gas (TIG) welding, is then used to fuse the peripheral support members to the respective ends of the collar 17 and thereby form a chamber 30. The localised heating process used to fuse the first and second end pieces 22, 24 to the collar 17, combined with the relatively low thermal conductivity of the stainless steel peripheral support members,

protects the sinter 15 from the heat of the welding process. The location of the electron-beam welds for the present embodiment are indicated in Figure 7, however it will be appreciated that the weld is typically made around the circumference of the peripheral support members. It is advantageous therefore that the inlet tube 12 and the outlet tube 32 extend along the central axis for the flow defector 16 and the chamber 30 because the assembly can then be rotated about the inlet tube 12 and the outlet tube 32 when performing the welding procedure, without needing to move the heating element. This process is amenable to automation and ensures that a reliable joint is welded.

The chamber 30 formed has a first region 26 separated from a second region 28 by the plate 18, with the inlet tube 12 arranged to flow a fluid into the first region, and the outlet tube 32 arranged to flow a fluid out of the second region. The inlet tube 12 and the outlet tube 32 form first and second portions of a first conduit 46 respectively, the first conduit 46 being arranged to flow a fluid through the chamber 30. When used within a dilution refrigerator the first conduit 46 and the chamber 30 will accommodate the flow of helium-3 rich phase of operational fluid during steady state operation from a still (including from the outside of the still) to a mixing chamber 45 of the dilution refrigerator. The first conduit 46 is also commonly referred to as the 'concentrated phase flow channel' in a dilution refrigerator. Arrows are included to Figure 8 (which is not to scale) to indicate the direction of flow of the fluid through the inside of the chamber 30. As shown, the arrangement of the apertures 20, which are radially dispersed from the central axis along which the inlet and outlet tubes 12, 32 are arranged, ensures that the fluid follows a non-linear flow path inside the chamber 30. This, combined with the use of the sintered material 15 on the first and second end pieces 22, 24, ensures that a large effective surface area is provided for heat exchange between a fluid inside the chamber 30 and another fluid in contact with the outside of the chamber 30. The origin and flow of this surrounding fluid will be now discussed with reference to steps 203 and 204 from Figure 12.

The method proceeds to step 203, at which point a mixing chamber 45 for the dilution refrigerator is formed. A mass of sinter 36 is formed directly onto, or

mounted to a high thermal conductivity support 8, which forms the lowest temperature stage of the dilution refrigerator. The material forming the mass of sinter 36 is typically the same material as was applied to the first and second foil members 10, 11 (e.g. silver and/or copper). An end portion 40 of the first conduit 46 is provided, the end portion 40 having a first region 42 and a second region 44, the second region 44 having a larger diameter than the first region 42. The end portion 40 is arranged so that the first region 42 is configured to receive a flow of the fluid from the outlet tube 32 and the second region 44 is arranged so that a proximal portion of the mass of sinter is arranged inside the second region 44 and a distal portion of the mass of sinter is outside the end portion 40. The end portion 40 is thus arranged relative to the mass of sinter 36 so that a phase boundary of the operational fluid between a helium-3 rich phase and a helium-3 poor phase exists inside the end portion 40 and preferably inside the second region 44, as shown by the broken line in Figure 9. Arrows are provided in Figure 9 to show the direction of flow of the fluid from along the first region 42 of the end portion 40 and around the mass of sinter 36 into a region surrounding the mixing chamber 45. Of course, this direction of flow is only possible when the dilution refrigerator is fully assembled and operational. In use, the concentrated steam is typically contained inside the end portion 40 and so the end portion 40 may also be referred to as a 'concentrated steam cap'.

Figure 10 shows a second conduit 48 formed surrounding the first conduit 46. The second conduit 48 is also referred to as the 'dilute phase flow channel' that is arranged to return the fluid from the mixing chamber 45 to the still. The second conduit 48 is co-axially arranged around the outside of the first conduit 46. The first conduit 46 and the second conduit 48 are each formed from a series of modules that are welded together at step 204 to form the heat exchanger assembly. With the end portion 40 arranged over the mass of sinter 36 (as discussed with reference to Figure 9), a first portion 50 of the second conduit 48 is arranged over and around the end portion 40 and mounted to the support 8. Typically, the first portion 50 of the second conduit 48 is sealed to the support 8 by an indium seal, alternatively though a ConFlat (CF) flange may be used to achieve this mounting. The first portion 50 of the second conduit 48 is

thereby arranged to receive a flow of operational fluid from the end of the first conduit 46.

A distal end of the outlet tube 32 is then welded to a proximal end of the first region 42 of the end portion 40. This fluidly couples the inlet tube 12 with the mixing chamber 45 and the second conduit 48. A distal end of a second portion 52 of the second conduit 48 is then fused to a proximal end of the first portion 50 of the second conduit 48. This joint is made around the central axis of the assembly and at a position between the chamber 30 and the mass of sinter 36, typically along the first region 42 of the end portion 40 of the first conduit 46. Figures 7-10 are schematic illustrations and thus not to scale, however, an approximate constant separation is maintained between the inner walls of the second conduit 48 and the outer walls of the first conduit 46. The second conduit 48 conforms around the shape of the chamber 30 to form a step in a step heat exchanger 53. In normal operation of a dilution refrigerator helium-3 is evaporated from the still and removed by a pumping system. This drives a flow of helum-3 atoms to cross the phase boundary at the mixing chamber 45 (from the concentrated to dilute phases) to replenish the helium-3 in the still. The dilution of helium-3 into the dilute phase causes cooling at the mixing chamber 45. The dilute phase of helium that flows along the second conduit 48 will therefore be cooler than the incoming concentrated phase of helium-3 conveyed along the first conduit 46. The relatively large surface area of the chamber 30 forms an effective heat exchanger so that the fluid in the first conduit 34 and chamber 30 is further cooled prior to arriving at the mixing chamber 45.

The heat exchanger assembly may comprise a plurality of step heat exchangers 53 or "steps", each step formed of a chamber (as described with reference to Figures 7 and 8) arranged along the first conduit 46, and being surrounded by a portion of the second conduit 48. Figure 10 shows a second such chamber 130 together with corresponding portions of the first conduit 46 arranged above the proximal end of the inlet tube 12. The respective portions of the first and second conduits would be fused together about the central axis, as discussed above, in a step-wise manner to form the completed assembly.

The arrangement of the heat exchanger assembly within a dilution refrigerator is shown by the schematic illustration in Figure 11, which will now be discussed. A cryostat 1 is provided comprising a large hollow cylinder, typically formed from stainless steel or aluminium, which comprises an outer vacuum vessel 5. A plurality of spatially dispersed stages is provided within the cryostat 1, comprising a first stage 6, a second stage 7 and a third stage 8. Each stage provides a platform formed from high conductivity material (e.g. copper) and is spaced apart from the remaining stages by low thermal conductivity rods (not shown). The second stage 7 is commonly referred to as the "cold plate" and provides an intermediary heat sink between the first stage 6 and the third stage 8. A sample holder 55 is shown mounted to the third stage 8, which forms the lowest temperature stage during steady state operation of the system.

The cryostat 1 in the present example is substantially cryogen-free (also referred to in the art as "dry") in that it is not principally cooled by contact with a reservoir of cryogenic fluid. The cooling of the cryostat is instead achieved by use of a mechanical refrigerator, which may be a Stirling refrigerator, a Gifford-McMahon (GM) refrigerator, or a pulse-tube refrigerator (PTR). However, despite being substantially cryogen free, some cryogenic fluid is typically present within the cryostat when in use to facilitate normal operation of the dilution unit. The main cooling power of cryostat 1 is provided in this embodiment by a PTR 2. PTRs generate cooling by controlling the compression and expansion of a working fluid which is supplied at high pressure from an external compressor. The first PTR stage will typically have a relatively high cooling power in comparison with the second PTR stage. In the present case, the PTR 2 cools a first PTR stage 3 to about 50 to 70 kelvin and a second PTR stage 4 to about 3 to 5 kelvin. The second PTR stage 4 therefore forms the lowest temperature stage of the PTR 2.

Various heat radiation shields are provided inside the outer vacuum vessel 5, wherein each shield encloses each of the remaining lower base-temperature components. The first PTR stage 3 is thermally coupled to a first radiation shield 19 and the second PTR stage 4 is thermally coupled to a second radiation shield 54. The first radiation shield 19 surrounds the second radiation shield 54 and

the second radiation shield 54 surrounds each of the first, second and third stages 6–8. Additionally, the first and second stages 6 and 7 could in theory be connected to respective heat radiation shields, in order to reduce any unwanted thermal communication between the stages.

The still 9 of the dilution refrigerator is operable to cool the first stage 6 to a base temperature of 0.5–2 kelvin. The mixing chamber 45 is mounted to the third stage 8 and is operable to cool the third stage 8 to a base temperature below 10 millikelvin. In use, the second stage 7 obtains a base temperature between that of the first stage 6 and the third stage 8, typically of 40–150 millikelvin.

The still 9 is fluidly coupled to a storage vessel 50 by a cooling circuit 37. The storage vessel 50 is arranged outside the cryostat 1 and contains an operational fluid in the form of a mixture of helium-3 and helium-4 isotopes. Various pumps 17, 39 are also arranged outside the cryostat 1, along conduits of the cooling circuit 37 for controlling a flow of the operational fluids around the circuit, as indicated by the solid arrowheads. The cooling circuit 37 comprises a supply line 41 which provides a conduit to facilitate a flow of operational fluid from the storage vessel 50 to a condensing line 46'. This fluid may then be conveyed along the condensing line 46' to the still 9 whereupon it is in thermal contact with the dilute phase of helium inside the still 9. The condensing line 46' then continues into a concentrated phase flow channel 46 from the still 9 to the mixing chamber 45. The condensing line 46' and the concentrated phase flow channel 46 further comprise one or more impedances (not shown) for reducing the temperature of the operational fluid due to the Joule-Thomson effect as it flows towards the mixing chamber 45. A compressor pump 13 is arranged along the condensing line 46' for providing this flow at a pressure of 0.5–2 bar. A dilute phase flow channel 48 is arranged to convey the operational fluid from the mixing chamber 45 through the still 9, whereupon this fluid is conveyed to a position exterior to the cryostat 1 by a still pumping line 48'. The operational fluid may then be circulated from this position back into the condensing line 46'. A turbomolecular pump 39 is arranged along the still pumping line 48' for providing a high vacuum on the low pressure side of the circuit (for example less

than 0.1 mbar), and so enables the flow of the operational fluid away from the still 9.

The concentrated phase flow channel 46 and dilute phase flow channel 48 form the first and second conduits respectively of the heat exchanger, as earlier discussed. These conduits are not explicitly shown between the first stage 6 and the third stage 8 in the schematic illustration of Figure 11 for sake of clarity. The first and second conduits 46, 48 are arranged to form a continuous heat exchanger 26 positioned between the first stage 6 and the second stage or 'cold plate' 7. Within the continuous heat exchanger 26, the first conduit 46 is arranged in a coil and the second conduit 48 is wrapped around the first conduit 46. This ensures that the helium-3 concentrated phase of fluid flowing along the first conduit 46 is cooled by the helium-3 dilute phase of fluid flowing along the second conduit 48. Continuous heat exchangers are only are only typically effective at temperatures above 30 millikelvin. Therefore a step heat exchanger assembly comprising a plurality of step heat exchangers 53, 53', 53" (as earlier discussed with reference to Figures 2-10) is arranged at the lower temperature region between the second stage 7 and the third stage 8. The fluid in the first conduit 46 flows from the second stage 7 to the mixing chamber 45 via a plurality of chambers comprising flow deflectors. The helium-3 dilute phase of fluid flows from the mixing chamber 45 back along the second conduit that encloses the chambers. The outgoing fluid in the second conduit is directly in contact with the outer walls of the first conduit and the chambers to further cool the incoming fluid in the first conduit.

The viscosity of a fluid may increase as the temperature is reduced and the flow of a viscous fluid can lead to unwanted heating, reducing the efficiency of the heat exchanger. To mitigate against this, the depth of the chambers and/or the number or size of apertures inside the chamber may increase for chambers that are arranged at lower temperatures. For example, the depth of the chamber (along the central axis of the assembly) may be smallest for the uppermost step heat exchanger (to reduce the total volume of helium-3 required for operation) and largest for the lowermost step heat exchanger (to reduce viscous heating).

It has been found that this increases thermal performance of the system by optimising the balance between viscous heating and total fluid volume.

The height of the first region 26 and the second region 28 is depicted as being relatively large in Figures 7 and 8 for ease of explanation but, in particular where used within a dilution refrigerator, is preferably of the order of 0.1-5.0 mm, preferably still 0.2-1.5 mm. This height may vary depending on the operating temperature of the heat exchanger, as determined by its position along the first conduit 46 (as described above). In general the shape and dimensions of the first region 26 and second region 28 are selected to promote circulation of the helium-3, reduce viscous heating, allow for an osmotic pressure to develop in the still 9 and mixing chamber 45, reduce the amount of helium-3 used and reduce hydrodynamic instabilities and convection. Similar considerations apply for the surrounding second conduit 48.

Figures 13 and 14 illustrate parts of a heat exchanger according to a second embodiment of the invention. Figure 13 is a cross-sectional illustration equivalent of that of Figure 7 in which primed reference numerals have been used to show like features. In this embodiment the plate 18' for the flow deflector is a foil element welded between two annular supports. The chamber 30' is otherwise formed essentially as described in the first embodiment with reference to Figures 2-8 but in this case dedicated flow channels 21' are formed within the sinter 15' for conveying the helium-3 concentrated phase of fluid from the inlet tube 12' through the apertures and returning it to the outlet tube 32' (where it is understood that similar features could also be applied to the sinters 15' on the opposite sides of the foil members 10', 11' for conveying the dilute phase fluid). Sinter 15' is applied to both faces of the first and second foil members 10', 11', however the first and second foil members 10', 11' are arranged within the chamber 30' so that the sinter 15' applied to a first face of the first foil member 10' and a first face of the second foil member 11' is separated from the opposing faces of the flow deflector plate 18' by a small gap, typically of 0.1-1.0 mm, preferably 0.2-0.6 mm (depending on the configuration). Optionally opposite sides of the flow deflector plate 18' instead abut against the

sinter 15' on the first face of the first and second foil members 10', 11' to leave no such separation. The flow channels 21' are typically imprinted into the sinter during step 201 and can take a variety of different patterns for controlling the direction of flow of the operational fluid. One or more channels may be provided inside the chamber 30' for conveying the concentrated phase of fluid through the first region to the apertures of the plate 18' and then through the second region of the chamber 30' to the outlet tube 32'. One or more channels may further be provided for conveying the dilute phase of fluid through the second conduit on the outside of the chamber 30'. Any number of different patterns could be applied including radial or spiralling. Figure 14 is a perspective view of the sinter 15' taken through the plane X-X' from Figure 13. In Figure 14 the flow channels 21' bifurcate to bring a greater portion of the sinter 15' into close contact with the operational fluid and so enhance the performance of the heat exchanger.

The profile of the flow channel 21' may be limited by what can be machined into the press tool, but could be semi-circular, elliptical, triangular, rectangular etc. The flow channel 21' will typically have a width in the range of 0.5-1.0 mm. The velocity of the fluid flow will (at a given total flow rate) depend on the number and width of the flow channels 21'. The width of the flow channel may therefore vary depending on the relative placement of the heat exchanger chamber 30' within a step heat exchanger assembly, with the width increasing at lower temperatures to optimise the balance between viscous heating and fluid volume within the assembly. This further increases the thermal performance of the system.

In the first and second embodiments, the first and second regions within the chamber generally have a constant height in the direction across the plate (generally between 0.5 to 4 mm). Consequently, the fluid flow rate typically decreases as the fluid spreads radially outwards over a wider area. This may mean more viscous heating occurs towards the central axis, which can limit the performance of the cryogenic system in which the heat exchanger is installed. Figure 15 illustrates parts of a heat exchanger according to a third embodiment of the invention. Double primed reference numerals are used to depict like components. The embodiment is similar to the first and second embodiments

except that the sinter 15" on the inside of the chamber 30" is profiled so that the height of the first region 26" and second region 28" continually decreases at larger radiuses from the central axis. This profiling is achieved by pressing the sinter with a shaped tool in step 201 (Figure 12). By profiling the sinter in this way, a 'deeper' flow channel is provided at smaller radiuses, which compensates the above effect and reduces any viscous heating. The maximum depth of the first region 26" and second region 28" is typically around 1.5 mm and the minimum depth is typically around 0.2 mm. The specific parameters may be varied, however, according to the operating temperature of the heat exchanger, for example as determined by its position in a stack of such heat exchangers.

In the example of Figure 15 the sinter 15" applied to the opposing first major faces of the first and second foil members 10", 11" is profiled so that the thickness of sinter 15" linearly increases with the radius. In contrast, the thickness of the sinter 15" applied to the opposite second major faces of the first and second foil members 10", 11" remains generally constant. It should be remembered, however, that the sinter 15" on the outside of the chamber 30" is in contact with fluid conveyed along the second conduit surrounding the chamber (as shown by Figure 10). In the context of a dilution refrigerator, this is typically the dilute phase of helium-3. Additional unwanted viscous heating can arise within the second conduit that may be mitigated by profiling the sinter applied to the second major faces of the first and second foil members 10", 11". This profiling is typically again performed so that the thickness of the sinter applied to the first and second foil members 10", 11" linearly increases with the radius. In practice one or both major surfaces of the first and second foil members may be profiled to control any viscous heating within the heat exchanger. Figure 16 illustrates part of a heat exchanger according to a fourth embodiment in which both surfaces of the first and second foil are profiled to reduce any viscous heating and so improve the performance of the cryogenic cooling system in which the heat exchanger is installed. Figures 13-16 are not to scale but show examples of different shapes that can be pressed into the sinter to control the flow of the fluids through the heat exchanger.

An effective heat exchanger is thereby provided, operable at low temperatures and which ensures reliable operation of a cryogenic cooling system. The design of the heat exchanger has a relatively simple construction, which lends itself well to welding and automated manufacturing processes that can guarantee a high degree of repeatability in terms of thermal performance. Lower temperatures may therefore be obtained in cryogenic cooling systems such as dilution refrigerators incorporating the heat exchanger, where the lowest obtainable temperature is dependent on the performance of the heat exchanger. Such processes may also be used to speed up the time required to manufacture the cryogenic cooling systems.

CLAIMS

1. A heat exchanger for a cryogenic cooling apparatus, comprising:

a first conduit, a second conduit and a chamber, wherein the chamber is arranged to receive a fluid from the first conduit, and wherein second conduit is thermally coupled to the outside of the chamber, the chamber having a first region and a second region, the first region separated from the second region by a plate extending through the chamber, the plate comprising one or more apertures for allowing a flow of the fluid from the first region to the second region.

2. A heat exchanger according to claim 1, wherein the plate is arranged to obstruct a flow of the fluid through the chamber.

3. A heat exchanger according to claims 1 or 2, wherein the chamber is arranged along the first conduit.

4. A heat exchanger according to any of claims 1 to 3, wherein the first conduit is fluidly coupled to the inside of the chamber at a first position within the first region and a second position within the second region, and wherein the one or more apertures are laterally offset from the first position and/or the second position in a direction along the plate.

5. A heat exchanger according to any of the preceding claims, wherein the heat exchanger comprises a central axis extending through the centre of the chamber, and wherein the first conduit is coupled to the chamber at two positions arranged along the central axis.

6. A heat exchanger according to claim 5, wherein the heat exchanger is rotationally symmetric about the central axis.

7. A heat exchanger according to any of the preceding claims, wherein the first conduit is arranged inside the second conduit.

8. A heat exchanger according to any of the preceding claims, wherein the chamber is arranged inside the second conduit.

9. A heat exchanger according to any of the preceding claims, wherein the chamber comprises a first end piece and a second end piece forming opposing sides of the chamber respectively, the first end piece coupled to the second end piece by a flow deflector, the flow deflector comprising a collar separating the first end piece from the second end piece, wherein the plate extends across the collar to form part of the flow deflector.

10. A heat exchanger according to claim 9, wherein one or both of the first end piece and the second end piece comprises a first face arranged inside the chamber, a second face arranged outside the chamber and a foil member arranged between the first face and the second face, wherein the first face and the second face each comprise a sintered material applied to the foil member.

11. A heat exchanger according to claim 10, wherein a peripheral support member is arranged around the perimeter of each said foil member, the peripheral support member being fused to the collar.

12. A heat exchanger according to claim 11, wherein the thermal conductivity of the foil member and/or the sintered material is at least twenty times larger than that of the peripheral support member and/or the collar when at a temperature of 300 K.

13. A heat exchanger according to claim 5 and any of claims 10 to 12, wherein the first face and/or the second face is profiled so that the thickness of the sinter on the foil member increases with the radial distance from the central axis.

14. A heat exchanger according to any of claims 9 to 13, wherein the chamber defines a flow channel for conveying the fluid through the first region and the second region, wherein the flow channel is formed within a sinter applied to the first end piece and the second end piece.

15. A heat exchanger according to claim 14, wherein the flow channel comprises one or more flow paths through the chamber, the one or more flow

paths shaped by the sinter applied to the first end piece and the second end piece.

16. A heat exchanger according to any of claims 1 to 13, wherein the chamber defines a flow channel for conveying the fluid through the first region and the second region.

17. A heat exchanger according to claims 5 and 16, wherein the depth of the flow channel decreases with the radial distance from the central axis.

18. A cryogenic cooling apparatus comprising:

a target refrigerator; and

a heat exchanger according to any of the preceding claims, wherein the first conduit is arranged to convey an operational fluid to the target refrigerator and the second conduit arranged to convey the operational fluid from the target refrigerator.

19. A dilution refrigerator comprising:

a still, a mixing chamber and a heat exchanger according to any of claims 1 to 17, wherein the first conduit is arranged to flow an operational fluid from the still to the mixing chamber and the second conduit is arranged to flow the operational fluid from the mixing chamber to the still, the heat exchanger configured to thermally couple the operational fluid in the first conduit with the operational fluid in the second conduit.

20. A dilution refrigerator according to claim 19, wherein the mixing chamber comprises a mass of sinter, and the first conduit comprises an end portion that is open and extends around a portion of the mass of sinter so as to bring said portion of the mass of sinter into contact with the operational fluid, the second conduit extending around the end portion and the mass of sinter so as to convey the operational fluid in a direction away from the mass of sinter.

21. A dilution refrigerator according to claim 20, the dilution refrigerator configured such that operation of the dilution refrigerator causes a phase

boundary to arise in the operational fluid at a position inside the end portion of the first conduit.

22. A dilution refrigerator according to any of claims 19 to 21, wherein the heat exchanger is arranged to obtain a temperature below 30mK in use.

23. A dilution refrigerator according to any of claims 19 to 22, further comprising a cold plate arranged between the still and the mixing chamber, the cold plate arranged to obtain a base temperature between that of the still and the mixing during operation of the dilution refrigerator, the dilution refrigerator further comprising a chamber assembly comprising one or more said chambers arranged along a portion of the first conduit extending between the cold plate and the mixing chamber, each said chamber being arranged to receive the operational fluid from the first conduit, and wherein second conduit is thermally coupled to the outside of each said chamber.

24. A dilution refrigerator according to claim 23, wherein the chamber assembly forms a step heat exchanger.

25. A dilution refrigerator according to claims 23 or 24, wherein the chamber assembly comprises a first said chamber and a second said chamber, the first said chamber being arranged between the cold plate and the second said chamber, wherein the depth of the second said chamber and/or the number of apertures through the plate of the second said chamber or the size of the apertures through the plate of the second said chamber is higher than that of the first said chamber.

26. A dilution refrigerator according to any of claims 23 to 25, wherein the chamber assembly and the mixing chamber are rotationally symmetric about an axis extending through the first conduit.

27. A dilution refrigerator according to any of claims 23 to 26, wherein each said chamber comprises one or more flow channels for conveying the fluid through the respective first region and the respective second region, wherein each said flow channel is formed within a sinter, wherein the chamber assembly

is arranged along a thermal gradient during operation of the dilution refrigerator so that a first said chamber is arranged to obtain a higher base temperature than a second said chamber, and wherein the diameter of the one or more flow channels in the first chamber is lower than the diameter of the one or more flow channels in the second chamber.

28. A dilution refrigerator according to any of claims 19 to 27, wherein the second conduit forms the exterior of the heat exchanger, and the second conduit is formed from a plurality of modules that are fused together.

29. A dilution refrigerator according to any of claims 19 to 28, wherein the first conduit is formed from a plurality of modules that are fused together.

30. A method of forming a heat exchanger for a cryogenic refrigerator, the method comprising:

providing a first conduit, a second conduit, a first end piece, a second end piece and a flow deflector, the flow deflector comprising a collar and a plate, the plate extending across the collar;

wherein providing the first end piece comprises:

fusing a first peripheral support member around the perimeter of a first foil member, and then applying a sintered material to opposing faces of the first foil member, the thermal conductivity of the first peripheral support member being at least twenty times lower than that of the first foil member when at a temperature of 300 K;

fusing the first peripheral support member to the collar so as to form a chamber, the chamber having a first region separated from a second region by the plate, the plate arranged between the first end piece and the second end piece;

wherein the first conduit is arranged to convey a fluid into the first region and out from the second region, and wherein the plate comprises one or more apertures for allowing a flow of the fluid from the first region to the second region; and

wherein second conduit is thermally coupled to the outside of the chamber.

31. A method according to claim 30, further comprising fusing a first portion of the first conduit to the first foil member so as to facilitate a flow of the fluid through the first foil member, wherein the first portion of the first conduit is preferably fused to the first foil member by welding or vacuum brazing.

32. A method according to claims 30 or 31, wherein providing the second end piece comprises:

fusing a second peripheral support member around the perimeter of a second foil member, and then applying a sintered material to opposing faces of the second foil member, the thermal conductivity of the second peripheral support member being at least twenty times lower than that of the second foil member when at a temperature of 300 K;

wherein forming the chamber further comprises fusing the second peripheral support member to the collar.

33. A method according to claim 32, further comprising fusing a second portion of the first conduit to the second foil member so as to facilitate a flow of the fluid through the second foil member, wherein the second portion of the first conduit is preferably fused to the second foil member by welding or vacuum brazing.

34. A method according to any of claims 30 to 33, wherein each said peripheral support member is fused to the respective foil member by welding or vacuum brazing.

35. A method according to any of claims 30 to 34, wherein each said support member is fused to the collar by a localised heat source, and preferably by laser or electron beam welding.

36. A method according to any of claims 30 to 35, wherein the apertures are arranged with respect to the first conduit so that the fluid follows a non-linear path through the chamber.

37. A method according to any of claims 28 to 34, further comprising imprinting a flow channel in the sintered material to define one or more pathways for the fluid to flow through the first region and the second region.

38. A method of forming a dilution refrigerator, comprising:

providing a still and a mixing chamber, and forming a heat exchanger according to any of the preceding claims, wherein the first conduit is arranged to flow an operational fluid from the still to the mixing chamber, and wherein the second conduit is arranged to flow the operational fluid from the mixing chamber to the still.

39. A method according to claim 38, wherein the first conduit comprises an end portion arranged to receive the operational fluid from the chamber, and wherein providing the mixing chamber comprises:

arranging the end portion around a portion of a mass of sinter so as to bring said portion of the mass of sinter into contact with the operational fluid; and

arranging the second conduit around the end portion and the mass of sinter so as to convey the operational fluid in a direction away from the mass of sinter.

40. A method according to claim 39, further comprising sealing the second conduit to a support on which the mass of sinter is mounted.

41. A method according to any of claims 38 to 40, wherein the first conduit and the second conduit are formed from a plurality of modules for assembly, the method further comprising fusing a first module of the first conduit together with a second module of the first conduit at a position between the chamber and the end portion, and/or fusing a first module of the second conduit together with a second module of the second conduit at a position between the chamber and the end portion.

42. A method according to any of claims 38 to 41, further comprising arranging a cold plate between the still and the mixing chamber so as to obtain a base temperature between that of the still and the mixing during operation of the dilution refrigerator; providing a plurality of said chambers arranged along a

portion of the first conduit extending between the cold plate and the mixing chamber, each said chamber arranged to receive the operational fluid from the first conduit, and wherein second conduit is thermally coupled to the outside of each said chamber, wherein the first conduit and the second conduit are formed from a plurality of modules for assembly, the method further comprising fusing a module of the first conduit together with another module of the first conduit at a position between two said chambers, and/or fusing a module of the second conduit together with another module of the second conduit at a position between two said chambers.

43. A method according to claims 41 or 42, wherein said modules are fused together using a localised heat source, and preferably by laser or electron beam welding.

44. A method according to any of claims 41 to 43, wherein a portion of the first conduit extending from the cold plate to the mixing chamber and the chambers are arranged inside the second conduit.

45. A dilution refrigerator comprising:

a still and a mixing chamber;

a first conduit arranged to convey an operational fluid from the still to the mixing chamber;

a second conduit arranged to convey the operational fluid from the mixing chamber to the still;

a heat exchanger arranged to thermally couple the operational fluid in the first conduit with the operational fluid in the second conduit at a position between the still and the mixing chamber;

characterised in that the heat exchanger comprises one or more chambers arranged along a portion of the first conduit, each said chamber having a first region and a second region, the first region separated from the second region by a plate extending through the chamber, the plate comprising one or more apertures for allowing a flow of the operational fluid from the first region to the second region, and wherein second conduit is arranged around the outside of each said chamber.

46. A dilution refrigerator according to claim 45, wherein a plurality of chambers is provided, the second conduit being formed of a plurality of modules that are welded together between each said chamber, and the first conduit is preferably formed of a plurality of modules that are welded together between each said chamber.

47. A dilution refrigerator according to claims 45 or 46, wherein each said chamber comprises a first end piece and a second end piece forming opposing sides of the chamber respectively, the first end piece coupled to the second end piece by a flow deflector, the flow deflector comprising a collar separating the first end piece from the second end piece, wherein the plate extends across the collar, wherein each of the first end piece and the second end piece has a first face arranged inside the chamber and a second face arranged outside the chamber, the first face and the second face being formed from a sintered material applied to a foil member arranged between the first face and the second face, wherein each of the first and second end pieces further comprise a respective outer support member extending around the perimeter of the respective foil member, the outer support member fused to the collar.

48. A dilution refrigerator according to claim 47, wherein the thermal conductivity of the foil members is at least twenty times larger than that of the outer support members when at a temperature of 300 K.

Fig. 1

Prior Art

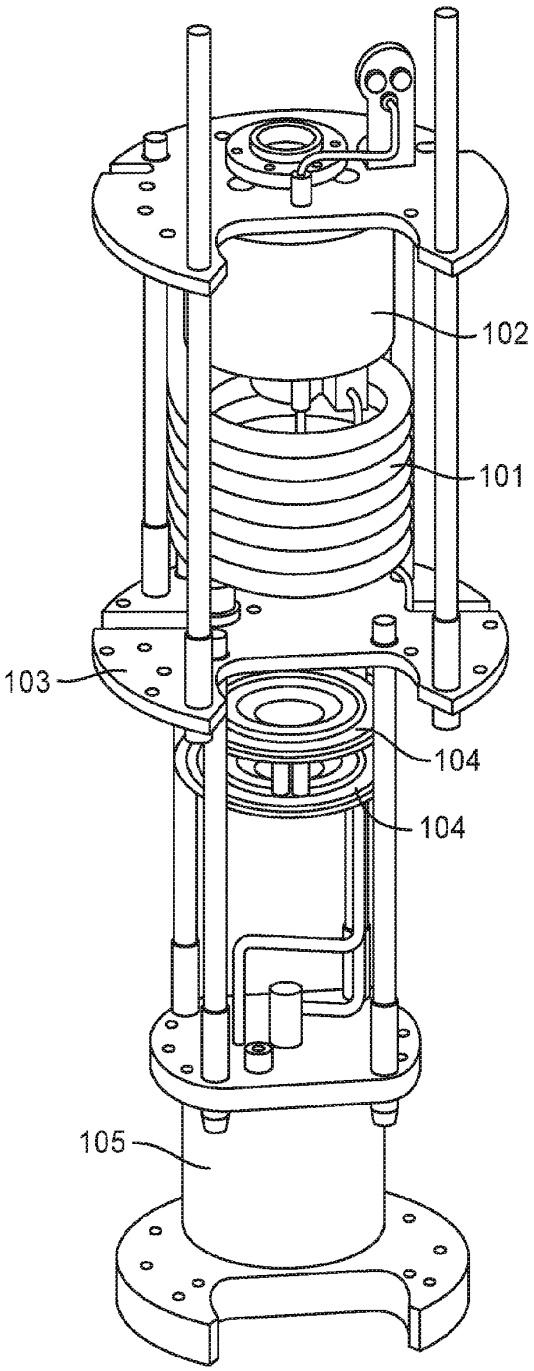


Fig. 2

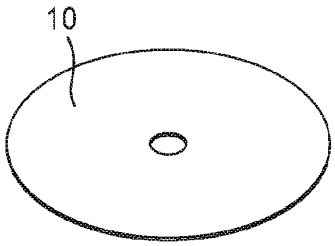


Fig. 3

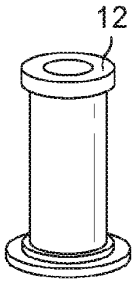


Fig. 4

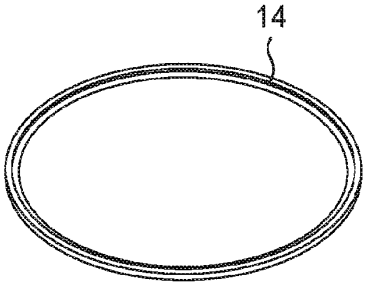


Fig. 5

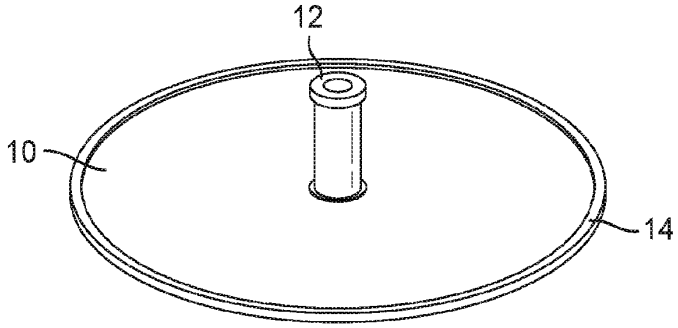


Fig. 6

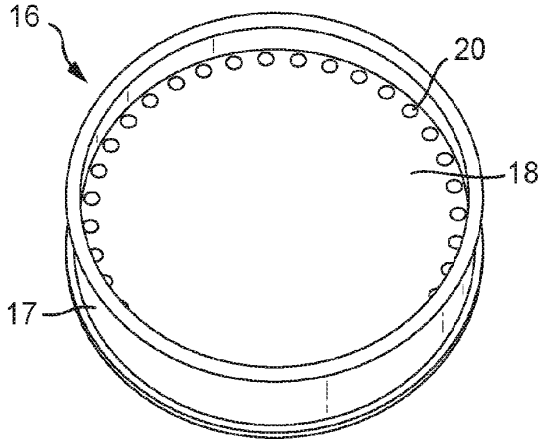


Fig. 7

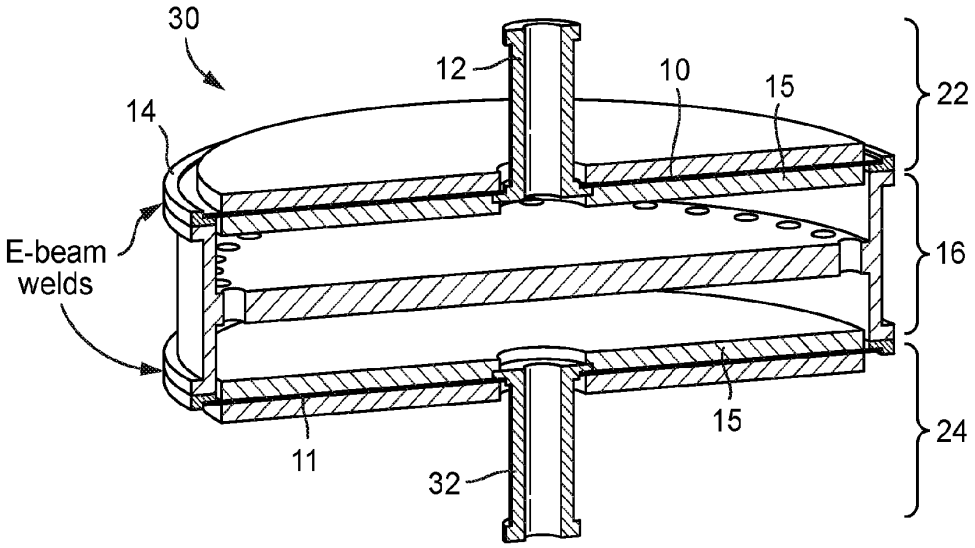


Fig. 8

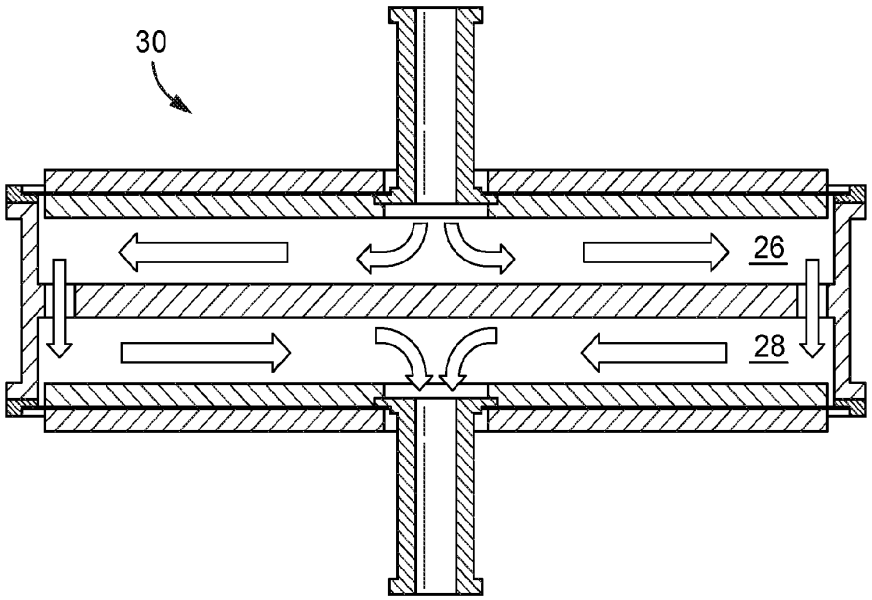


Fig. 9

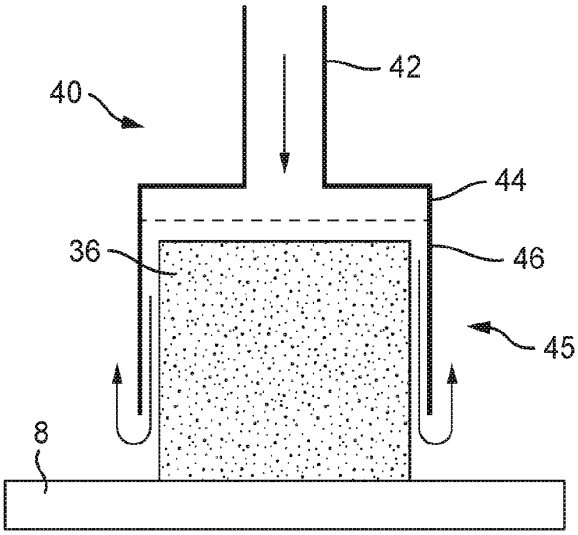


Fig. 10

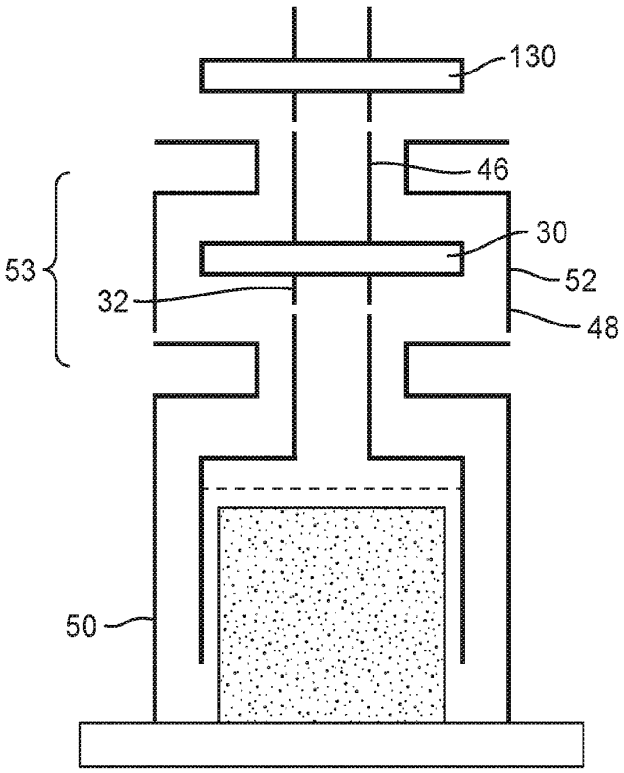


Fig. 11

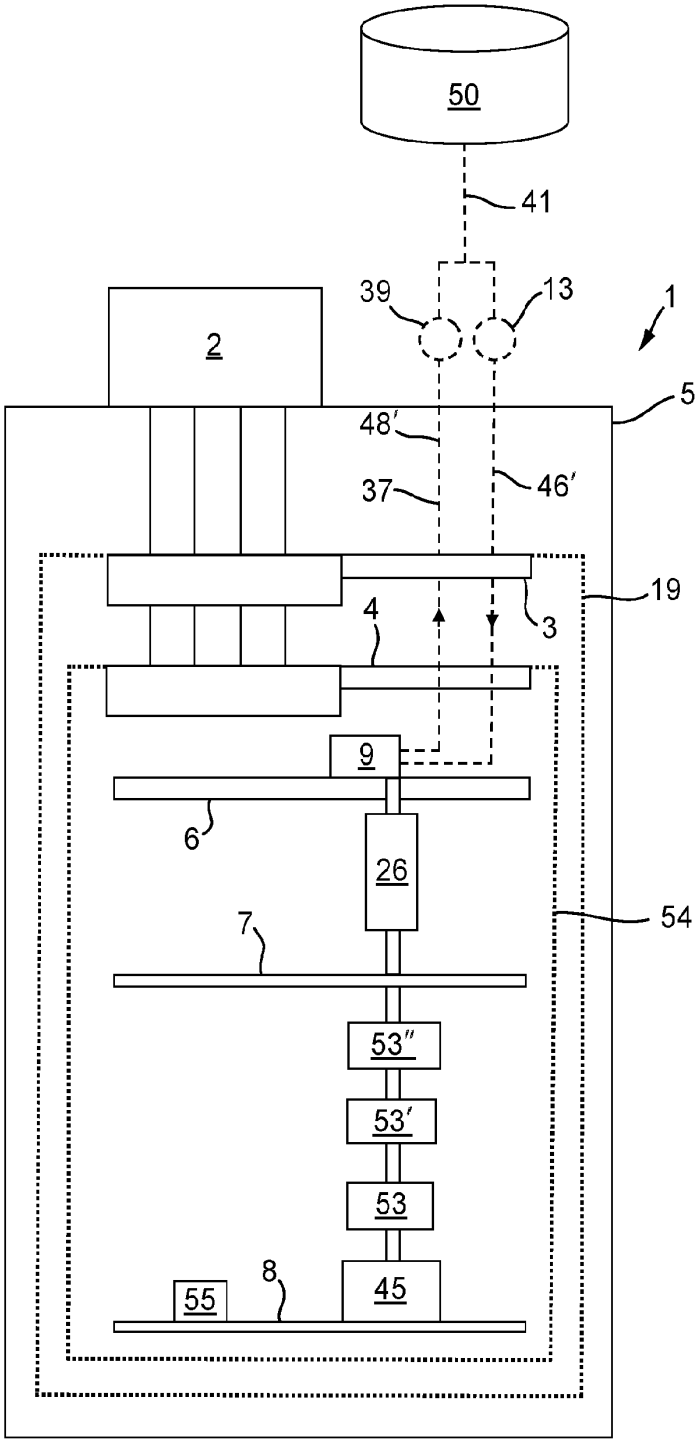


Fig. 12

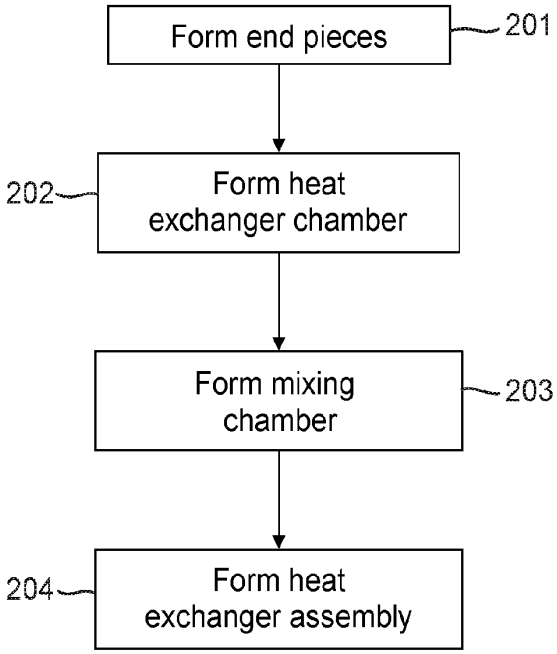

Form end pieces
201
202
Form heat exchanger chamber
Form mixing chamber
203
204
Form heat exchanger assembly

Fig. 13

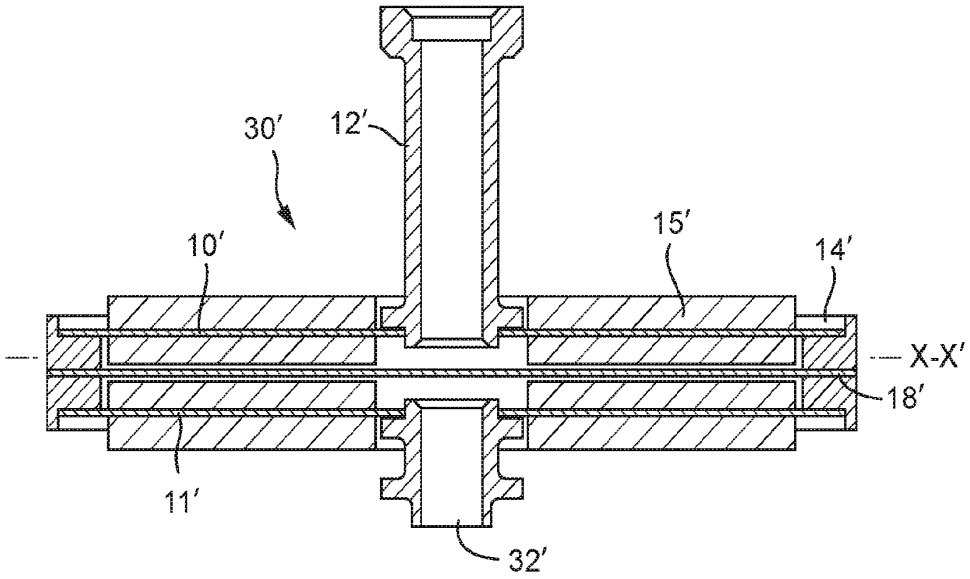


Fig. 14

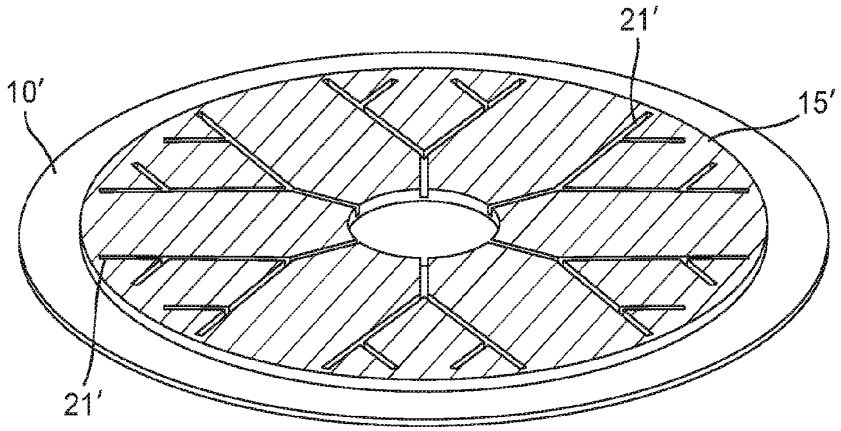


Fig. 15

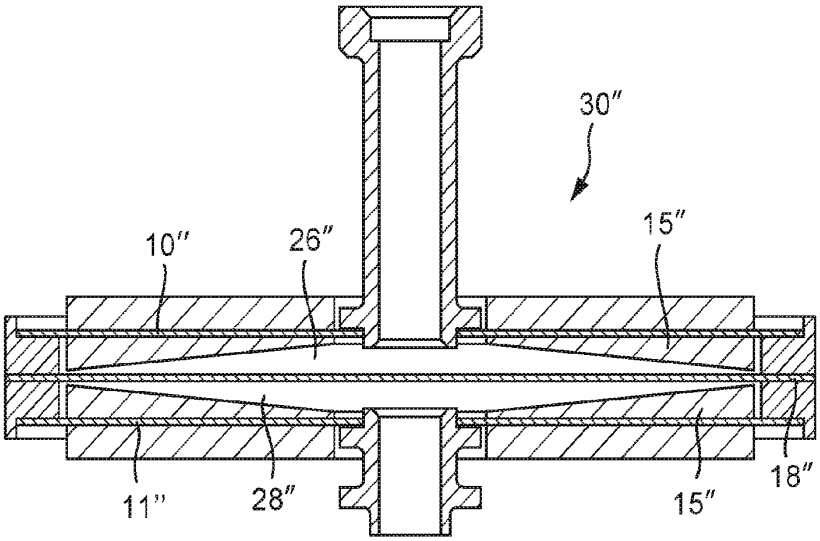
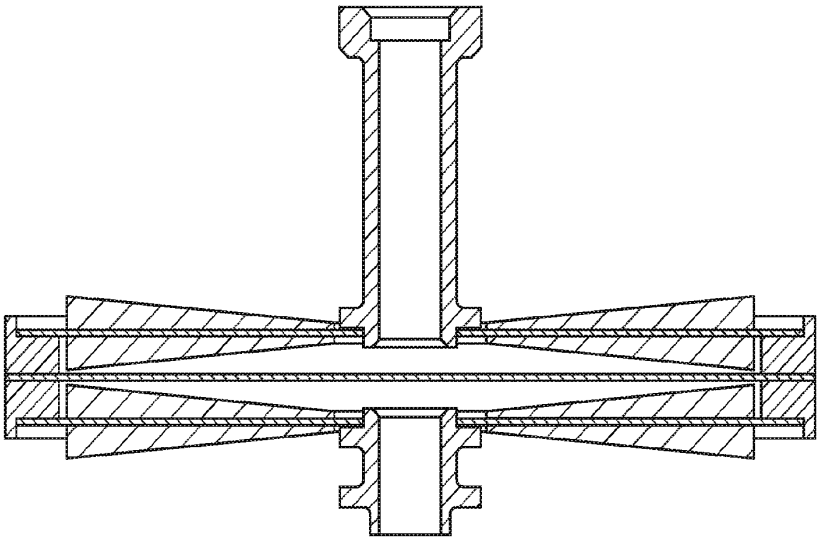


Fig. 16



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2022/050501

A. CLASSIFICATION OF SUBJECT MATTER
INV. F25B9/12 F25B9/10 F25B9/14 F25D19/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25B F25D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	US 2004/187519 A1 (ZHU SHAOWEI [JP] ET AL) 30 September 2004 (2004-09-30) paragraph [0055] - paragraph [0123]; figures 1, 15-18	1-8, 16-18 19-22, 29,38-46 9-15, 23-28, 30-37, 47,48

X	US 5 101 894 A (HENDRICKS JOHN B [US]) 7 April 1992 (1992-04-07) column 4, paragraph 43 - column 5, paragraph 51; figures 3-5	1-8,16, 17

Y	EP 3 742 076 A1 (OXFORD INSTRUMENTS NANOTECHNOLOGY TOOLS LTD [GB]) 25 November 2020 (2020-11-25) paragraph [0008] - paragraph [0048]; figures 1-5	19-22, 29,38-46

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 May 2022	01/06/2022

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lucic, Anita

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2022/050501

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		JP 2020190406 A	26-11-2020
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Form PCT/ISA/210 (patent family annex) (April 2005)

FORM PTO-1449/A and B (modified PTO/SB/08)	APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
	FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet 1 of 1	GROUP ART UNIT: 3763	EXAMINER: L. W. Nouketcha

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
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		2024-0295347	A1	Tillemann-Dick et al.	09-05-2024
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Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		WO	2022/200761	A1	Oxford Instruments Nanotechnology Tools, Ltd	09-29-2022	

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)
		International Search Report and Written Opinion mailed August 6, 2024, in connection with International Application No. PCT/US2024/018062 (M1567.70003WO00).	
		Invitation to Pay Additional Fees mailed May 28, 2024, in connection with International Application No. PCT/US2024/018062 (M1567.70003WO00).	
		International Preliminary Report on Patentability dated December 14, 2023, in connection with International Application No. PCT/US2022/036531 (M1567.70000WO00).	

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EXAMINER:	DATE CONSIDERED:

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

12792505.1

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PATENT AND TRADEMARK OFFICE

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ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**10/24/2024 12:49:07 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Jennifer Weaver
PATENT CENTER #	67704690	FILING DATE	07/08/2022
CUSTOMER #	23628	FIRST NAMED INVENTOR	Corban I. Tillemann-Dick
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	Sarah Schlotter

Documents

TOTAL DOCUMENTS: 7

DOCUMENT	PAGES	DESCRIPTION	SIZE (KB)
M156770000WO00_IPRP_12-14-2023.pdf	7	Other reference-Patent/Application/Search Documents	622 KB
M156770000US04-IDS1449-SCS.pdf	1	Information Disclosure Statement (IDS) Form (SB08)	25 KB
Warning: This is not a USPTO supplied IDS fillable form. Data in the form cannot be automatically loaded to other USPTO systems.			
M156770000US04-IDSBODY-SCS.pdf	3	Letter specifying the conditions for filing under 37 CFR 1.97	34 KB
M156770003WO00_IPAF_dtd_05-28-2024.pdf	2	Other reference-Patent/Application/Search Documents	2645 KB
M156770000US04-TRN-	1	Miscellaneous Incoming Letter	26 KB

SCS.pdf			
M156770003WO00_ISRWO_dtd_08-06-2024.pdf	13	Other reference-Patent/Application/Search Documents	1948 KB
WO2022200761A_FOR.pdf	48	Foreign Reference	3955 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
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WO2022200761A_FOR.pdf	F450B6FB3ADE215352677B315281177440F402D014F7DA228FC369989D90E9BF05B1FFA9A047E3DD2E54D68252DF7136ABEA29C434A04CFDBF7D81DBB216C9D9

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage

submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

DOCKET NO.: M1567.70000US04

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	L. W. Nouketcha
Art Unit:	3763

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: October 24, 2024 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

MAIL STOP AMENDMENT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

STATEMENT FILED PURSUANT TO THE DUTY OF DISCLOSURE UNDER 37 C.F.R. §§ 1.56, 1.97 AND 1.98

Commissioner:

Pursuant to the duty of disclosure under 37 C.F.R. §§ 1.56, 1.97 and 1.98, the undersigned requests consideration of this Information Disclosure Statement.

PART I: Compliance with 37 C.F.R. § 1.97

This Information Disclosure Statement has been filed before the mailing of a first Office Action on the merits.

No fee or certification is required.

PART II: Information Cited

The undersigned hereby makes of record in the above-identified application the information listed on the attached form PTO-1449 (modified PTO/SB/08). The order of presentation of the references should not be construed as an indication of the importance of the references.

The undersigned hereby makes the following additional information of record in the above-identified application.

The undersigned would like to bring to the Examiner's attention the following applications that may contain subject matter related to this application:

Serial No.	Filing Date	Inventor(s)	Docket No.
* 18/435,459	02-07-2024	Tillemann-Dick et al.	M1567.70000US08
* 18/649,321	04-29-2024	Tillemann-Dick et al.	M1567.70000US09
*18/593,161	03-01-2024	Thompson et al.	M1567.70003US01

*A copy of this reference is not provided as the Office has waived the requirement under 37 C.F.R. § 1.98(a)(2)(iii) for submitting a copy of a cited U.S. patent application if it is scanned to the Image File Wrapper system and is available on Patent Center.

The undersigned would like to bring to the Examiner's attention the enclosed search reports or other communications from noted International or Foreign National Applications:

Serial No.	Date of Mailing	Type(s) of Communication	Docket No.
PCT/US2024/018062	08-06-2024	International Search Report and Written Opinion	M1567.70003WO00
PCT/US2024/018062	05-28-2024	Invitation to Pay to Additional Fees	M1567.70003WO00
PCT/US2022/036531	12-14-2023	International Preliminary Report on Patentability	M1567.70000WO00

PART III: Remarks

Documents cited anywhere in the Information Disclosure Statement are enclosed unless otherwise indicated. It is respectfully requested that:

1. The Examiner consider completely the cited information, along with any other information, in reaching a determination concerning the patentability of the present claims;

2. The enclosed form PTO-1449 (modified PTO/SB/08) be signed by the Examiner to evidence that the cited information has been fully considered by the United States Patent and Trademark Office during the examination of this application;

3. The citations for the information be printed on any patent which issues from this application.

By submitting this Information Disclosure Statement, the undersigned makes no representation that a search has been performed, of the extent of any search performed, or that more relevant information does not exist.

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, material to patentability as defined in 37 C.F.R. § 1.56(b).

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, in fact, prior art as defined by 35 U.S.C. § 102, or an admission by Applicant as prior art.

Notwithstanding any statements by the undersigned, the Examiner is urged to form his or her own conclusion regarding the relevance of the cited information.

An early and favorable action is hereby requested.

The Director is hereby authorized to charge any deficiency or credit any overpayment in the fees occasioned by the filing of this Information Disclosure Statement to our Deposit Account No. 23/2825 under Docket No. M1567.70000US04 from which the undersigned is authorized to draw.

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

Docket No.: M1567.70000US04
Date: October 23, 2024

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
17/860,950	07/08/2022	Corban I. Tillemann-Dick	M1567.70000US04

CONFIRMATION NO. 9208

23628
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

37 CFR 1.48(f)
ACKNOWLEDGEMENT LETTER

OC000000071154001

Date Mailed: 04/17/2024

NOTICE OF ACCEPTANCE OF REQUEST UNDER 37 CFR 1.48(f)

This is in response to the applicant's request under 37 CFR 1.48(f) submitted on 04/15/2024.

The request under 37 CFR 1.48(f) to correct the inventorship, to correct or update the name of an inventor, or to correct the order of names of joint inventors is accepted.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/ttran/

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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
17/860,950	07/08/2022	3763	910	M1567.70000US04	20	1

CONFIRMATION NO. 9208

UPDATED FILING RECEIPT

23628
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

OC000000071154002

Date Mailed: 04/17/2024

Receipt is acknowledged of this non-provisional utility patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF FIRST INVENTOR, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection.

Please verify the accuracy of the data presented on this receipt. If an error is noted on this Filing Receipt, please submit a written request for a corrected Filing Receipt, including a properly marked-up ADS showing the changes with strike-through for deletions and underlining for additions. If you received a "Notice to File Missing Parts" or other Notice requiring a response for this application, please submit any request for correction to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections provided that the request is grantable.

Inventor(s)

Corban I. Tillemann-Dick, Denver, CO;
Kyle J. Thompson, Boulder, CO;
Bryan J. Choo, New York, NY;
John Ogando Dos Santos Allan, Boulder, CO;
Jonathan Michael Byars, Golden, CO;

Applicant(s)

Maybell Quantum Industries, Inc., Denver, CO;

Assignment For Published Patent Application

Maybell Quantum Industries, Inc., Denver, CO

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 63/319,248 03/11/2022
and claims benefit of 63/219,795 07/08/2021

Foreign Applications for which priority is claimed (You may be eligible to benefit from the Patent Prosecution Highway program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 07/25/2022
The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 17/860,950**
Projected Publication Date: 01/12/2023
Non-Publication Request: No
Early Publication Request: No
**** SMALL ENTITY ****
Title

INTEGRATED DILUTION REFRIGERATORS

Preliminary Class

062

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

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this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

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Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

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EXHIBIT 1004 – Page 196 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

POST AIA

DECLARATION (37 C.F.R. § 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 C.F.R. § 1.76)

Title of Invention	INTEGRATED DILUTION REFRIGERATORS

As the below named inventor, I declare that:

This declaration is directed to:

☐ The attached application, or

☒ United States application or PCT international application number 17/860,950 filed on July 8, 2022

The above-identified application was made or authorized to be made by me.

I believe I am the original inventor or an original joint inventor of a claimed invention in the application.

I have reviewed and understand the contents of the above-identified application, including the claims.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in 37 C.F.R. § 1.56.

All statements made herein of my own knowledge are true, and all statements made herein on information and belief are believed to be true.

I hereby acknowledge that any willful false statement and the like made in this declaration is punishable by fine or imprisonment of not more than five (5) years, or both, under 18 U.S.C. § 1001, and may jeopardize the validity of the application or any patent issuing thereon.

LEGAL NAME OF SOLE OR FIRST INVENTOR

Inventor one: Corban J. Tillemann-Dick Date: 7/25/2023

Signature:

LEGAL NAME OF ADDITIONAL JOINT INVENTOR, if any

Inventor two: Kyle J. Thompson Date: 7/25/2023

Signature:

LEGAL NAME OF ADDITIONAL JOINT INVENTOR, if any

Inventor three: Bryan J. Choo Date: 7/25/2023

Signature:

LEGAL NAME OF ADDITIONAL JOINT INVENTOR, if any

Inventor four: John Ogando Dos Santos Allan Date: 9/8/23

Signature:

☒ Additional inventors are being named on 1 Additional form(s) attached hereto.

EXHIBIT 1004 – Page 197 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

POST AIA

DECLARATION FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET	ADDITIONAL INVENTOR(S) Supplemental Sheet Page 1 of 1
LEGAL NAME OF ADDITIONAL JOINT INVENTOR, if any	
Inventor five: Jonathan Michael Byars Date: 7/25/2023	
Signature:	

EXHIBIT 1004 – Page 198 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission	

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban I. Tillemann-Dick
Art Unit	3763
Examiner Name	L. W. Nouketcha
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

- [X] Fee Transmittal Form
  - [ ] Fee Attached
- [ ] Amendment/Reply
  - [ ] After Final
  - [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [ ] Information Disclosure Statement
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- [ ] Drawing(s)
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- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
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- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- [ ] Proprietary Information
- [ ] Status Letter
- [X] Other Enclosure(s) (please Identify below):
  - Preliminary Amendment
  - Inventor Oath/Declaration
  - Corrected Application Data Sheet
  - Request to Correct Inventorship
  - Substitute Specification (clean and marked-up versions)

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Sarah C. C. Schlotter/		
Printed name	Sarah C.C. Schlotter, PhD		
Date	April 15, 2024	Reg. No.	79,027

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Dated: April 15, 2024 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

12331876.1

SUBSTITUTE SPECIFICATION MARKED-UP COPY

INTEGRATED DILUTION REFRIGERATORS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 63/319,248 filed on March 11, 2022, and titled "INTEGRATED DILUTION REFRIGERATORS," and of U.S. Provisional Patent Application No. 63/219,795 filed on July 8, 2021, and titled "INTEGRATED DILUTION REFRIGERATORS," the contents of each of which are incorporated by reference herein in their entirety.

BACKGROUND

Dilution refrigerators are cryogenic devices that rely on the heat of mixing of the ^{3}He and ^{4}He isotopes to provide cooling down to temperatures between approximately 2 mK and 1 K. Classic dilution refrigerators, or "wet" dilution refrigerators, precool the ^{3}He/^{4}He mixture using liquid nitrogen and ^{4}He baths before further cooling of the ^{3}He/^{4}He mixture below 4 K. Modern dilution refrigerators, or "dry" dilution refrigerators, precool the ^{3}He/^{4}He mixture using devices such as a cryocooler rather than cryogenic liquid baths.

SUMMARY

Some embodiments are directed to a dilution refrigerator comprising: an outer vacuum chamber comprising at least one substantially planar surface; and an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises a sample stage housed within the outer vacuum chamber, wherein the opening is configured to provide access to the sample stage through the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the sample stage are slidable and/or removable to provide access to the sample stage.

In some embodiments, the at least one substantially planar surface comprises a first surface disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator.

EXHIBIT 1004 – Page 200 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

In some embodiments, the at least one substantially planar surface comprises: first surfaces disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator; and second surfaces disposed within a plane parallel to the plane of the floor, wherein the first surfaces and the second surfaces are arranged as a rectangular prism.

In some embodiments, the opening comprises a hermetic opening.

In some embodiments, the opening comprises a hinged door.

In some embodiments, the dilution refrigerator further comprises one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the hinged door are slidable and/or removable to provide access to the interior of the outer vacuum chamber.

In some embodiments, the opening further comprises a load lock.

In some embodiments, the outer vacuum chamber comprises: a first section; and a second section suspended from the first section.

In some embodiments, the first section is coupled to the second section by integrated clamps and/or cams.

In some embodiments, the first and/or second section of the outer vacuum chamber are configured to be at least partially removed from the dilution refrigerator to provide access to an interior of the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises an external system configured to lift and/or lower the first and/or second section of the outer vacuum chamber.

In some embodiments, the external system comprises pneumatic and/or hydraulic devices configured to lift and/or lower the first and/or second sections.

In some embodiments, the external system comprises a screw mechanism configured to lift and/or lower the first and/or second sections.

In some embodiments, the outer vacuum chamber is configured to fit within a server rack-type container.

In some embodiments, the server rack-type container is configured to integrate with commercial server rack infrastructure.

In some embodiments, the server rack-type container is a 19-inch server rack.

In some embodiments, the server rack-type container comprises an external housing comprising an integrated horizontal surface.

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In some embodiments, the integrated horizontal surface is configured to be stowed when not in use.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing. In the drawings:

FIG. 1 is a schematic diagram of a closed-cycle dilution refrigerator, in accordance with some embodiments described herein.

FIG. 2 is a schematic diagram of helium cleaning devices in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 3 is a schematic diagram of a cooldown turbo charger device in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 4 is a schematic diagram of a still including a device to separate ^{3}He and ^{4}He using second sound effects, in accordance with some embodiments described herein.

FIG. 5A shows illustrative components of a removable dilution insert for the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 5B is a view of an illustrative thermalization plate insert of the removable dilution insert of FIG. 5A, in accordance with some embodiments described herein.

FIG. 5C is a cross-sectional view of an illustrative integrated heat exchanger showing channels for helium flow, in accordance with some embodiments described herein.

FIG. 5D is an image of a high surface area material for use in an integrated heat exchanger, in accordance with some embodiments described herein.

FIG. 5E is an illustrative implementation of a continuous heat exchanger and discrete heat exchanger of the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIGs. 6A-6F are schematic diagrams of illustrative ^{4}He film separation devices, in accordance with some embodiments described herein.

FIG. 7A is an image of sintered metal particles for use in a heat exchanger.

FIG. 7B is an image of nanowires for use in a heat exchanger, in accordance with some embodiments described herein.

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FIG. 7C is an image of a nanocluster for use in a heat exchanger, in accordance with some embodiments described herein.

FIG. 7D includes images of different nanopellets for use in a heat exchanger in accordance with some embodiments described herein.

FIG. 8A is a schematic diagram of an illustrative vibration isolation system for use in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 8B shows an illustrative spring for use in the vibration isolation system of FIG. 8A, in accordance with some embodiments described herein.

FIG. 9 is a side view of an illustrative external support rack and integrated lift configured to raise and lower portions of the vacuum chamber, in accordance with some embodiments described herein.

FIG. 10A is a side view of an illustrative implementation of the dilution refrigerator of FIG. 1 including elements configured to provide tool-free assembly of the vacuum chamber and access to the experimental volume, in accordance with some embodiments described herein.

FIGs. 10B and 10C are views of integrated latches in open and closed positions, respectively, configured to provide tool-free assembly of the vacuum chamber, in accordance with some embodiments described herein.

FIG. 11 is an exterior view of a housing configured to support a dilution refrigerator, in accordance with some embodiments described herein.

FIG. 12A is a schematic diagram of an inverted dilution refrigerator, in accordance with some embodiments described herein.

FIGs. 12B and 12C are schematic diagrams of illustrative components of an inverted dilution refrigerator, in accordance with some embodiments described herein.

FIG. 13 is a schematic diagram of a distributed cooling system, in accordance with some embodiments described herein.

FIG. 14 depicts, schematically, an illustrative computing device on which aspects of the technology described herein may be implemented.

DETAILED DESCRIPTION

Dilution refrigerators are cryogenic devices that can provide cooling down to temperatures between approximately 2 mK and 1 K and are used in a variety of

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applications requiring these extremely low temperatures. For example, dilution refrigerators can be used to support quantum computing (e.g., superconducting quantum computing technologies and qubits) and low-temperature condensed matter physics research, among other applications.

As described above, dilution refrigerators rely on the heat of mixing of ^{3}He and ^{4}He isotopes to provide cooling. When cooled below approximately 870 mK, a ^{3}He/^{4}He mixture undergoes spontaneous phase separation to form a ^{3}He-rich phase (the "concentrated" phase) and a ^{3}He-poor phase (the "dilute" phase). These two phases are maintained in equilibrium in a mixing chamber, the coldest part of the dilution refrigerator, and are separated by a phase boundary. In the mixing chamber, the ^{3}He is diluted as it moves from the concentrated phase through the phase boundary into the dilute phase, and the heat necessary for this endothermic dilution process provides the cooling power of the dilution refrigerator.

However, conventional dilution refrigerators can suffer from a multitude of drawbacks and failure points. For example, wet dilution refrigerators require significant amounts of liquid cryogens, which are costly to maintain and supply. As another example, dry dilution refrigerators can be subject to unwanted mechanical vibrations introduced by the cryocooler system and/or may draw large amounts of energy to power the cryocooler.

Conventional dilution refrigerators also typically occupy a large footprint, which may be prohibitive for applications requiring multiple dilution refrigerators. For example, a single conventional dry dilution refrigerator typically requires approximately 300 square feet and ceiling heights between 12 and 14 feet. This space is occupied not only by the dilution refrigerator itself but is also required to support any auxiliary systems such as pumps, compressors, water cooling systems and/or cryocooler systems.

The inventors have recognized and appreciated that, for quantum computing and other quantum technologies to be easily scalable, the quantum technology industry needs reliable, easy-to-use, easy-to-maintain, and compact dilution refrigerators. Accordingly, the inventors have developed dilution refrigerators and distributed cooling systems that can be integrated with commercially available server rack infrastructure (e.g., 19-inch server racks). Additionally, the inventors have developed a number of features, described herein, to ease maintenance of the dilution refrigerators, speed cooling of the dilution refrigerators without the use of mechanical pumps, and to reduce the transmission of mechanical vibrations to the experimental volume of the dilution refrigerator.

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I. Improved Closed-Cycle Dilution Refrigerator

FIG. 1 is a schematic diagram of a dry, closed-cycle dilution refrigerator 100, in accordance with some embodiments described herein. In some embodiments, the dilution refrigerator 100 includes an outer vacuum chamber 106 at room temperature (e.g., approximately 300K) and a number of thermal stages 108a-108f (e.g., thermalization plates) held at decreasing temperature intervals (e.g., approximately 50 K, 9-10 K, 3 K, etc.). For example, the first thermal stage 108a may be at approximately 50 K, the second thermal stage 108b may be at approximately 9-10 K, the third thermal stage 108c may be at approximately 3-4 K, the fourth thermal stage 108d may be at approximately 800 mK, the fifth thermal stage 108e may be at approximately 100 mK, and the sixth thermal stage 108f may be at approximately 10 mK.

In some embodiments, the dilution refrigerator 100 may include a pump system 102 that pressurizes a $^3He/^4He$ gas mixture (e.g., to a pressure at or near 1 bar). The $^3He/^4He$ gas mixture may enter the outer vacuum chamber 106 through one or more inlets and thereafter may travel through the inner thermal stages 108a-108f through the condensing line 102a. After performing its cooling function, the $^3He/^4He$ mixture may return to the pump system through the return 102b.

In some embodiments, the $^3He/^4He$ mixture may be purified prior to traveling along the condensing line 102a through the thermal stages 108a-108f. Contaminants in the helium flowing through the dilution refrigerator can clog certain components (e.g., the Joule-Thomson expander or capillaries in the heat exchangers) and lead to performance degradation or system failure. Conventionally, to reduce the risk of contaminants making their way into the system, helium is first passed through an external 'cleaning trap' filled with activated charcoal before entering the dilution unit of the dilution refrigerator. These external traps must be surrounded by liquid nitrogen and refilled at frequent intervals, which requires user maintenance and interaction.

The inventors have recognized and appreciated that passive helium filters, without the need for refilling of liquid nitrogen, can improve the user experience and reduce maintenance frequency of a dilution refrigeration system. Accordingly, in some embodiments, the dilution refrigerator 100 includes one or more helium cleaning devices 110. In some embodiments, where the dilution refrigerator 100 includes two or more helium cleaning devices 110, the dilution refrigerator 100 may further include a switching

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system 109 configured to direct the flow of the helium to a single helium cleaning device 110.

FIG. 2 shows a schematic diagram of helium cleaning devices 110, in accordance with some embodiments described herein. The helium cleaning devices 110 may be coupled to the pump system 102 by a switching system 109 that is disposed outside of the outer vacuum chamber 106. The switching system 109 may include one or more helium-compatible valves. The switching system 109 may be configured to switch helium flow between each of the helium cleaning devices 110. In this manner, one helium cleaning device 110 may be used for actively filtering helium while the dilution refrigerator is in operation while the other helium cleaning device may be cleaned (e.g., by heating and pumping out of impurities), enabling indefinite periods of operation of the dilution refrigerator 100.

In some embodiments, the helium cleaning devices 110 include a counter flow heat exchanger 110a, a trap 110b, and a weak thermal contact 110c (e.g., a gas gap heat exchanger, a low thermal conductivity attachment, etc.). The counter flow heat exchanger 110a and the weak thermal contact 110c may reduce the thermal load of the helium cleaning devices 110 on the dilution refrigerator 100 and may eliminate the use of cryogenic valves in the helium cleaning devices 110. The trap 110b may include, for example, a high surface area material (e.g., charcoal, activated charcoal, and/or a metal powder) configured to capture non-helium impurities in the dilution refrigerator 100.

Returning to FIG. 1, in some embodiments, the dilution refrigerator 100 may include a cooldown turbo charger device 111. Dry dilution refrigerators conventionally use an auxiliary compressor to enable the flow of warm helium, which initially has a high impedance and resists such movement. The extra pressure from the auxiliary compressor also pressurizes the helium, causing the helium to reach a pressure that starts isenthalpic expansion and cooling at a higher temperature. These auxiliary mechanical compressor pumps are costly, prone to reliability issues, frequently leak, and can cause performance degradation over time. The inventors have recognized and appreciated that, alternatively, the helium may be pulsed through the dilution refrigerator during cooldown without the use of an auxiliary mechanical pump, enabling a faster and more efficient cooldown process.

FIG. 3 shows a schematic diagram of a cooldown turbo charger device 111, in accordance with some embodiments described herein. The cooldown turbo charger device

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111 may include a volume of a high surface area material 111a, a heater 111b, a first valve 111c, and a second valve 111d. The first and second valves 111c, 111d may be, for example, cold valves located inside the vacuum chamber 106. As another example, the first and second valves 111c, 111d may be room temperature valves located outside of the vacuum chamber 106. In some embodiments, the heater 111b and the first and second valves 111c, 111d may be communicatively coupled to a controller 330. The controller 330 may be, for example, a computer as described in connection with FIG. 14 herein.

In some embodiments, the cooldown turbo charger device 111 may be thermally coupled to a thermal stage (e.g., to a thermalization plate). In the example of FIG. 3, the high surface area material 111a is thermally coupled to the second thermal stage 108b, though it should be appreciated that the high surface area material 111a could be thermally coupled to another thermal stage in some embodiments (e.g., first thermal stage 108a).

Alternatively, in some embodiments, the cooldown turbo charger device 111 may be thermally coupled to multiple thermal stages (e.g., across two or more thermal stages 108a-108f). In such embodiments, the sequential heating and cooling of the high surface area material 111a may be mediated by heat switches. For example, the cooldown turbo charger device 111 may be switchably thermally coupled between a warmer thermal stage and a colder thermal stage such that the cooldown turbo charger device 111 may be thermally coupled to either the warmer thermal stage or the colder thermal stage. When the cooldown turbo charger device 111 is thermally coupled to the warmer thermal stage, the high surface area material 111a may release any adsorbed helium. When the cooldown turbo charger device 111 is thermally coupled to the colder thermal stage, helium may begin adsorbing to the high surface area material 111a. In this manner, a sequential flushing of helium through the condensing line 102a may be implemented.

In some embodiments, the high surface area material 111a may comprise a material with a porous and/or textured surface such that helium adsorbs to the high surface area material 111a during the cooldown process. For example, the high surface area material 111a may comprise activated charcoal, a metal powder (e.g., a copper or silver powder), and/or a material composite formed of nanostructures (e.g., nanowires, nanoparticles, etc.).

In some embodiments, the cooldown turbo charger device 111 may be operated using a sequential opening and closing of the valves 111c, 111d in concert with operation of the heater 111b. For example, to cause helium to adsorb the high surface area material 111a, the first valve 111c may be closed to prevent helium from flowing to the lower stages

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of the dilution refrigerator 100 and the second valve 111d may be opened to allow helium to reach the high surface area material 111a. The first valve 111c may be closed and the second valve 111d may be opened by the controller 330 in response to a measured pressure or temperature or in response to a timing signal generated by controller 330.

In some embodiments, after sufficient helium has adsorbed onto the high surface area material 111a, the second valve 111d may be closed and the first valve 111c may be opened. The first and second valves 111c, 111d may be opened and/or closed in response to measured temperatures or pressures and/or in response to a timing signal generated by controller 330.

In some embodiments, when the second valve 111d is closed and the first valve 111c is opened, the heater 111b may also be caused, at a same or similar time, to heat the high surface area material 111a in response to a signal generated by controller 330. For example, the heater 111b may be a resistive heater that is caused to heat the high surface area material 111a by a flow of current through the heater 111b. In response to the heat from the heater 111b, the helium adsorbed to the high surface area material 111a may act as a reserve that is then released from the high surface area material 111a. This release of the adsorbed helium may increase the pressure in the remainder of the condensing line 102a, and the increased pressure may enable the start of isenthalpic expansion to speed cooling of the dilution refrigerator 100.

In some embodiments, once the helium has been released from the high surface area material 111a, the first valve 111c may be closed, the second valve 111d may be opened, and the heater 111b may be turned off by the controller 330, allowing new helium to adsorb to the high surface area material 111a. The controller 330 may be configured to periodically (e.g., at regular time intervals, at irregular time intervals, at time intervals determined by the temperature of the experimental volume, at time intervals determined by the pressure of the experimental volume) open and/or close the valves 111c, 111d and to operate the heater 111b to flush the helium intake path. In some embodiments, the controller 330 may be configured to "pulse" the helium from the high surface area material 111a through the condensing line 102a, causing the dilution refrigerator to be cooled.

Returning to FIG. 1, during operation of the dilution refrigerator, the $^{3}He/^{4}He$ mixture may be progressively cooled as it travels along the condensing line 102a from the first thermal stage 108a to the mixing chamber 122. At the first thermal stage, the helium may be initially cooled to approximately 50 K. After exiting the cooldown turbo charger

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device, the $^3He/^4He$ mixture may next be cooled by a cryocooler 104. A portion of the cryocooler 104 may be disposed partially outside of the outer vacuum chamber 106, in some embodiments. The cryocooler 104 may be vibrationally isolated from outer vacuum chamber 106 by a vibration isolation stage 105, which may comprise padding and/or any other suitable vibration isolation techniques.

In some embodiments, the cryocooler 104 may be coupled to a cryocooler support 103. The cryocooler support 103 may be, for example, a compressor and/or compression system, in some embodiments. The cryocooler support 103 may include cooling members 103a, in some embodiments, configured to provide air-cooling to the dilution refrigerator 100. The cooling members 103a may be, as a non-limiting example, cooling fins, fans, and/or heat pipes configured to remove waste heat generated by the cryocooler support 103 and/or the cryocooler 104.

The cooling members 103a are in contrast to conventional closed-cycle dilution refrigerators, which typically rely on water-cooling to remove waste heat generated by the integrated cryocooler. Water-cooling of the cryocooler, however, requires installing a large and/or expensive water-cooling system in conjunction with the dilution refrigerator. Additionally, such water-cooling systems are not typically integrated with commercial computing facilities, which typically rely on air-cooling as it is less expensive and does not present hazards (e.g., leaking coolant, flooding, etc.) to the electronic equipment. The inventors have accordingly recognized that using air-cooling to remove heat from the cryocooler of the dilution refrigerator may reduce the costs of manufacturing dilution refrigerators and enable their use in commercial computing facilities.

In some embodiments, the dilution refrigerator 100 may be disposed above a plenum (not pictured) disposed under a floor supporting the dilution refrigerator. The plenum may supply the cooling members 103a with air flow to provide air-cooling. In some embodiments, the cooling members 103a may include inlets and/or louvers configured to draw in air from the plenum. Alternatively or additionally, in some embodiments, the dilution refrigerator 100 may be disposed in a facility including ductwork and/or heat pipes (not pictured) arranged to remove heat from the cooling members 103a, the cryocooler support 103, and/or the cryocooler 104 and to minimize vibrations experienced by the dilution refrigerator 100.

In some embodiments, the $^3He/^4He$ mixture may be cooled by the cryocooler 104 in two steps. The condensing line 102a may be wound around two portions of the

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cryocooler 104 to effect heat exchange between the $^3He/^4He$ mixture in the condensing line 102a and the cryocooler 104. In a first step, the $^3He/^4He$ mixture may be cooled to approximately 10 K by the cryocooler 104. In a second step, the $^3He/^4He$ mixture may be cooled to approximately 3-4 K by the cryocooler 104.

In some embodiments, after being cooled by the cryocooler 104, the $^3He/^4He$ mixture may pass through the third thermal stage 108c. The third thermal stage 108c may be thermally coupled but mechanically decoupled from cryocooler 104, in some embodiments, in order to provide vibration isolation to the later thermal stages 108d-108f. As a non-limiting example, in some embodiments, third thermal stage 108c may be mechanically decoupled from the cryocooler by a copper braid, heat strap, or other hanging component configured to maintain thermal coupling between the third thermal stage 108c and the cryocooler 104.

In some embodiments, after passing through the third thermal stage 108c, the $^3He/^4He$ mixture may enter a primary impedance stage 112. The primary impedance stage 112 may be a Joule-Thomson expander configured to reduce the temperature and/or pressure of the $^3He/^4He$ mixture. For example, in some embodiments, the $^3He/^4He$ mixture may be at approximately 3-5 K before entering the primary impedance stage 112 and may be at approximately 1 K after exiting the primary impedance stage 112.

In some embodiments, the primary impedance stage 112 may be a Joule-Thomson expander formed from a fiber optic cable. Conventionally, Joule-Thomson expanders may be formed as metal tubes that are manufactured by pulling. However, such metal Joule-Thomson expanders may suffer from irregularities and/or may have a larger diameter that reduces the cooling power of the device. A hollow-core fiber optic cable may reliably and reproducibly provide the narrow opening needed for a Joule-Thomson expander.

In some embodiments, the dilution refrigerator 100 may include a bypass device 113a configured to increase the speed of cooldown of the dilution refrigerator 100. For example, during the initial cooldown of a dilution refrigerator, the helium flow rate may be low due to the large impedance of Joule-Thomson expanders in the dilution refrigerator and the warm, low density, and viscous circulating helium. This reduced helium flow rate reduces the rate of cooling of the lower portions of the refrigerator. To combat this effect, conventionally, a needle valve may be incorporated at a location on the condensing line above the Joule-Thomson expander to reduce the impedance of the initially-warm helium gas. However, the needle valve includes mechanical components that may fail over time.

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The inventors have recognized and appreciated that the helium flow rate may be improved without reliance on a mechanical component such as a needle valve.

In some embodiments, the bypass device 113a may be disposed along the condensing line 102a in parallel with the primary impedance stage 112 and on a bypass line 113b that bypasses the primary impedance stage 112 (e.g., allowing the $^3He/^4He$ mixture to flow around the primary impedance stage 112). The bypass device 113a may include a sheet of vacuum-compatible material configured to allow helium to diffuse through the material at temperatures above a threshold temperature value. For example, the bypass device 113a may allow the $^3He/^4He$ mixture to diffuse through the bypass device 113a at temperatures in a range from approximately 40 K to 300 K, in a range from 50 K to 300 K, in a range from 80 K to 300 K, in a range from 100 K to 300 K, in a range from 150 K, or in any range within those ranges. In some embodiments, the bypass device 113a may include a sheet of a vacuum-compatible polymer material. For example, the bypass device 113a may be formed of a sheet of Kapton, PEEK, and/or mylar, as some non-limiting examples. The bypass device 113a therefore allows for the high impedance of the primary impedance stage 112 to be circumvented when the $^3He/^4He$ mixture is warm, thereby increasing the helium flow rate and rate of cooling of the dilution refrigerator 100. When the dilution refrigerator 100 has cooled sufficiently (e.g., to below the threshold temperature value), the $^3He/^4He$ mixture will no longer diffuse through the bypass device 113a and instead will flow through the primary impedance stage 112.

In some embodiments, after exiting the primary impedance stage 112 or the bypass device 113a, the $^3He/^4He$ mixture then travels past the fourth thermal stage 108d and into the still 114. The still 114 may contain a different mixture of liquid $^3He/^4He$ that cools the incoming $^3He/^4He$ mixture as it passes through the condensing line 102a running through the still 114. In some embodiments, the $^3He/^4He$ mixture in the condensing line may be cooled to approximately 400-900 mK by the still 114.

In some embodiments, the still 114 may include a membrane configured to use second sound to improve ^3He evaporation within the still. Second sound is a superfluid phenomenon present in superfluid helium and may be produced, for example, when a porous membrane is oscillated or a heated wire is cycled within a bath of superfluid helium. The two-fluid model specifies that the superfluid helium in the mixture moves through the membrane while non-superfluid components of the helium bath cannot pass through the porous membrane as easily. In superfluid helium, this creates an enthalpy or

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temperature wave. Analogously in helium mixtures, the non-superfluid ^{3}He may be preferentially pushed by the oscillating membrane while the superfluid ^{4}He remains relatively stationary. The inventors have recognized and appreciated that this second sound phenomenon can be implemented within the still 114 to increase the ^{3}He evaporation rate at a lower temperature and to reduce a concentration of ^{4}He in the vapor above the liquid helium mixture in the still.

FIG. 4 is a schematic diagram of a still 400 including a device to separate ^{3}He and ^{4}He using second sound effects, in accordance with some embodiments described herein. The still 400 may be implemented as still 114 of dilution refrigerator 100, in some embodiments. The still 400 may include a stationary surface 402 and a porous, movable membrane 404. The porous membrane 404 may be oscillated along the Z direction to create standing concentration waves of ^{3}He within the still so that there are regions 406 of lower ^{3}He concentration and regions 408 of high ^{3}He concentration. The standing wave may be tuned such that regions 408 of high ^{3}He concentration are disposed adjacent an outlet of the still, thereby allowing for improved ^{3}He purification.

Returning to FIG. 1, in some embodiments, after exiting the still 114, the ^{3}He/^{4}He mixture may flow through the condensing line 102a to a secondary impedance stage 116. The secondary impedance stage 116 may be configured to ensure that only liquid ^{3}He/^{4}He proceeds further downstream in the dilution refrigerator 100 and that gas cavitation in the still 114 does not occur (e.g., by maintaining a threshold pressure in the still 114). The secondary impedance stage 116 may therefore reduce downstream cooling loads due to a latent heat of gaseous ^{3}He/^{4}He.

In some embodiments, after exiting the secondary impedance stage 116, the ^{3}He/^{4}He mixture may then flow into a first heat exchanger 118. The first heat exchanger 118 may be a continuous heat exchanger. For example, the first heat exchanger 118 may be a counterflow (e.g., a tube-tube heat exchanger), a cross-counterflow, and/or coflow heat exchanger. At the exit of the first heat exchanger 118, the ^{3}He/^{4}He mixture in the condensing line 102a may be cooled to a temperature of approximately 20 mK.

In conventional closed-cycle dilution refrigerators, prior to entering the still, the ^{3}He/^{4}He mixture in the condensing line typically must pass through a first impedance stage. This first impedance stage typically acts as an independent refrigeration stage, known as a Joule-Thomson refrigerator, where the ^{3}He/^{4}He mixture is cooled by isenthalpic expansion. In order to control the cooling power of the ^{3}He/^{4}He mixture

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expansion, the pressure of the $^3He/^4He$ mixture in the condensing line is typically raised by an external compressor.

The inventors have recognized and appreciated that reducing the temperature of the $^3He/^4He$ mixture prior to entering the first impedance stage can achieve the same cooling effect (e.g., the $^3He/^4He$ mixture can reach the same base temperature after passing through the first impedance stage) while using a lower pressure differential. Such a configuration can improve the efficiency of the dilution refrigerator and reduce or eliminate the need to pressurize the $^3He/^4He$ mixture before the first impedance stage. Further, the inventors have recognized that the heat removed from the $^3He/^4He$ mixture prior to the first impedance stage can be returned to the still, thereby eliminating or reducing the need for a supplemental heater within the still to raise the vapor pressure, and enabling evaporation, of the different $^3He/^4He$ mixture present in the still.

Accordingly, in some embodiments, the dilution refrigerator 100 may include a heat exchange line 117 configured to transfer heat from the incoming condensing line 102a to a return helium mixture being transported from the first heat exchanger 118 to the still 114. The heat exchange line 117 may cool the condensing line 102a at a location above the primary impedance stage 112. The heat exchange line 117 then cools the $^3He/^4He$ mixture in the condensing line 102a prior to entering the primary impedance stage 112. Thereafter, the warmed mixture in the heat exchange line 117 is transported to the still 114.

Cooling the incoming $^3He/^4He$ mixture before it enters the primary impedance stage 112 causes the primary impedance stage 112 to output a $^3He/^4He$ mixture with a higher proportion of ^3He in the liquid state rather than in the vapor state. Thus, the primary impedance stage 112 can be made more efficient by including the additional heat exchange line 117. Additionally, this improved efficiency eliminates or mitigates the need for supplemental pressure (e.g., an external compressor) and may lower the flow impedance of the circulating helium mixture. This is particularly useful in reducing the complexity and size of smaller dilution refrigerators that include smaller (i.e., less powerful) pulse tubes or other cryocoolers.

In some embodiments, after exiting the first heat exchanger 118, the $^3He/^4He$ mixture passes through the fifth thermal stage 108e and enters continuous heat exchanger 119. The continuous heat exchanger 119 may be a counterflow (e.g., a tube-tube heat exchanger), a cross-counterflow, and/or coflow heat exchanger. The continuous heat

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exchanger 119 is disposed below the fifth thermal stage 108e. The fifth thermal stage 108e may be an intermediate cold plate (ICP) configured to be cooled to a temperature of approximately 100-200 mK. While continuous heat exchangers are typically more efficient than discrete heat exchangers, they become less efficient below a temperature of approximately 80 mK. However, adding continuous heat exchanger 119 below the fifth thermal stage 108e may enable the fifth thermal stage 108e to operate with more cooling power during the process of cooling down the dilution refrigerator.

In some embodiments, after exiting the continuous heat exchanger 119, the ^{3}He/^{4}He mixture enters discrete heat exchangers 120. The discrete heat exchangers 120 may be formed of sintered nanoparticles, in some embodiments. Alternatively or additionally, in some embodiments the discrete heat exchangers 120 may be formed of sintered nanowires, as described herein in connection with FIGs. 7A-7D herein. The discrete heat exchangers 120 may be configured to further cool the ^{3}He/^{4}He mixture to a temperature below approximately 10-20mK.

The inventors have additionally recognized and appreciated that the user experience may be improved by allowing users to easily swap parts in and out of the dilution refrigerator 100 (e.g., for maintenance, to change the characteristics of the dilution refrigerator 100, and/or to upgrade the dilution refrigerator 100 as technological innovations are developed). The inventors have accordingly developed a swappable dilution insert that is easily removed and replaced. FIG. 5A shows illustrative components of a removable dilution insert 540 for the dilution refrigerator 100 of FIG. 1, in accordance with some embodiments described herein.

In some embodiments, the removable dilution insert 540 includes detachable plates 540a, 540b, 540c removably coupled to thermal stages 108d, 108e, and 108f, respectively. As shown in the example of FIG. 5A, the detachable plates 540a, 540b, and 540c may be removably coupled using mechanical fasteners (e.g., bolts and/or screws). In some embodiments, the removable dilution insert 540 further includes detachable connections 540d above the still (e.g., flanges) and to the condensing line 102a to further simplify replacement of the removable dilution insert 540.

FIG. 5B shows a close-up view of a detachable plate 540b of the removable dilution insert of FIG. 5A, in accordance with some embodiments described herein. The detachable plate 540b includes an input A and an outlet B to allow helium to flow through the detachable plate 540b, in some embodiments.

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In some embodiments, the detachable plates 540a, 540b, and/or 540c may include integrated heat exchangers. In some embodiments, the integrated heat exchangers may be channels 542 formed in the detachable plates 540a and/or 540b, as illustrated by the example of FIG. 5C, which shows a cross section through the detachable plate 540b of FIG. 5B. The channels 542 may be configured to have a high surface area. By allowing helium to flow through the channels 542 in the detachable plates 540a and/or 540b, the helium's rate of cooling may be increased. In some embodiments, the channels 542 may be formed by machining, welding, and/or by additive fabrication techniques (e.g., three-dimensional printing techniques).

In some embodiments, the integrated heat exchangers may be a high surface area material structure formed in the detachable plate 540c. For example, the integrated heat exchangers may be a lattice structure, as shown in the example of FIG. 5D. The lattice structure may be, as a non-limiting example, a square lattice structure having a periodicity in a range from approximately 400 μm to approximately 1000 μm. For example, the lattice structure may have a periodicity of approximately 600 μm.

In some embodiments, the lattice structure may be fabricated using additive fabrication techniques (e.g., three-dimensional printing techniques). The lattice structure may be fabricated to have a rough surface texture to increase the surface area of the material in contact with the helium mixture passing through the integrated heat exchanger, thereby improving heat exchange. In some embodiments, the lattice structure may be formed of a metal. As non-limiting examples, the lattice structure may be formed of copper, silver, and/or aluminum.

In some embodiments, the dilution insert 540 may include one or more heat exchangers, as described in connection with dilution refrigerator 100 of FIG. 1. FIG. 5E shows an illustrative implementation of a continuous heat exchanger 119 and discrete heat exchanger 120, in accordance with some embodiments described herein. As shown in FIG. 5E, the helium flows from the detachable plate 540b coupled to fifth thermal stage 108e into the continuous heat exchanger 119 followed by the discrete heat exchanger 120 and the detachable plate 540c.

Refrigeration cycles in cryogenic coolers typically use a method to control the flow of heat throughout the system. This control may be achieved with a superconductor, a gas gap, or other mechanisms to make or break a thermal connection between components within the system (i.e., heat switches). One common type of heat switch, a gas gap,

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typically comprises two high surface area objects with a small gap between them that is filled with a gas. As the system falls below a certain temperature, the conductive gas is adsorbed onto surface area in the heat switch, creating a vacuum and reducing heat transfer between the surfaces. Another common type of heat switch is a superconducting switch where a material passes through a superconducting transition and reduces thermal conductivity.

In some embodiments, the dilution refrigerator 100 may further include combined gas gap and/or superconducting heat switches between thermal stages of the dilution refrigerator 100. The example of FIG. 5E shows such a combined gas gap and superconducting heat switch 550 thermally coupled between thermal stages 108e and 108f. The combined gas gap and superconducting heat switches 550 include both a superconducting material (e.g., aluminum, titanium) that becomes superconducting at a temperature higher than a target temperature of the thermal stage to which it is thermally coupled and a gas gap heat switch to improve thermal isolation between the thermal stages.

Returning to FIG. 1, after the $^{3}He/^{4}He$ mixture exits the discrete heat exchanger 120, it passes through the sixth thermal stage 108f and enters the mixing chamber 122. In the mixing chamber 122, ^{3}He atoms may be pumped from a concentrated phase into a dilute phase (i.e., mixed with ^{4}He). This mixing causes the ^{3}He to be cooled as it passes through the phase transition between the concentrated phase to the dilute phase, and this endothermic phase transition provides the final cooling power of the dilution refrigerator 100.

In some embodiments, an experimental volume 124 (e.g., a sample stage or plate) may be thermally coupled to the mixing chamber 122 and configured to support a sample and/or quantum device. Because the experimental volume 124 is thermally coupled to the mixing chamber 122, the sample and/or quantum device may be held at or near the mixing chamber temperature.

In some embodiments, the experimental volume 124 may be accessed by the user when the dilution refrigerator 100 is not in operation through an opening in the vacuum chamber 106 and door 125. The door 125 may be, in some embodiments, a removable panel (e.g., secured with mechanical fasteners) or may be a hinged door that a user may open using a clamped handle (e.g., as shown in the example of FIG. 10A herein).

As illustrated in the example of FIG. 1, certain components of the dilution refrigerator 100 may be thermally coupled to a thermal stage and disposed on one side

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(e.g., above or below) the thermal stage. For example, the still 114 is shown as being disposed on a lower surface of the fourth thermal stage 108d. It should be appreciated that in some embodiments, such components may be disposed on either side of the associated thermal stage, as aspects of the technology described herein are not limited in this respect. For example, in some embodiments the still 114 may be disposed on an upper surface of the fourth thermal stage 108d. As another example, the helium cleaning devices 110 may be disposed on a lower surface of the first thermal stage 108a, in some embodiments.

In some embodiments, after entering the dilute phase, the ^{3}He/^{4}He mixture may be pumped out of the mixing chamber 122 and back through the dilution refrigerator 100, exiting the outer vacuum chamber 106 through return 102b. At low temperatures and pressures, ^{4}He forms a thick and mobile film that can move long distances across surfaces, including moving in a direction counter to the force of gravity. This helium creep can result in ^{4}He entering portions of a dilution refrigeration system where it is unwanted (e.g., spanning the gap between thermally isolated areas). FIGs. 6A-6F are schematic diagrams of exemplary ^{4}He separation devices that may be implemented at outlets in, for example, the mixing chamber 122 and/or the still 114, in accordance with some embodiments described herein.

FIG. 6A illustrates a cooling stage 600 (e.g., a still, the mixing chamber, etc.) including a bath 602 of a dilute phase helium mixture (e.g., a ^{3}He /^{4}He mixture), in some embodiments. ^{4}He can creep up an outlet pipe (e.g., a still pumping outlet pipe, a mixing chamber outlet pipe) and exit the cooling stage 600 unless a barrier 606 prevents the helium creep. In the example of FIG. 6A, barrier 606 comprises a sharp edge at a right-angled surface configured to prevent helium from exiting the cooling stage 600 through the low pressure pumping outlet.

Other embodiments of a barrier configured to prevent ^{4}He creep are shown in the examples of FIGs. 6B, 6C, 6D, and 6E. In the example of FIG. 6B, a ring 608 with a knife edge 609 is configured to prevent ^{4}He from exiting through the ^{3}He outlet. In some embodiments, the ring 608 may include a heating device (e.g., a resistive heater or any other suitable heater) configured to cause the creeping ^{4}He to leave the superfluid phase, thereby mitigating creep.

In the examples of FIGs. 6C, 6D, and 6E, vertical knife edges are used to prevent ^{4}He from exiting through the ^{3}He outlet. In some embodiments, and in the example of FIG. 6C, the knife edge 610 is on the exterior circumference of the outlet pipe. Alternatively,

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as shown in the example of FIG. 6D, the knife edge 611 may be beveled on the interior circumference of the outlet pipe. Further, as shown in the example of FIG. 6E, the knife edge 612 may be beveled on both the exterior and interior circumferences of the outlet pipe.

In some embodiments, and as shown in the example of FIG. 6F, the ^{3}He outlet may include a p-trap 621 configured to collect ^{4}He 622 at a lower surface of the p-trap 621. The ^{3}He outlet may include a normal leak or a superleak 624 configured to allow normal or superfluid ^{4}He to exit the p-trap 621, and a pump 626 (e.g., a fountain pump) may transport the ^{4}He away from the p-trap 621. In some embodiments, a further barrier 627 may be present on an interior surface of the outlet pipe. For example, the barrier 627 may be configured as a ring. In some embodiments, the barrier 627 may include a heating device to further prevent ^{4}He from exiting the outlet.

The inventors have recognized and appreciated that nanomaterials can provide advantages compared to conventional sintered metal powders (e.g., silver and/or copper powder) used in typical discrete heat exchangers. Accordingly, the inventors have developed nanomaterial heat exchangers that provide efficient heat exchange because of the nanomaterials' large surface area, high mechanical contact strength, and good neck growth between nanowires.

Typical discrete heat exchangers are commonly made out of sintered metal power (e.g., silver and/or copper powder). An example of such sintered particulates is shown in FIG. 7A. To have efficient heat exchange at the sub-Kelvin temperatures, however, a number of factors must be true with regards to the heat exchanger materials. The heat exchange material should have a large surface area, provide high mechanical and/or thermal contact between the liquid helium and the heat exchange material, allow for good neck growth, and provide space inside the heat exchange material for the liquid helium to move through the heat exchanger.

FIG. 7B shows an image of a nanomaterial comprising nanowires for use in a heat exchanger. FIG. 7C shows an image of a nanomaterial comprising nanoclusters for use in a heat exchanger. FIG. 7D shows images of nanomaterials comprising different examples of nanopellet shapes for use in a heat exchanger, in accordance with some embodiments described herein. These nanomaterials may be implemented in dilution refrigerator 100 in discrete heat exchanger 120 and/or in a block heat exchanger (e.g., present in the mixing chamber 122). It should be appreciated that FIGs. 7B-7D show examples of nanomaterial

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shapes, but that embodiments of nanomaterial for use in a discrete heat exchanger are not so limited. For example, the nanomaterial may alternatively be a nanofoam, nanotube, and/or any other suitable nanoshape.

In some embodiments, such a nanomaterial-based heat exchanger may be formed by bonding the nanomaterial through sintering. For example, the nanomaterial may be formed as a chemical precipitate and/or by electronic deposition or electroplating techniques. A substrate with a rough surface (e.g., comprising nucleation sites) may be provided for the nanomaterial to be grown on or adhered to. In some embodiments, the heat exchanger may be produced under heat and/or compression. The nanomaterial may be held in compression during the sintering process to form the nanowire heat exchanger. In some embodiments, the substrate may be patterned with macroscopic structures (e.g., a lattice or series of posts). In some embodiments, the substrate may be a tube, and the nanomaterial may be adhered to the interior or exterior surface of the tube. In some embodiments, the substrate may be formed of a material with a lower thermal conductivity than the nanomaterial adhered to the substrate.

In some embodiments, the nanomaterial may be formed out of one of a selection of vacuum-compatible materials including but not limited to copper, silver, vacuum-compatible polymers, carbon, and/or carbon fiber. For example, the nanomaterial may be nanowires comprising at least one of copper nanowires, silver nanowires, gold nanowires, platinum nanowires, polymer nanowires, carbon nanowires, and/or carbon fiber nanowires.

II. Improved Vibration Isolation

Many experiments conducted at sub-Kelvin temperatures are sensitive to vibrational noise both from the surrounding environment and the dilution refrigerator's cooling system pumps and components. Additionally, at sub-Kelvin temperatures, mechanical vibrations can generate a heat load, reducing the cooling power of the dilution refrigerator or producing tribo-electric noise on electrical inputs and/or outputs of the dilution refrigerator. The inventors have recognized and appreciated that improved vibration isolation can improve the cooling power and other performance characteristics (e.g., magnetic flux disruption) of a dilution refrigerator. Accordingly, the inventors have developed vibration isolation components configured to mechanically decouple the lower thermal stages 108d-108f from the upper thermal stages 108a-108c.

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FIG. 8A shows another schematic diagram of dilution refrigerator 100 including mechanical elements configured to provide vibration isolation, in accordance with some embodiments described herein. The vibration isolation elements include a first suspension system 832, at least one second suspension system 840, and a third suspension system 834.

In some embodiments, the first suspension system 832 may be configured to suspend the first thermal stage 108a, the second thermal stage 108b, and/or the third thermal stage 108c from the top surface of the outer vacuum chamber 106. The first suspension system 832 may include one or more rods configured to rigidly couple the first, second, and/or third thermal stages 108a-108c to the top surface of the outer vacuum chamber 106. The rods may be formed of a material having a high spring constant. For example, the rods may be formed of carbon fiber and/or stainless steel.

In some embodiments, the second suspension system 840 may be configured to independently suspend the fourth thermal stage 108d, the fifth thermal stage 108e, and/or the sixth thermal stage 108f from the top surface of the outer vacuum chamber 106. This independent suspension of the lower thermal stages 108d-108f vibrationally isolates the lower thermal stages 108d-108f from the upper thermal stages 108a-108c, thereby improving the vibration isolation of the lower thermal stages 108d-108f.

In some embodiments, the second suspension system 840 may include one or more springs 842, rods 843, and/or connectors 844. While the example of FIG. 8A shows only one second suspension system 840, it should be appreciated that multiple second suspension systems 840 may be used to suspend the lower thermal stages 108d-108f, in some embodiments. For example, there may be two, three, or four such second suspension systems 840, in some embodiments.

In some embodiments, the springs 842 may be configured to provide a constant spring tension under different loads (e.g., for different dampened masses hanging from the springs 842). An example of a spring 842 is shown in FIG. 8B. The springs 842 may be leaf suspension springs, in some embodiments, and may include an upper flexure 842a separated from a lower flexure 842b by rigid portions 842c. The springs 842 may flex through the flexing of upper and lower flexures 842a, 842b, providing vibrational isolation to the lower thermal stages 108d-108f along the Z axis (e.g., perpendicular to a plane of the floor supporting the dilution refrigerator 100). In some embodiments, a spring constant of the spring 842 may be determined by pre-tensioning the upper and/or lower flexures 842a, 842b. Alternatively or additionally, the spring constant of the spring 842 may be

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determined by changing a length of the upper and/or lower flexures 842a, 842b (e.g., having a lower spring constant for longer lengths of flexures 842a, 842b).

In some embodiments, the springs 842 may be coupled to the third thermal stage 108d by rods 843. The rods 843 may be soft rods having a low spring constant. For example, the rods 843 may be formed out of a polymer (e.g., DELRIN), in some embodiments. The rods 843, due to their softness, may provide vibrational isolation to the lower thermal stages 108d-108f in the X-Y plane (e.g., in a plane parallel to a plane of the floor supporting the dilution refrigerator 100 and perpendicular to the Z axis).

In some embodiments, the connectors 844 may be arranged in a triangular configuration to provide stability to the suspension of the fourth thermal stage 108d. The connectors 844 may be made of materials configured to have a high spring constant. For example, the connectors 844 may be formed of stainless steel and/or carbon fiber.

In some embodiments, the third suspension system 834 may be configured to suspend the fifth thermal stage 108e and the sixth thermal stage 108f from the fourth thermal stage 108d. In this manner, the three lower thermal stages 108d-108f may all be suspended from the top surface of the vacuum chamber 106 using the second suspension system 840. The third suspension system 834 may include one or more rods configured to rigidly couple the fifth and/or sixth thermal stages 108e, 108f to the fourth thermal stage 108d. The rods may be formed of a material having a high spring constant. For example, the rods may be formed of carbon fiber and/or stainless steel, in some embodiments.

It should be appreciated that while the example of FIG. 8A shows the first and third suspension systems 832, 834 as being formed out of rods, in some embodiments, the first and/or the third suspension system 832, 834 may be formed out of flexible springs, as aspects of the present disclosure are not limited in this respect. Additionally, it should be appreciated that while the example of FIG. 8A shows the second suspension system 840 as being formed out of springs, in some embodiments, the second suspension system 840 may be formed out of rods, as aspects of the present disclosure are not limited in this respect.

III. Integrated Dilution Refrigerator

Conventional dilution refrigerator technology often requires large amounts of space and expensive supporting infrastructure such as custom-built floating foundations, high ceilings, and/or access pits. These infrastructure requirements may reduce the

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scalability of quantum technologies that operate at low temperatures. As a non-limiting example, the adoption of certain quantum computing technologies may be limited by the required use of large dilution refrigerators. The inventors have recognized and appreciated that reducing the size and infrastructure requirements of dilution refrigerators may enable the scalability of quantum technologies. The inventors have further recognized that integrating dilution refrigerators with commercial computing infrastructure (e.g., commercial server infrastructure) can further enable the scalability of dilution refrigerators and associated quantum technologies dependent on dilution refrigerators. Such integrated dilution refrigerators may be more easily integrated into telecommunications networks, can use existing telecommunications heat removal architectures, and integrate with fiberoptic networks and systems.

FIG. 9 is a side view of an illustrative external support rack 950, in accordance with some embodiments described herein. In some embodiments, the external support rack 950 may support the dilution refrigerator 100 by suspending the dilution refrigerator 100 off of the floor below the dilution refrigerator 100. As shown in the example of FIG. 9, the external support rack 950 may include arms 952 that are coupled to portions of the top surface of the vacuum chamber 106 by vibration isolation components 954 to suspend the dilution refrigerator 100 off of the floor. In some embodiments, the vibration isolation components 954 may be air pistons, electromagnetic dampeners, and/or springs.

In some embodiments, the external support rack 950 may include castors (not shown) configured to assist in transportation of the dilution refrigerator 100. The castors may be retractable such that the wheels of the castors are not in contact with the floor supporting the external support rack 950 when the dilution refrigerator 100 is not being transported and/or is in operation.

In some embodiments, the external support rack 950 further includes floor supports 958. Floor supports 958 may be configured to extend from the external support rack 950 when the dilution refrigerator 100 is not being transported. Floor supports 958 may extend from the external support rack 950, for example, by the use of screws. The floor supports 958 may be used to lift and/or level the external support rack 950 away from the floor and/or to lift the castors of the external support rack 950 off of the floor. In some embodiments, the floor supports 958 may be used to correct the positioning of the external support rack 950 in the case of an uneven floor surface.

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In some embodiments, the external support rack 950 may support additional components external to the outer vacuum chamber 106 of dilution refrigerator 100. For example, the external support rack 950 may house compressors, pumps, and/or cooling equipment configured to support the operation of the dilution refrigerator 100. Alternatively, these external components may be housed in an adjacent (e.g., a different) server rack-type container and/or support rack 950 than the dilution refrigerator 100, in some embodiments.

In some embodiments, the external support rack 950 may include elements configured to provide tool-free assembly and/or disassembly of the vacuum chamber 106 and access to the experimental volume, in accordance with some embodiments described herein. As shown in the example of FIG. 9, the vacuum chamber 106 includes three sections, a first section 106a, a second section 106b suspended from the first section 106a, and a third section 106c suspended from the second section 106b. It should be appreciated that the technology described herein is not limited to three sections, and that a vacuum chamber may have one, two, four, five, or six sections in some embodiments.

In some embodiments, the vacuum chamber 106 may have one or more substantially planar surfaces. In some embodiments, at least one of the one or more substantially planar surfaces may be disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator. As shown in the example of FIG. 9, the sections 106a-106c may each have at least four substantially planar surfaces such that, when assembled, the vacuum chamber 106 is arranged to form a rectangular prism. In some embodiments, the vacuum chamber 106 may include two substantially planar surfaces disposed within a plane parallel to the plane of the floor and arranged to close the rectangular prism formed by the surfaces of the sections 106a-106c. In some embodiments, and as described below, the vacuum chamber 106 may have an opening accessible by a door 1070 in at least one of the substantially planar surfaces.

In some embodiments, the three sections 106a-106c of the vacuum chamber 106 may be partially or fully removable in order to provide access to internal portions of the dilution refrigerator 100. For example, the three sections 106a-106c of the vacuum chamber 106 may comprise removable panels (e.g., side panels, panels attached to a frame, etc.), in some embodiments. The three sections 106a-106c may be configured to allow a user of the dilution refrigerator 100 to be able to remove the vacuum chamber 106 from the dilution refrigerator 100 without needed a large clearance above or below the dilution

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refrigerator 100 (e.g., without needing high ceilings or a pit underneath the dilution refrigerator 100).

In some embodiments, the external support rack 950 may include an integrated lift 956a configured to support the three sections 106a-106c of the vacuum chamber during assembly, disassembly, and/or maintenance of the dilution refrigerator 100. The integrated lift 956a may be configured to raise and/or lower the sections 106a-106c of the vacuum chamber. For example, the integrated lift 956a may be configured to raise and/or lower arms 956b configured to support portions (e.g., the flanges) of the three sections 106a-106c. In some embodiments, the integrated lift 956a may be operated manually (e.g., using screws and/or cables). In some embodiments, the integrated lift 956a may be operated using an electronically-operated machine (e.g., pneumatic or hydraulic devices).

In some embodiments, the external support rack 950 may include one or more carts 957. The carts 957 may be configured to receive one or more of the sections 106a-106c when lowered manually or by using the integrated lift 956a. For example, the integrated lift 956a may be used to lower the third section 106c onto a cart 957. Thereafter, the third section 106c may be transported using the cart 957 along direction C to provide a user of the dilution refrigerator 100 space under the interior components of the dilution refrigerator 100.

In some embodiments, the integrated lift 956a may be removably coupled to the external support rack 950. For example, the integrated lift 956a may be slidably removable from the external support rack 950 (e.g., sliding horizontally outward along the direction C). Removal of the integrated lift 956a may be desired to provide the user with extra space (e.g., during maintenance of the dilution refrigerator 100).

In some embodiments, the three sections 106a-106c of the vacuum chamber 106 may be suspended from one another by integrated clamps and/or cams. Such integrated clamps and/or cams may be configured to enable a user to unclamp or clamp two sections of the three sections 106a-106c together without the use of any additional tools. FIGS. 10A-10C illustrate an example of an integrated cam 1060, with FIG. 10B showing the integrated cam 1060 in an open position and FIG. 10C showing the integrated cam 1060 in a closed position.

In some embodiments, the integrated cam 1060 includes a handle 1062 that enables a user to clamp or unclamp two sections of the three sections 106a-106c together or apart. The handle 1062 is coupled to two latches 1064 that are configured to connect to bars

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1066. The handle 1062 and latches 1064 are hingedly coupled to a section of the vacuum chamber 106 by cams 1068, which provide the requisite range of motion to perform clamping and unclamping motions.

In some embodiments, a compressive layer may be included at the connection points between the three sections 106a-106c of the vacuum chamber 106 to ensure a proper vacuum-safe seal. For example, a rubber O-ring, copper or indium gasket, or other vacuum-safe compressive layer may be placed between sections 106a-106c.

Returning to FIG. 10A, in some embodiments, the vacuum chamber 106 may include an external opening to provide access to an internal volume within the dilution refrigerator 100. For example, the opening may provide access to a sample stage or experimental volume of the dilution refrigerator 100, or any other interior portion of the dilution refrigerator 100. In some embodiments, the opening may be sealed by a hermetic seal. In some embodiments, the opening may be sealed by a door 1070, as shown in the example of FIG. 10A. The door 1070 may be sealed, for example, using a hinge and/or a clamp that may be manually engaged and disengaged. In some embodiments, the door 1070 may be coupled to the opening by a load lock.

In some embodiments, the door 1070 may provide access through all of the inner radiation shields (not shown, and which may be thermally coupled to one or more of the thermal stages 108a-108f) of the dilution refrigerator 100 to allow a user to access the experimental volume. For example, a portion of the inner radiation shields (not shown) may be coupled to the door 1070 such that when a user opens the door 1070, the inner radiation shields slide or otherwise move to provide the user access with the interior portion of the dilution refrigerator. In some embodiments, a portion the inner radiation shields may be removable through the door 1070 and/or slidable through the door 1070.

In some embodiments, the external support rack 950 may be configured to be integrated with a server rack-type container. For example, the external support rack 950 may be configured to integrate the dilution refrigerator 100 with commercial server rack infrastructure (e.g., server racks). In some embodiments, the external support rack 950 may be configured to integrate the dilution refrigerator 100 with 19-inch server racks.

In some embodiments, the external support rack 950 and dilution refrigerator 100 may be housed within an outer housing. An example of an outer housing 1100 is illustrated in FIG. 11. In some embodiments, the outer housing 1100 may include an integrated horizontal surface 1110. For example, the integrated horizontal surface 1110 may be used

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as a desk or support surface when the user interacts with the dilution refrigerator. The integrated horizontal surface 1110 may be configured to be stowed by folding (as shown in the example of FIG. 11) or sliding away when not in use. In some embodiments, the outer housing 1100 may further include one or more storage locations (e.g., drawers, shelves) for the storage of related parts and/or tools for maintenance of the dilution refrigerator 100.

In some embodiments, the outer housing 1100 may further include a door 1125 providing access through an opening 1120 to the experimental volume of the dilution refrigerator 100. For example, the door 1125 may open to provide access to the experimental volume through the vacuum chamber 106 and the radiation shields inside of the vacuum chamber 106. In some embodiments, the vacuum chamber exterior and/or the radiation shields may be coupled to the door 1125 such that when a user opens the door 1125, the user opens the vacuum chamber exterior 106 and/or the radiation shields. In some embodiments, the radiation shields may alternatively be slidably and/or hingedly movable such that the user may move the radiation shields such that they no longer block access to the experimental volume as needed.

In some embodiments, the housing 1100 may further be configured to perform sound dampening. For example, the housing 1100 may include sound dampening materials to perform passive sound dampening. Alternatively or additionally, the housing 1100 may include audio equipment (e.g., speakers) configured to provide active sound dampening through the emission of destructive interference of the sounds generated by functional components of the system.

IV. Inverted Dilution Refrigerator

Conventionally, dilution refrigerators are oriented such that warmer thermal stages are positioned towards the top of the system with the thermal stages getting increasingly colder as the $^3He/^4He$ mixture progresses to the bottom of the dilution refrigerator. The inventors have recognized and appreciated that an inverted geometry, with the coldest stage disposed at the top of the system (e.g., furthest from the floor) may simplify the operation and use of a dilution refrigerator by making the experimental volume more accessible to a user and offer improved thermodynamic qualities compared to a conventional dilution refrigerator. Accordingly, the inventors have developed an inverted, dry dilution refrigerator.

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FIG. 12A is a schematic diagram of an inverted dilution refrigerator 1200, in accordance with some embodiments described herein. The inverted dilution refrigerator 1200 may include a pump system 1202 configured to circulate the $^3He/^4He$ mixture through the dilution refrigerator 1200. The inverted dilution refrigerator 1200 also may include a cryocooler 1204. The cryocooler may be coupled to a cryocooler support (not pictured) as described in connection with cryocooler support 103 herein.

In some embodiments, the inverted dilution refrigerator 1200 may include an outer vacuum chamber 1206 and a series of thermal stages 1208a-1208f disposed inside of the outer vacuum chamber 1206. The series of thermal stages 1208a-1208f may be held at same or similar temperatures as the thermal stages 108a-108f described in connection with FIG. 1 herein.

In some embodiments, the inverted dilution refrigerator 1200 may include an opening in the outer vacuum chamber 1206 and/or through the inner radiation shields to provide ease of access to the coldest stage of the inverted dilution refrigerator 1200. In some embodiments, the opening may comprise hermetic seals and/or an opening mechanism 1225 that may withstand the vacuum within the outer vacuum chamber when the inverted dilution refrigerator 1200 is in operation. For example, the opening mechanism 1225 may include a hinged door and/or a removable panel.

In some embodiments, the inverted dilution refrigerator 1200 may include a number of components arranged along the length of the dilution refrigerator (e.g., from within the vacuum chamber 1206 to within the sixth thermal stage 1208f). The components may be arranged with the coldest thermal stage, the mixing chamber ~~1222~~1224, disposed above warmer thermal stages (e.g., the still 1214, impedance stages 1212 and 1216, heat exchangers 1218, 1219, 1220, etc.).

In some embodiments, the inverted dilution refrigerator 1200 includes a de-mixing chamber ~~1224~~1222 coupled to the mixing chamber ~~1222~~1224. In some embodiments, the de-mixing chamber ~~1224~~1222 may be thermally coupled to the mixing chamber ~~1222~~1224 by a heat exchanger 1223 (e.g., a co-flow heat exchanger). The de-mixing chamber ~~1224~~1222 may be fluidly connected to the mixing chamber ~~1222~~1224 such that ^3He may be transported from the de-mixing chamber ~~1224~~1222 to the mixing chamber ~~1222~~1224 to provide additional cooling to the mixing chamber ~~1222~~1224. The de-mixing chamber ~~1224~~1222 may additionally have ^4He injected into the de-mixing chamber ~~1224~~1222 to

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provide a co-flow of ^{3}He and ^{4}He in order to mitigate a concentration gradient forming between the still 1214 and the mixing chamber ~~1222~~1224.

FIGs. 12B and 12C are schematic diagrams of exemplary internal components of an inverted dilution refrigerator, in accordance with some embodiments described herein. It should be appreciated that the exemplary components of FIGs. 12B and 12C could be implemented within inverted dilution refrigerator 1200 of FIG. 12A (e.g., within the third thermal stage 1208c).

As shown in the example of FIG. 12B, in some embodiments the inverted dilution refrigerator may include a ^{4}He line 1226 configured to transport ^{4}He from the still 1214 to the de-mixing chamber ~~1224~~1222. In some embodiments, the ^{4}He line 1226 may include a pump 1228 configured to assist in the transportation of the ^{4}He to the de-mixing chamber ~~1224~~1222. The pump 1228 may be, for example, a fountain pump in some embodiments. Alternatively or additionally, the ^{4}He line 1226 may include additional heat exchangers to cool the ^{4}He as it travels to the de-mixing chamber ~~1224~~1222.

As shown in the example of FIG. 12C, in some embodiments, the inverted dilution refrigerator may include a heat exchange stage 1230 configured to cool the incoming ^{3}He/^{4}He mixture prior to the primary impedance stage 1212. As should be appreciated from the description of FIG. 1, such a configuration may increase the efficiency of the first impedance stage and/or eliminate or reduce the need for pressurization of the incoming ^{3}He/^{4}He mixture.

V. Distributed Cooling

Dilution refrigerators generally include an integrated cryocooler (e.g., such as a pulse tube or a Gifford-McMahon cryocooler) to pre-cool the ^{3}He/^{4}He mixture gas below 5 K. Conventionally, a dilution refrigerator is paired with at least one of these cryocoolers, and dilution refrigerators do not share cooling systems. Such small-scale dilution refrigeration systems typically rely on low-power cryocooling systems that are relatively inefficient (e.g., requiring more power for each Watt of cooling power at 4 K) in comparison to larger, higher-power cryocooling systems. The inventors have recognized and appreciated that a single, high-efficiency cooling system may be thermally coupled to multiple cryogenic systems such as dilution refrigerators to distribute this first stage of cooling across multiple cryogenic systems. Such distributed cooling therefore allows for increased cooling efficiency across multiple cryogenic systems.

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FIG. 13 is a schematic diagram of a distributed cooling system 1300, in accordance with some embodiments described herein. The distributed cooling system 1300 may include multiple housings 1305. In some embodiments, the housings 1305 may be server rack-type containers (e.g., commercial server rack infrastructure, 19-inch server racks).

As shown in the example of FIG. 13, each housing 1305 may contain a cooling system 1310 or a cryogenic device 1320. It should be appreciated that cryogenic devices 1320 and/or cooling systems 1310 may be grouped within housings 1305, in some embodiments. It should further be appreciated that while FIG. 13 shows three cryogenic devices 1320 coupled to the cooling system 1310, in some embodiments, there may be two, four, ten, or many tens of cryogenic devices 1320 coupled to the cooling system 1310, as aspects of this disclosure are not so limited.

In some embodiments, the cooling system 1310 may be a cryocooling system configured to cool a first stage of the cryogenic devices 1320 to a temperature of at least 5 K and/or to a temperature of approximately 4-5 K. In some embodiments, the cooling system 1310 may be a pulse tube. For example, the cooling system 1310 may be a pulse tube, a helium liquefier system, and/or a Brayton cryocooler.

In some embodiments, the cooling system 1310 may be thermally coupled to multiple cryogenic devices 1320. Cooling may be distributed to cryogenic devices 1320 from cooling system 1310 by cooling line 1312. Additionally, heat may be returned from the cryogenic devices 1320 to cooling system by return 1314. The cooling line 1312 and/or return 1314 may be lines configured to transfer liquid and/or gaseous helium. For example, the cooling line 1312 and/or return 1314 may be pipes that are vacuum insulated to maintain the temperature of the transported helium. In some embodiments, the cooling line 1312 and/or return 1314 may be fill lines, heat pipes (e.g., traditional and/or pulsed heat pipes), and/or a superfluid loop.

In some embodiments, the cryogenic devices 1320 may include any suitable refrigeration system configured to reach temperatures at or below 5 K. In some embodiments, cryogenic devices 1320 may include one or more dilution refrigerators (e.g., dilution refrigerator 100 as described herein, configured to reach temperatures below 1 K). Alternatively or additionally, it should be appreciated that cryogenic devices 1320 may include cryogenic systems other than dilution refrigerators (e.g., microscopy systems such as scanning tunneling microscopy or atomic force microscopy systems, ^{3}He refrigeration systems, superconducting CMOS systems, etc.).

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In the embodiment shown in FIG. 14, the computer 1400 includes a processing unit 1401 having one or more processors and a non-transitory computer-readable storage medium 1402 that may include, for example, volatile and/or non-volatile memory. The memory 1402 may store one or more instructions to program the processing unit 1401 to perform any of the functions described herein. The computer 1400 may also include other types of non-transitory computer-readable medium, such as storage 1405 (e.g., one or more disk drives) in addition to the system memory 1402. The storage 1405 may also store one or more application programs and/or resources used by application programs (e.g., software libraries), which may be loaded into the memory 1402.

The computer 1400 may have one or more input devices and/or output devices, such as devices 1406 and 1407 illustrated in FIG. 14. These devices can be used, among other things, to present a user interface. Examples of output devices that can be used to provide a user interface include printers or display screens for visual presentation of output and speakers or other sound generating devices for audible presentation of output. Examples of input devices that can be used for a user interface include keyboards and pointing devices, such as mice, touch pads, and digitizing tablets. As another example, the input devices 1407 may include a microphone for capturing audio signals, and the output devices 1406 may include a display screen for visually rendering, and/or a speaker for audibly rendering, recognized text.

As shown in FIG. 14, the computer 1400 may also comprise one or more network interfaces (e.g., the network interface 1410) to enable communication via various networks (e.g., the network 1420). Examples of networks include a local area network or a wide area network, such as an enterprise network or the Internet. Such networks may be based on any suitable technology and may operate according to any suitable protocol and may include wireless networks, wired networks or fiber optic networks. Such networks may include analog and/or digital networks.

Various aspects of the embodiments described above may be used alone, in combination, or in a variety of arrangements not specifically discussed in the embodiments described in the foregoing and is therefore not limited in its application to the details and arrangement of components set forth in the foregoing description or illustrated in the drawings. For example, aspects described in one embodiment may be combined in any manner with aspects described in other embodiments.

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All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

The indefinite articles "a" and "an," as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean "at least one."

The phrase "and/or," as used herein in the specification and in the claims, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, a reference to "A and/or B," when used in conjunction with open-ended language such as "comprising" can refer, in one embodiment, to A only (optionally including elements other than B); in another embodiment, to B only (optionally including elements other than A); in yet another embodiment, to both A and B (optionally including other elements); etc.

As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements); etc.

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Use of ordinal terms such as "first," "second," "third," etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another or the temporal order in which acts of a method are performed, but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish the claim elements.

In the claims, as well as in the specification above, all transitional phrases such as "comprising," "including," "carrying," "having," "containing," "involving," "holding," "composed of," and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of" and "consisting essentially of" shall be closed or semi-closed transitional phrases, respectively.

The terms "approximately," "about," and "substantially" may be used to mean within ±20% of a target value in some embodiments, within ±10% of a target value in some embodiments, within ±5% of a target value in some embodiments, within ±2% of a target value in some embodiments. The terms "approximately," "about," and "substantially" may include the target value.

Having thus described several aspects of at least one embodiment, it is to be appreciated that various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure and are intended to be within the spirit and scope of the principles described herein. Accordingly, the foregoing description and drawings are by way of example only.

What is claimed is:

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Docket No.: M1567.70000US04
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	L. W. Nouketcha
Art Unit:	3763

Certificate of Electronic Filing under 37 C.F.R. § 1.8
I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: April 15, 2024 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

FIRST PRELIMINARY AMENDMENT UNDER 37 C.F.R. § 1.115

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Commissioner:

INTRODUCTORY COMMENTS

Prior to examination on the merits, please amend the above-identified U.S. patent application as follows:

Amendments to the Specification begin on page 2 of this amendment.

Remarks/Arguments begin on page 3 of this amendment.

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AMENDMENTS TO THE SPECIFICATION

Please enter the substitute specification filed herewith as permitted under 37 C.F.R. § 1.121(b)(3). Applicant is filing herewith both clean and marked-up copies as required under 37 C.F.R. § 1.125.

The substitute specification includes amendments to the recitation of certain reference numerals in the description of FIG. 12A. The amendments begin on page 28, line 22 of the substitute specification filed herewith. The amendments to the specification correct inadvertent typographical errors that incorrectly identified the de-mixing and mixing chambers of FIG. 12A.

Additionally, Applicant submits that the de-mixing and mixing chambers were identified correctly in the specifications of U.S. Provisional Application Nos. 63/219,795 and 63/319,248 from which the present application claims the benefit under 35 U.S.C. § 119(e) and which are each incorporated by reference within the present application such that no new matter is added by this amendment.

Attachments: Substitute Specification (Clean); and
Substitute Specification (Marked-Up)

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REMARKS

Applicant requests entrance of this amendment to amend the Specification of this Application. Applicant submits that no new matter is added to the Application by the Substitute Specification.

The pending application is believed to be in condition for substantive examination.

The Director is hereby authorized to charge any additional fees which may be required with this Amendment, or credit any overpayment, to Deposit Account No. 23/2825, under Docket No. M1567.70000US04.

Dated: April 15, 2024

Respectfully submitted,

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IPR2026-00291 - U.S. Patent No. 12,313,320

Corrected Application Data Sheet

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

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Correspondence Information

Correspondence Customer Number::	23628

Application Information

Application Number::	17/860,950
Filing Date::	07/08/22
Application Type::	Nonprovisional
Subject Matter::	Utility
CD-ROM or CD-R?::	None
Sequence submission?::	None
Computer Readable Form (CRF)?::	No
Title::	INTEGRATED DILUTION REFRIGERATORS
Attorney Docket Number::	M1567.70000US04
Request for Early Publication?::	No
Request for Non-Publication?::	No
Total Drawing Sheets::	23
Small Entity?::	Yes
Petition included?::	No
Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2::	No

Representative Information

Representative Customer Number::	23628

Domestic Priority Information

Application::	Continuity Type::	Parent Application::	Parent Filing Date::	Prior Appl Status::
This Application	Claims benefit of provisional	63/319248	03/11/22	~~Pending~~ Expired
This Application	Claims benefit of provisional	63/219795	07/08/21	~~Pending~~ Expired

Foreign Priority Information

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Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Sarah C. C. Schlotter/	Date (YYYY-MM-DD)	2024-04-15
Name	Sarah C.C. Schlotter, PhD	Registration Number	79,027

PTO/SB/92 (11-23)
Approved for use through 05/31/2024. OMB 0561-0031
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   OR

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/Morgan L. Ryan/	April 15, 2024
Signature	Date
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Typed or printed name	Telephone number

Note: Each paper must have its own certificate of mailing or transmission, or this certificate must identify each submitted paper:

Corrected Application Data Sheet (7 pages)

UNITED STATES
PATENT AND TRADEMARK OFFICE

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ELECTRONIC PAYMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	04/15/2024 12:23:06 PM Z ET	M1567.70000US04

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Morgan Ryan
PATENT CENTER #	65092361	AUTHORIZED BY	Sarah Schlotter
CUSTOMER #	23628	FILING DATE	07/08/2022
CORRESPONDENCE ADDRESS	-	FIRST NAMED INVENTOR	Corban Tillemann-Dick

Payment Information

PAYMENT METHOD	PAYMENT TRANSACTION ID	PAYMENT AUTHORIZED BY
CARD / 8543	E20244EC24048343	Morgan Ryan

FEE CODE	DESCRIPTION	ITEM PRICE($)	QUANTITY	ITEM TOTAL($)
2830	PROCESSING FEE, EXCEPT IN PROVISIONAL APPLICATIONS	56.00	1	56.00
			TOTAL AMOUNT:	$56.00

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

SUBSTITUTE SPECIFICATION CLEAN COPY

INTEGRATED DILUTION REFRIGERATORS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 63/319,248 filed on March 11, 2022, and titled "INTEGRATED DILUTION REFRIGERATORS," and of U.S. Provisional Patent Application No. 63/219,795 filed on July 8, 2021, and titled "INTEGRATED DILUTION REFRIGERATORS," the contents of each of which are incorporated by reference herein in their entirety.

BACKGROUND

Dilution refrigerators are cryogenic devices that rely on the heat of mixing of the ^{3}He and ^{4}He isotopes to provide cooling down to temperatures between approximately 2 mK and 1 K. Classic dilution refrigerators, or "wet" dilution refrigerators, precool the ^{3}He/^{4}He mixture using liquid nitrogen and ^{4}He baths before further cooling of the ^{3}He/^{4}He mixture below 4 K. Modern dilution refrigerators, or "dry" dilution refrigerators, precool the ^{3}He/^{4}He mixture using devices such as a cryocooler rather than cryogenic liquid baths.

SUMMARY

Some embodiments are directed to a dilution refrigerator comprising: an outer vacuum chamber comprising at least one substantially planar surface; and an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises a sample stage housed within the outer vacuum chamber, wherein the opening is configured to provide access to the sample stage through the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the sample stage are slidable and/or removable to provide access to the sample stage.

In some embodiments, the at least one substantially planar surface comprises a first surface disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator.

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In some embodiments, the at least one substantially planar surface comprises: first surfaces disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator; and second surfaces disposed within a plane parallel to the plane of the floor, wherein the first surfaces and the second surfaces are arranged as a rectangular prism.

In some embodiments, the opening comprises a hermetic opening.

In some embodiments, the opening comprises a hinged door.

In some embodiments, the dilution refrigerator further comprises one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the hinged door are slidable and/or removable to provide access to the interior of the outer vacuum chamber.

In some embodiments, the opening further comprises a load lock.

In some embodiments, the outer vacuum chamber comprises: a first section; and a second section suspended from the first section.

In some embodiments, the first section is coupled to the second section by integrated clamps and/or cams.

In some embodiments, the first and/or second section of the outer vacuum chamber are configured to be at least partially removed from the dilution refrigerator to provide access to an interior of the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises an external system configured to lift and/or lower the first and/or second section of the outer vacuum chamber.

In some embodiments, the external system comprises pneumatic and/or hydraulic devices configured to lift and/or lower the first and/or second sections.

In some embodiments, the external system comprises a screw mechanism configured to lift and/or lower the first and/or second sections.

In some embodiments, the outer vacuum chamber is configured to fit within a server rack-type container.

In some embodiments, the server rack-type container is configured to integrate with commercial server rack infrastructure.

In some embodiments, the server rack-type container is a 19-inch server rack.

In some embodiments, the server rack-type container comprises an external housing comprising an integrated horizontal surface.

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In some embodiments, the integrated horizontal surface is configured to be stowed when not in use.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing. In the drawings:

FIG. 1 is a schematic diagram of a closed-cycle dilution refrigerator, in accordance with some embodiments described herein.

FIG. 2 is a schematic diagram of helium cleaning devices in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 3 is a schematic diagram of a cooldown turbo charger device in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 4 is a schematic diagram of a still including a device to separate ^{3}He and ^{4}He using second sound effects, in accordance with some embodiments described herein.

FIG. 5A shows illustrative components of a removable dilution insert for the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 5B is a view of an illustrative thermalization plate insert of the removable dilution insert of FIG. 5A, in accordance with some embodiments described herein.

FIG. 5C is a cross-sectional view of an illustrative integrated heat exchanger showing channels for helium flow, in accordance with some embodiments described herein.

FIG. 5D is an image of a high surface area material for use in an integrated heat exchanger, in accordance with some embodiments described herein.

FIG. 5E is an illustrative implementation of a continuous heat exchanger and discrete heat exchanger of the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIGs. 6A-6F are schematic diagrams of illustrative ^{4}He film separation devices, in accordance with some embodiments described herein.

FIG. 7A is an image of sintered metal particles for use in a heat exchanger.

FIG. 7B is an image of nanowires for use in a heat exchanger, in accordance with some embodiments described herein.

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FIG. 7C is an image of a nanocluster for use in a heat exchanger, in accordance with some embodiments described herein.

FIG. 7D includes images of different nanopellets for use in a heat exchanger in accordance with some embodiments described herein.

FIG. 8A is a schematic diagram of an illustrative vibration isolation system for use in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 8B shows an illustrative spring for use in the vibration isolation system of FIG. 8A, in accordance with some embodiments described herein.

FIG. 9 is a side view of an illustrative external support rack and integrated lift configured to raise and lower portions of the vacuum chamber, in accordance with some embodiments described herein.

FIG. 10A is a side view of an illustrative implementation of the dilution refrigerator of FIG. 1 including elements configured to provide tool-free assembly of the vacuum chamber and access to the experimental volume, in accordance with some embodiments described herein.

FIGs. 10B and 10C are views of integrated latches in open and closed positions, respectively, configured to provide tool-free assembly of the vacuum chamber, in accordance with some embodiments described herein.

FIG. 11 is an exterior view of a housing configured to support a dilution refrigerator, in accordance with some embodiments described herein.

FIG. 12A is a schematic diagram of an inverted dilution refrigerator, in accordance with some embodiments described herein.

FIGs. 12B and 12C are schematic diagrams of illustrative components of an inverted dilution refrigerator, in accordance with some embodiments described herein.

FIG. 13 is a schematic diagram of a distributed cooling system, in accordance with some embodiments described herein.

FIG. 14 depicts, schematically, an illustrative computing device on which aspects of the technology described herein may be implemented.

DETAILED DESCRIPTION

Dilution refrigerators are cryogenic devices that can provide cooling down to temperatures between approximately 2 mK and 1 K and are used in a variety of

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applications requiring these extremely low temperatures. For example, dilution refrigerators can be used to support quantum computing (e.g., superconducting quantum computing technologies and qubits) and low-temperature condensed matter physics research, among other applications.

As described above, dilution refrigerators rely on the heat of mixing of ^{3}He and ^{4}He isotopes to provide cooling. When cooled below approximately 870 mK, a ^{3}He/^{4}He mixture undergoes spontaneous phase separation to form a ^{3}He-rich phase (the "concentrated" phase) and a ^{3}He-poor phase (the "dilute" phase). These two phases are maintained in equilibrium in a mixing chamber, the coldest part of the dilution refrigerator, and are separated by a phase boundary. In the mixing chamber, the ^{3}He is diluted as it moves from the concentrated phase through the phase boundary into the dilute phase, and the heat necessary for this endothermic dilution process provides the cooling power of the dilution refrigerator.

However, conventional dilution refrigerators can suffer from a multitude of drawbacks and failure points. For example, wet dilution refrigerators require significant amounts of liquid cryogens, which are costly to maintain and supply. As another example, dry dilution refrigerators can be subject to unwanted mechanical vibrations introduced by the cryocooler system and/or may draw large amounts of energy to power the cryocooler.

Conventional dilution refrigerators also typically occupy a large footprint, which may be prohibitive for applications requiring multiple dilution refrigerators. For example, a single conventional dry dilution refrigerator typically requires approximately 300 square feet and ceiling heights between 12 and 14 feet. This space is occupied not only by the dilution refrigerator itself but is also required to support any auxiliary systems such as pumps, compressors, water cooling systems and/or cryocooler systems.

The inventors have recognized and appreciated that, for quantum computing and other quantum technologies to be easily scalable, the quantum technology industry needs reliable, easy-to-use, easy-to-maintain, and compact dilution refrigerators. Accordingly, the inventors have developed dilution refrigerators and distributed cooling systems that can be integrated with commercially available server rack infrastructure (e.g., 19-inch server racks). Additionally, the inventors have developed a number of features, described herein, to ease maintenance of the dilution refrigerators, speed cooling of the dilution refrigerators without the use of mechanical pumps, and to reduce the transmission of mechanical vibrations to the experimental volume of the dilution refrigerator.

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I. Improved Closed-Cycle Dilution Refrigerator

FIG. 1 is a schematic diagram of a dry, closed-cycle dilution refrigerator 100, in accordance with some embodiments described herein. In some embodiments, the dilution refrigerator 100 includes an outer vacuum chamber 106 at room temperature (e.g., approximately 300K) and a number of thermal stages 108a-108f (e.g., thermalization plates) held at decreasing temperature intervals (e.g., approximately 50 K, 9-10 K, 3 K, etc.). For example, the first thermal stage 108a may be at approximately 50 K, the second thermal stage 108b may be at approximately 9-10 K, the third thermal stage 108c may be at approximately 3-4 K, the fourth thermal stage 108d may be at approximately 800 mK, the fifth thermal stage 108e may be at approximately 100 mK, and the sixth thermal stage 108f may be at approximately 10 mK.

In some embodiments, the dilution refrigerator 100 may include a pump system 102 that pressurizes a $^3He/^4He$ gas mixture (e.g., to a pressure at or near 1 bar). The $^3He/^4He$ gas mixture may enter the outer vacuum chamber 106 through one or more inlets and thereafter may travel through the inner thermal stages 108a-108f through the condensing line 102a. After performing its cooling function, the $^3He/^4He$ mixture may return to the pump system through the return 102b.

In some embodiments, the $^3He/^4He$ mixture may be purified prior to traveling along the condensing line 102a through the thermal stages 108a-108f. Contaminants in the helium flowing through the dilution refrigerator can clog certain components (e.g., the Joule-Thomson expander or capillaries in the heat exchangers) and lead to performance degradation or system failure. Conventionally, to reduce the risk of contaminants making their way into the system, helium is first passed through an external 'cleaning trap' filled with activated charcoal before entering the dilution unit of the dilution refrigerator. These external traps must be surrounded by liquid nitrogen and refilled at frequent intervals, which requires user maintenance and interaction.

The inventors have recognized and appreciated that passive helium filters, without the need for refilling of liquid nitrogen, can improve the user experience and reduce maintenance frequency of a dilution refrigeration system. Accordingly, in some embodiments, the dilution refrigerator 100 includes one or more helium cleaning devices 110. In some embodiments, where the dilution refrigerator 100 includes two or more helium cleaning devices 110, the dilution refrigerator 100 may further include a switching

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system 109 configured to direct the flow of the helium to a single helium cleaning device 110.

FIG. 2 shows a schematic diagram of helium cleaning devices 110, in accordance with some embodiments described herein. The helium cleaning devices 110 may be coupled to the pump system 102 by a switching system 109 that is disposed outside of the outer vacuum chamber 106. The switching system 109 may include one or more helium-compatible valves. The switching system 109 may be configured to switch helium flow between each of the helium cleaning devices 110. In this manner, one helium cleaning device 110 may be used for actively filtering helium while the dilution refrigerator is in operation while the other helium cleaning device may be cleaned (e.g., by heating and pumping out of impurities), enabling indefinite periods of operation of the dilution refrigerator 100.

In some embodiments, the helium cleaning devices 110 include a counter flow heat exchanger 110a, a trap 110b, and a weak thermal contact 110c (e.g., a gas gap heat exchanger, a low thermal conductivity attachment, etc.). The counter flow heat exchanger 110a and the weak thermal contact 110c may reduce the thermal load of the helium cleaning devices 110 on the dilution refrigerator 100 and may eliminate the use of cryogenic valves in the helium cleaning devices 110. The trap 110b may include, for example, a high surface area material (e.g., charcoal, activated charcoal, and/or a metal powder) configured to capture non-helium impurities in the dilution refrigerator 100.

Returning to FIG. 1, in some embodiments, the dilution refrigerator 100 may include a cooldown turbo charger device 111. Dry dilution refrigerators conventionally use an auxiliary compressor to enable the flow of warm helium, which initially has a high impedance and resists such movement. The extra pressure from the auxiliary compressor also pressurizes the helium, causing the helium to reach a pressure that starts isenthalpic expansion and cooling at a higher temperature. These auxiliary mechanical compressor pumps are costly, prone to reliability issues, frequently leak, and can cause performance degradation over time. The inventors have recognized and appreciated that, alternatively, the helium may be pulsed through the dilution refrigerator during cooldown without the use of an auxiliary mechanical pump, enabling a faster and more efficient cooldown process.

FIG. 3 shows a schematic diagram of a cooldown turbo charger device 111, in accordance with some embodiments described herein. The cooldown turbo charger device

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111 may include a volume of a high surface area material 111a, a heater 111b, a first valve 111c, and a second valve 111d. The first and second valves 111c, 111d may be, for example, cold valves located inside the vacuum chamber 106. As another example, the first and second valves 111c, 111d may be room temperature valves located outside of the vacuum chamber 106. In some embodiments, the heater 111b and the first and second valves 111c, 111d may be communicatively coupled to a controller 330. The controller 330 may be, for example, a computer as described in connection with FIG. 14 herein.

In some embodiments, the cooldown turbo charger device 111 may be thermally coupled to a thermal stage (e.g., to a thermalization plate). In the example of FIG. 3, the high surface area material 111a is thermally coupled to the second thermal stage 108b, though it should be appreciated that the high surface area material 111a could be thermally coupled to another thermal stage in some embodiments (e.g., first thermal stage 108a).

Alternatively, in some embodiments, the cooldown turbo charger device 111 may be thermally coupled to multiple thermal stages (e.g., across two or more thermal stages 108a-108f). In such embodiments, the sequential heating and cooling of the high surface area material 111a may be mediated by heat switches. For example, the cooldown turbo charger device 111 may be switchably thermally coupled between a warmer thermal stage and a colder thermal stage such that the cooldown turbo charger device 111 may be thermally coupled to either the warmer thermal stage or the colder thermal stage. When the cooldown turbo charger device 111 is thermally coupled to the warmer thermal stage, the high surface area material 111a may release any adsorbed helium. When the cooldown turbo charger device 111 is thermally coupled to the colder thermal stage, helium may begin adsorbing to the high surface area material 111a. In this manner, a sequential flushing of helium through the condensing line 102a may be implemented.

In some embodiments, the high surface area material 111a may comprise a material with a porous and/or textured surface such that helium adsorbs to the high surface area material 111a during the cooldown process. For example, the high surface area material 111a may comprise activated charcoal, a metal powder (e.g., a copper or silver powder), and/or a material composite formed of nanostructures (e.g., nanowires, nanoparticles, etc.).

In some embodiments, the cooldown turbo charger device 111 may be operated using a sequential opening and closing of the valves 111c, 111d in concert with operation of the heater 111b. For example, to cause helium to adsorb the high surface area material 111a, the first valve 111c may be closed to prevent helium from flowing to the lower stages

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of the dilution refrigerator 100 and the second valve 111d may be opened to allow helium to reach the high surface area material 111a. The first valve 111c may be closed and the second valve 111d may be opened by the controller 330 in response to a measured pressure or temperature or in response to a timing signal generated by controller 330.

In some embodiments, after sufficient helium has adsorbed onto the high surface area material 111a, the second valve 111d may be closed and the first valve 111c may be opened. The first and second valves 111c, 111d may be opened and/or closed in response to measured temperatures or pressures and/or in response to a timing signal generated by controller 330.

In some embodiments, when the second valve 111d is closed and the first valve 111c is opened, the heater 111b may also be caused, at a same or similar time, to heat the high surface area material 111a in response to a signal generated by controller 330. For example, the heater 111b may be a resistive heater that is caused to heat the high surface area material 111a by a flow of current through the heater 111b. In response to the heat from the heater 111b, the helium adsorbed to the high surface area material 111a may act as a reserve that is then released from the high surface area material 111a. This release of the adsorbed helium may increase the pressure in the remainder of the condensing line 102a, and the increased pressure may enable the start of isenthalpic expansion to speed cooling of the dilution refrigerator 100.

In some embodiments, once the helium has been released from the high surface area material 111a, the first valve 111c may be closed, the second valve 111d may be opened, and the heater 111b may be turned off by the controller 330, allowing new helium to adsorb to the high surface area material 111a. The controller 330 may be configured to periodically (e.g., at regular time intervals, at irregular time intervals, at time intervals determined by the temperature of the experimental volume, at time intervals determined by the pressure of the experimental volume) open and/or close the valves 111c, 111d and to operate the heater 111b to flush the helium intake path. In some embodiments, the controller 330 may be configured to "pulse" the helium from the high surface area material 111a through the condensing line 102a, causing the dilution refrigerator to be cooled.

Returning to FIG. 1, during operation of the dilution refrigerator, the $^3He/^4He$ mixture may be progressively cooled as it travels along the condensing line 102a from the first thermal stage 108a to the mixing chamber 122. At the first thermal stage, the helium may be initially cooled to approximately 50 K. After exiting the cooldown turbo charger

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device, the $^3He/^4He$ mixture may next be cooled by a cryocooler 104. A portion of the cryocooler 104 may be disposed partially outside of the outer vacuum chamber 106, in some embodiments. The cryocooler 104 may be vibrationally isolated from outer vacuum chamber 106 by a vibration isolation stage 105, which may comprise padding and/or any other suitable vibration isolation techniques.

In some embodiments, the cryocooler 104 may be coupled to a cryocooler support 103. The cryocooler support 103 may be, for example, a compressor and/or compression system, in some embodiments. The cryocooler support 103 may include cooling members 103a, in some embodiments, configured to provide air-cooling to the dilution refrigerator 100. The cooling members 103a may be, as a non-limiting example, cooling fins, fans, and/or heat pipes configured to remove waste heat generated by the cryocooler support 103 and/or the cryocooler 104.

The cooling members 103a are in contrast to conventional closed-cycle dilution refrigerators, which typically rely on water-cooling to remove waste heat generated by the integrated cryocooler. Water-cooling of the cryocooler, however, requires installing a large and/or expensive water-cooling system in conjunction with the dilution refrigerator. Additionally, such water-cooling systems are not typically integrated with commercial computing facilities, which typically rely on air-cooling as it is less expensive and does not present hazards (e.g., leaking coolant, flooding, etc.) to the electronic equipment. The inventors have accordingly recognized that using air-cooling to remove heat from the cryocooler of the dilution refrigerator may reduce the costs of manufacturing dilution refrigerators and enable their use in commercial computing facilities.

In some embodiments, the dilution refrigerator 100 may be disposed above a plenum (not pictured) disposed under a floor supporting the dilution refrigerator. The plenum may supply the cooling members 103a with air flow to provide air-cooling. In some embodiments, the cooling members 103a may include inlets and/or louvers configured to draw in air from the plenum. Alternatively or additionally, in some embodiments, the dilution refrigerator 100 may be disposed in a facility including ductwork and/or heat pipes (not pictured) arranged to remove heat from the cooling members 103a, the cryocooler support 103, and/or the cryocooler 104 and to minimize vibrations experienced by the dilution refrigerator 100.

In some embodiments, the $^3He/^4He$ mixture may be cooled by the cryocooler 104 in two steps. The condensing line 102a may be wound around two portions of the

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cryocooler 104 to effect heat exchange between the $^3He/^4He$ mixture in the condensing line 102a and the cryocooler 104. In a first step, the $^3He/^4He$ mixture may be cooled to approximately 10 K by the cryocooler 104. In a second step, the $^3He/^4He$ mixture may be cooled to approximately 3-4 K by the cryocooler 104.

In some embodiments, after being cooled by the cryocooler 104, the $^3He/^4He$ mixture may pass through the third thermal stage 108c. The third thermal stage 108c may be thermally coupled but mechanically decoupled from cryocooler 104, in some embodiments, in order to provide vibration isolation to the later thermal stages 108d-108f. As a non-limiting example, in some embodiments, third thermal stage 108c may be mechanically decoupled from the cryocooler by a copper braid, heat strap, or other hanging component configured to maintain thermal coupling between the third thermal stage 108c and the cryocooler 104.

In some embodiments, after passing through the third thermal stage 108c, the $^3He/^4He$ mixture may enter a primary impedance stage 112. The primary impedance stage 112 may be a Joule-Thomson expander configured to reduce the temperature and/or pressure of the $^3He/^4He$ mixture. For example, in some embodiments, the $^3He/^4He$ mixture may be at approximately 3-5 K before entering the primary impedance stage 112 and may be at approximately 1 K after exiting the primary impedance stage 112.

In some embodiments, the primary impedance stage 112 may be a Joule-Thomson expander formed from a fiber optic cable. Conventionally, Joule-Thomson expanders may be formed as metal tubes that are manufactured by pulling. However, such metal Joule-Thomson expanders may suffer from irregularities and/or may have a larger diameter that reduces the cooling power of the device. A hollow-core fiber optic cable may reliably and reproducibly provide the narrow opening needed for a Joule-Thomson expander.

In some embodiments, the dilution refrigerator 100 may include a bypass device 113a configured to increase the speed of cooldown of the dilution refrigerator 100. For example, during the initial cooldown of a dilution refrigerator, the helium flow rate may be low due to the large impedance of Joule-Thomson expanders in the dilution refrigerator and the warm, low density, and viscous circulating helium. This reduced helium flow rate reduces the rate of cooling of the lower portions of the refrigerator. To combat this effect, conventionally, a needle valve may be incorporated at a location on the condensing line above the Joule-Thomson expander to reduce the impedance of the initially-warm helium gas. However, the needle valve includes mechanical components that may fail over time.

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The inventors have recognized and appreciated that the helium flow rate may be improved without reliance on a mechanical component such as a needle valve.

In some embodiments, the bypass device 113a may be disposed along the condensing line 102a in parallel with the primary impedance stage 112 and on a bypass line 113b that bypasses the primary impedance stage 112 (e.g., allowing the $^3He/^4He$ mixture to flow around the primary impedance stage 112). The bypass device 113a may include a sheet of vacuum-compatible material configured to allow helium to diffuse through the material at temperatures above a threshold temperature value. For example, the bypass device 113a may allow the $^3He/^4He$ mixture to diffuse through the bypass device 113a at temperatures in a range from approximately 40 K to 300 K, in a range from 50 K to 300 K, in a range from 80 K to 300 K, in a range from 100 K to 300 K, in a range from 150 K, or in any range within those ranges. In some embodiments, the bypass device 113a may include a sheet of a vacuum-compatible polymer material. For example, the bypass device 113a may be formed of a sheet of Kapton, PEEK, and/or mylar, as some non-limiting examples. The bypass device 113a therefore allows for the high impedance of the primary impedance stage 112 to be circumvented when the $^3He/^4He$ mixture is warm, thereby increasing the helium flow rate and rate of cooling of the dilution refrigerator 100. When the dilution refrigerator 100 has cooled sufficiently (e.g., to below the threshold temperature value), the $^3He/^4He$ mixture will no longer diffuse through the bypass device 113a and instead will flow through the primary impedance stage 112.

In some embodiments, after exiting the primary impedance stage 112 or the bypass device 113a, the $^3He/^4He$ mixture then travels past the fourth thermal stage 108d and into the still 114. The still 114 may contain a different mixture of liquid $^3He/^4He$ that cools the incoming $^3He/^4He$ mixture as it passes through the condensing line 102a running through the still 114. In some embodiments, the $^3He/^4He$ mixture in the condensing line may be cooled to approximately 400-900 mK by the still 114.

In some embodiments, the still 114 may include a membrane configured to use second sound to improve ^3He evaporation within the still. Second sound is a superfluid phenomenon present in superfluid helium and may be produced, for example, when a porous membrane is oscillated or a heated wire is cycled within a bath of superfluid helium. The two-fluid model specifies that the superfluid helium in the mixture moves through the membrane while non-superfluid components of the helium bath cannot pass through the porous membrane as easily. In superfluid helium, this creates an enthalpy or

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temperature wave. Analogously in helium mixtures, the non-superfluid ^{3}He may be preferentially pushed by the oscillating membrane while the superfluid ^{4}He remains relatively stationary. The inventors have recognized and appreciated that this second sound phenomenon can be implemented within the still 114 to increase the ^{3}He evaporation rate at a lower temperature and to reduce a concentration of ^{4}He in the vapor above the liquid helium mixture in the still.

FIG. 4 is a schematic diagram of a still 400 including a device to separate ^{3}He and ^{4}He using second sound effects, in accordance with some embodiments described herein. The still 400 may be implemented as still 114 of dilution refrigerator 100, in some embodiments. The still 400 may include a stationary surface 402 and a porous, movable membrane 404. The porous membrane 404 may be oscillated along the Z direction to create standing concentration waves of ^{3}He within the still so that there are regions 406 of lower ^{3}He concentration and regions 408 of high ^{3}He concentration. The standing wave may be tuned such that regions 408 of high ^{3}He concentration are disposed adjacent an outlet of the still, thereby allowing for improved ^{3}He purification.

Returning to FIG. 1, in some embodiments, after exiting the still 114, the ^{3}He/^{4}He mixture may flow through the condensing line 102a to a secondary impedance stage 116. The secondary impedance stage 116 may be configured to ensure that only liquid ^{3}He/^{4}He proceeds further downstream in the dilution refrigerator 100 and that gas cavitation in the still 114 does not occur (e.g., by maintaining a threshold pressure in the still 114). The secondary impedance stage 116 may therefore reduce downstream cooling loads due to a latent heat of gaseous ^{3}He/^{4}He.

In some embodiments, after exiting the secondary impedance stage 116, the ^{3}He/^{4}He mixture may then flow into a first heat exchanger 118. The first heat exchanger 118 may be a continuous heat exchanger. For example, the first heat exchanger 118 may be a counterflow (e.g., a tube-tube heat exchanger), a cross-counterflow, and/or coflow heat exchanger. At the exit of the first heat exchanger 118, the ^{3}He/^{4}He mixture in the condensing line 102a may be cooled to a temperature of approximately 20 mK.

In conventional closed-cycle dilution refrigerators, prior to entering the still, the ^{3}He/^{4}He mixture in the condensing line typically must pass through a first impedance stage. This first impedance stage typically acts as an independent refrigeration stage, known as a Joule-Thomson refrigerator, where the ^{3}He/^{4}He mixture is cooled by isenthalpic expansion. In order to control the cooling power of the ^{3}He/^{4}He mixture

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expansion, the pressure of the $^3He/^4He$ mixture in the condensing line is typically raised by an external compressor.

The inventors have recognized and appreciated that reducing the temperature of the $^3He/^4He$ mixture prior to entering the first impedance stage can achieve the same cooling effect (e.g., the $^3He/^4He$ mixture can reach the same base temperature after passing through the first impedance stage) while using a lower pressure differential. Such a configuration can improve the efficiency of the dilution refrigerator and reduce or eliminate the need to pressurize the $^3He/^4He$ mixture before the first impedance stage. Further, the inventors have recognized that the heat removed from the $^3He/^4He$ mixture prior to the first impedance stage can be returned to the still, thereby eliminating or reducing the need for a supplemental heater within the still to raise the vapor pressure, and enabling evaporation, of the different $^3He/^4He$ mixture present in the still.

Accordingly, in some embodiments, the dilution refrigerator 100 may include a heat exchange line 117 configured to transfer heat from the incoming condensing line 102a to a return helium mixture being transported from the first heat exchanger 118 to the still 114. The heat exchange line 117 may cool the condensing line 102a at a location above the primary impedance stage 112. The heat exchange line 117 then cools the $^3He/^4He$ mixture in the condensing line 102a prior to entering the primary impedance stage 112. Thereafter, the warmed mixture in the heat exchange line 117 is transported to the still 114.

Cooling the incoming $^3He/^4He$ mixture before it enters the primary impedance stage 112 causes the primary impedance stage 112 to output a $^3He/^4He$ mixture with a higher proportion of ^3He in the liquid state rather than in the vapor state. Thus, the primary impedance stage 112 can be made more efficient by including the additional heat exchange line 117. Additionally, this improved efficiency eliminates or mitigates the need for supplemental pressure (e.g., an external compressor) and may lower the flow impedance of the circulating helium mixture. This is particularly useful in reducing the complexity and size of smaller dilution refrigerators that include smaller (i.e., less powerful) pulse tubes or other cryocoolers.

In some embodiments, after exiting the first heat exchanger 118, the $^3He/^4He$ mixture passes through the fifth thermal stage 108e and enters continuous heat exchanger 119. The continuous heat exchanger 119 may be a counterflow (e.g., a tube-tube heat exchanger), a cross-counterflow, and/or coflow heat exchanger. The continuous heat

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exchanger 119 is disposed below the fifth thermal stage 108e. The fifth thermal stage 108e may be an intermediate cold plate (ICP) configured to be cooled to a temperature of approximately 100-200 mK. While continuous heat exchangers are typically more efficient than discrete heat exchangers, they become less efficient below a temperature of approximately 80 mK. However, adding continuous heat exchanger 119 below the fifth thermal stage 108e may enable the fifth thermal stage 108e to operate with more cooling power during the process of cooling down the dilution refrigerator.

In some embodiments, after exiting the continuous heat exchanger 119, the ^{3}He/^{4}He mixture enters discrete heat exchangers 120. The discrete heat exchangers 120 may be formed of sintered nanoparticles, in some embodiments. Alternatively or additionally, in some embodiments the discrete heat exchangers 120 may be formed of sintered nanowires, as described herein in connection with FIGs. 7A-7D herein. The discrete heat exchangers 120 may be configured to further cool the ^{3}He/^{4}He mixture to a temperature below approximately 10-20mK.

The inventors have additionally recognized and appreciated that the user experience may be improved by allowing users to easily swap parts in and out of the dilution refrigerator 100 (e.g., for maintenance, to change the characteristics of the dilution refrigerator 100, and/or to upgrade the dilution refrigerator 100 as technological innovations are developed). The inventors have accordingly developed a swappable dilution insert that is easily removed and replaced. FIG. 5A shows illustrative components of a removable dilution insert 540 for the dilution refrigerator 100 of FIG. 1, in accordance with some embodiments described herein.

In some embodiments, the removable dilution insert 540 includes detachable plates 540a, 540b, 540c removably coupled to thermal stages 108d, 108e, and 108f, respectively. As shown in the example of FIG. 5A, the detachable plates 540a, 540b, and 540c may be removably coupled using mechanical fasteners (e.g., bolts and/or screws). In some embodiments, the removable dilution insert 540 further includes detachable connections 540d above the still (e.g., flanges) and to the condensing line 102a to further simplify replacement of the removable dilution insert 540.

FIG. 5B shows a close-up view of a detachable plate 540b of the removable dilution insert of FIG. 5A, in accordance with some embodiments described herein. The detachable plate 540b includes an input A and an outlet B to allow helium to flow through the detachable plate 540b, in some embodiments.

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In some embodiments, the detachable plates 540a, 540b, and/or 540c may include integrated heat exchangers. In some embodiments, the integrated heat exchangers may be channels 542 formed in the detachable plates 540a and/or 540b, as illustrated by the example of FIG. 5C, which shows a cross section through the detachable plate 540b of FIG. 5B. The channels 542 may be configured to have a high surface area. By allowing helium to flow through the channels 542 in the detachable plates 540a and/or 540b, the helium's rate of cooling may be increased. In some embodiments, the channels 542 may be formed by machining, welding, and/or by additive fabrication techniques (e.g., three-dimensional printing techniques).

In some embodiments, the integrated heat exchangers may be a high surface area material structure formed in the detachable plate 540c. For example, the integrated heat exchangers may be a lattice structure, as shown in the example of FIG. 5D. The lattice structure may be, as a non-limiting example, a square lattice structure having a periodicity in a range from approximately 400 μm to approximately 1000 μm. For example, the lattice structure may have a periodicity of approximately 600 μm.

In some embodiments, the lattice structure may be fabricated using additive fabrication techniques (e.g., three-dimensional printing techniques). The lattice structure may be fabricated to have a rough surface texture to increase the surface area of the material in contact with the helium mixture passing through the integrated heat exchanger, thereby improving heat exchange. In some embodiments, the lattice structure may be formed of a metal. As non-limiting examples, the lattice structure may be formed of copper, silver, and/or aluminum.

In some embodiments, the dilution insert 540 may include one or more heat exchangers, as described in connection with dilution refrigerator 100 of FIG. 1. FIG. 5E shows an illustrative implementation of a continuous heat exchanger 119 and discrete heat exchanger 120, in accordance with some embodiments described herein. As shown in FIG. 5E, the helium flows from the detachable plate 540b coupled to fifth thermal stage 108e into the continuous heat exchanger 119 followed by the discrete heat exchanger 120 and the detachable plate 540c.

Refrigeration cycles in cryogenic coolers typically use a method to control the flow of heat throughout the system. This control may be achieved with a superconductor, a gas gap, or other mechanisms to make or break a thermal connection between components within the system (i.e., heat switches). One common type of heat switch, a gas gap,

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typically comprises two high surface area objects with a small gap between them that is filled with a gas. As the system falls below a certain temperature, the conductive gas is adsorbed onto surface area in the heat switch, creating a vacuum and reducing heat transfer between the surfaces. Another common type of heat switch is a superconducting switch where a material passes through a superconducting transition and reduces thermal conductivity.

In some embodiments, the dilution refrigerator 100 may further include combined gas gap and/or superconducting heat switches between thermal stages of the dilution refrigerator 100. The example of FIG. 5E shows such a combined gas gap and superconducting heat switch 550 thermally coupled between thermal stages 108e and 108f. The combined gas gap and superconducting heat switches 550 include both a superconducting material (e.g., aluminum, titanium) that becomes superconducting at a temperature higher than a target temperature of the thermal stage to which it is thermally coupled and a gas gap heat switch to improve thermal isolation between the thermal stages.

Returning to FIG. 1, after the $^{3}He/^{4}He$ mixture exits the discrete heat exchanger 120, it passes through the sixth thermal stage 108f and enters the mixing chamber 122. In the mixing chamber 122, ^{3}He atoms may be pumped from a concentrated phase into a dilute phase (i.e., mixed with ^{4}He). This mixing causes the ^{3}He to be cooled as it passes through the phase transition between the concentrated phase to the dilute phase, and this endothermic phase transition provides the final cooling power of the dilution refrigerator 100.

In some embodiments, an experimental volume 124 (e.g., a sample stage or plate) may be thermally coupled to the mixing chamber 122 and configured to support a sample and/or quantum device. Because the experimental volume 124 is thermally coupled to the mixing chamber 122, the sample and/or quantum device may be held at or near the mixing chamber temperature.

In some embodiments, the experimental volume 124 may be accessed by the user when the dilution refrigerator 100 is not in operation through an opening in the vacuum chamber 106 and door 125. The door 125 may be, in some embodiments, a removable panel (e.g., secured with mechanical fasteners) or may be a hinged door that a user may open using a clamped handle (e.g., as shown in the example of FIG. 10A herein).

As illustrated in the example of FIG. 1, certain components of the dilution refrigerator 100 may be thermally coupled to a thermal stage and disposed on one side

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(e.g., above or below) the thermal stage. For example, the still 114 is shown as being disposed on a lower surface of the fourth thermal stage 108d. It should be appreciated that in some embodiments, such components may be disposed on either side of the associated thermal stage, as aspects of the technology described herein are not limited in this respect. For example, in some embodiments the still 114 may be disposed on an upper surface of the fourth thermal stage 108d. As another example, the helium cleaning devices 110 may be disposed on a lower surface of the first thermal stage 108a, in some embodiments.

In some embodiments, after entering the dilute phase, the ^{3}He/^{4}He mixture may be pumped out of the mixing chamber 122 and back through the dilution refrigerator 100, exiting the outer vacuum chamber 106 through return 102b. At low temperatures and pressures, ^{4}He forms a thick and mobile film that can move long distances across surfaces, including moving in a direction counter to the force of gravity. This helium creep can result in ^{4}He entering portions of a dilution refrigeration system where it is unwanted (e.g., spanning the gap between thermally isolated areas). FIGs. 6A-6F are schematic diagrams of exemplary ^{4}He separation devices that may be implemented at outlets in, for example, the mixing chamber 122 and/or the still 114, in accordance with some embodiments described herein.

FIG. 6A illustrates a cooling stage 600 (e.g., a still, the mixing chamber, etc.) including a bath 602 of a dilute phase helium mixture (e.g., a ^{3}He /^{4}He mixture), in some embodiments. ^{4}He can creep up an outlet pipe (e.g., a still pumping outlet pipe, a mixing chamber outlet pipe) and exit the cooling stage 600 unless a barrier 606 prevents the helium creep. In the example of FIG. 6A, barrier 606 comprises a sharp edge at a right-angled surface configured to prevent helium from exiting the cooling stage 600 through the low pressure pumping outlet.

Other embodiments of a barrier configured to prevent ^{4}He creep are shown in the examples of FIGs. 6B, 6C, 6D, and 6E. In the example of FIG. 6B, a ring 608 with a knife edge 609 is configured to prevent ^{4}He from exiting through the ^{3}He outlet. In some embodiments, the ring 608 may include a heating device (e.g., a resistive heater or any other suitable heater) configured to cause the creeping ^{4}He to leave the superfluid phase, thereby mitigating creep.

In the examples of FIGs. 6C, 6D, and 6E, vertical knife edges are used to prevent ^{4}He from exiting through the ^{3}He outlet. In some embodiments, and in the example of FIG. 6C, the knife edge 610 is on the exterior circumference of the outlet pipe. Alternatively,

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as shown in the example of FIG. 6D, the knife edge 611 may be beveled on the interior circumference of the outlet pipe. Further, as shown in the example of FIG. 6E, the knife edge 612 may be beveled on both the exterior and interior circumferences of the outlet pipe.

In some embodiments, and as shown in the example of FIG. 6F, the ^{3}He outlet may include a p-trap 621 configured to collect ^{4}He 622 at a lower surface of the p-trap 621. The ^{3}He outlet may include a normal leak or a superleak 624 configured to allow normal or superfluid ^{4}He to exit the p-trap 621, and a pump 626 (e.g., a fountain pump) may transport the ^{4}He away from the p-trap 621. In some embodiments, a further barrier 627 may be present on an interior surface of the outlet pipe. For example, the barrier 627 may be configured as a ring. In some embodiments, the barrier 627 may include a heating device to further prevent ^{4}He from exiting the outlet.

The inventors have recognized and appreciated that nanomaterials can provide advantages compared to conventional sintered metal powders (e.g., silver and/or copper powder) used in typical discrete heat exchangers. Accordingly, the inventors have developed nanomaterial heat exchangers that provide efficient heat exchange because of the nanomaterials' large surface area, high mechanical contact strength, and good neck growth between nanowires.

Typical discrete heat exchangers are commonly made out of sintered metal power (e.g., silver and/or copper powder). An example of such sintered particulates is shown in FIG. 7A. To have efficient heat exchange at the sub-Kelvin temperatures, however, a number of factors must be true with regards to the heat exchanger materials. The heat exchange material should have a large surface area, provide high mechanical and/or thermal contact between the liquid helium and the heat exchange material, allow for good neck growth, and provide space inside the heat exchange material for the liquid helium to move through the heat exchanger.

FIG. 7B shows an image of a nanomaterial comprising nanowires for use in a heat exchanger. FIG. 7C shows an image of a nanomaterial comprising nanoclusters for use in a heat exchanger. FIG. 7D shows images of nanomaterials comprising different examples of nanopellet shapes for use in a heat exchanger, in accordance with some embodiments described herein. These nanomaterials may be implemented in dilution refrigerator 100 in discrete heat exchanger 120 and/or in a block heat exchanger (e.g., present in the mixing chamber 122). It should be appreciated that FIGs. 7B-7D show examples of nanomaterial

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shapes, but that embodiments of nanomaterial for use in a discrete heat exchanger are not so limited. For example, the nanomaterial may alternatively be a nanofoam, nanotube, and/or any other suitable nanoshape.

In some embodiments, such a nanomaterial-based heat exchanger may be formed by bonding the nanomaterial through sintering. For example, the nanomaterial may be formed as a chemical precipitate and/or by electronic deposition or electroplating techniques. A substrate with a rough surface (e.g., comprising nucleation sites) may be provided for the nanomaterial to be grown on or adhered to. In some embodiments, the heat exchanger may be produced under heat and/or compression. The nanomaterial may be held in compression during the sintering process to form the nanowire heat exchanger. In some embodiments, the substrate may be patterned with macroscopic structures (e.g., a lattice or series of posts). In some embodiments, the substrate may be a tube, and the nanomaterial may be adhered to the interior or exterior surface of the tube. In some embodiments, the substrate may be formed of a material with a lower thermal conductivity than the nanomaterial adhered to the substrate.

In some embodiments, the nanomaterial may be formed out of one of a selection of vacuum-compatible materials including but not limited to copper, silver, vacuum-compatible polymers, carbon, and/or carbon fiber. For example, the nanomaterial may be nanowires comprising at least one of copper nanowires, silver nanowires, gold nanowires, platinum nanowires, polymer nanowires, carbon nanowires, and/or carbon fiber nanowires.

II. Improved Vibration Isolation

Many experiments conducted at sub-Kelvin temperatures are sensitive to vibrational noise both from the surrounding environment and the dilution refrigerator's cooling system pumps and components. Additionally, at sub-Kelvin temperatures, mechanical vibrations can generate a heat load, reducing the cooling power of the dilution refrigerator or producing tribo-electric noise on electrical inputs and/or outputs of the dilution refrigerator. The inventors have recognized and appreciated that improved vibration isolation can improve the cooling power and other performance characteristics (e.g., magnetic flux disruption) of a dilution refrigerator. Accordingly, the inventors have developed vibration isolation components configured to mechanically decouple the lower thermal stages 108d-108f from the upper thermal stages 108a-108c.

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FIG. 8A shows another schematic diagram of dilution refrigerator 100 including mechanical elements configured to provide vibration isolation, in accordance with some embodiments described herein. The vibration isolation elements include a first suspension system 832, at least one second suspension system 840, and a third suspension system 834.

In some embodiments, the first suspension system 832 may be configured to suspend the first thermal stage 108a, the second thermal stage 108b, and/or the third thermal stage 108c from the top surface of the outer vacuum chamber 106. The first suspension system 832 may include one or more rods configured to rigidly couple the first, second, and/or third thermal stages 108a-108c to the top surface of the outer vacuum chamber 106. The rods may be formed of a material having a high spring constant. For example, the rods may be formed of carbon fiber and/or stainless steel.

In some embodiments, the second suspension system 840 may be configured to independently suspend the fourth thermal stage 108d, the fifth thermal stage 108e, and/or the sixth thermal stage 108f from the top surface of the outer vacuum chamber 106. This independent suspension of the lower thermal stages 108d-108f vibrationally isolates the lower thermal stages 108d-108f from the upper thermal stages 108a-108c, thereby improving the vibration isolation of the lower thermal stages 108d-108f.

In some embodiments, the second suspension system 840 may include one or more springs 842, rods 843, and/or connectors 844. While the example of FIG. 8A shows only one second suspension system 840, it should be appreciated that multiple second suspension systems 840 may be used to suspend the lower thermal stages 108d-108f, in some embodiments. For example, there may be two, three, or four such second suspension systems 840, in some embodiments.

In some embodiments, the springs 842 may be configured to provide a constant spring tension under different loads (e.g., for different dampened masses hanging from the springs 842). An example of a spring 842 is shown in FIG. 8B. The springs 842 may be leaf suspension springs, in some embodiments, and may include an upper flexure 842a separated from a lower flexure 842b by rigid portions 842c. The springs 842 may flex through the flexing of upper and lower flexures 842a, 842b, providing vibrational isolation to the lower thermal stages 108d-108f along the Z axis (e.g., perpendicular to a plane of the floor supporting the dilution refrigerator 100). In some embodiments, a spring constant of the spring 842 may be determined by pre-tensioning the upper and/or lower flexures 842a, 842b. Alternatively or additionally, the spring constant of the spring 842 may be

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determined by changing a length of the upper and/or lower flexures 842a, 842b (e.g., having a lower spring constant for longer lengths of flexures 842a, 842b).

In some embodiments, the springs 842 may be coupled to the third thermal stage 108d by rods 843. The rods 843 may be soft rods having a low spring constant. For example, the rods 843 may be formed out of a polymer (e.g., DELRIN), in some embodiments. The rods 843, due to their softness, may provide vibrational isolation to the lower thermal stages 108d-108f in the X-Y plane (e.g., in a plane parallel to a plane of the floor supporting the dilution refrigerator 100 and perpendicular to the Z axis).

In some embodiments, the connectors 844 may be arranged in a triangular configuration to provide stability to the suspension of the fourth thermal stage 108d. The connectors 844 may be made of materials configured to have a high spring constant. For example, the connectors 844 may be formed of stainless steel and/or carbon fiber.

In some embodiments, the third suspension system 834 may be configured to suspend the fifth thermal stage 108e and the sixth thermal stage 108f from the fourth thermal stage 108d. In this manner, the three lower thermal stages 108d-108f may all be suspended from the top surface of the vacuum chamber 106 using the second suspension system 840. The third suspension system 834 may include one or more rods configured to rigidly couple the fifth and/or sixth thermal stages 108e, 108f to the fourth thermal stage 108d. The rods may be formed of a material having a high spring constant. For example, the rods may be formed of carbon fiber and/or stainless steel, in some embodiments.

It should be appreciated that while the example of FIG. 8A shows the first and third suspension systems 832, 834 as being formed out of rods, in some embodiments, the first and/or the third suspension system 832, 834 may be formed out of flexible springs, as aspects of the present disclosure are not limited in this respect. Additionally, it should be appreciated that while the example of FIG. 8A shows the second suspension system 840 as being formed out of springs, in some embodiments, the second suspension system 840 may be formed out of rods, as aspects of the present disclosure are not limited in this respect.

III. Integrated Dilution Refrigerator

Conventional dilution refrigerator technology often requires large amounts of space and expensive supporting infrastructure such as custom-built floating foundations, high ceilings, and/or access pits. These infrastructure requirements may reduce the

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scalability of quantum technologies that operate at low temperatures. As a non-limiting example, the adoption of certain quantum computing technologies may be limited by the required use of large dilution refrigerators. The inventors have recognized and appreciated that reducing the size and infrastructure requirements of dilution refrigerators may enable the scalability of quantum technologies. The inventors have further recognized that integrating dilution refrigerators with commercial computing infrastructure (e.g., commercial server infrastructure) can further enable the scalability of dilution refrigerators and associated quantum technologies dependent on dilution refrigerators. Such integrated dilution refrigerators may be more easily integrated into telecommunications networks, can use existing telecommunications heat removal architectures, and integrate with fiberoptic networks and systems.

FIG. 9 is a side view of an illustrative external support rack 950, in accordance with some embodiments described herein. In some embodiments, the external support rack 950 may support the dilution refrigerator 100 by suspending the dilution refrigerator 100 off of the floor below the dilution refrigerator 100. As shown in the example of FIG. 9, the external support rack 950 may include arms 952 that are coupled to portions of the top surface of the vacuum chamber 106 by vibration isolation components 954 to suspend the dilution refrigerator 100 off of the floor. In some embodiments, the vibration isolation components 954 may be air pistons, electromagnetic dampeners, and/or springs.

In some embodiments, the external support rack 950 may include castors (not shown) configured to assist in transportation of the dilution refrigerator 100. The castors may be retractable such that the wheels of the castors are not in contact with the floor supporting the external support rack 950 when the dilution refrigerator 100 is not being transported and/or is in operation.

In some embodiments, the external support rack 950 further includes floor supports 958. Floor supports 958 may be configured to extend from the external support rack 950 when the dilution refrigerator 100 is not being transported. Floor supports 958 may extend from the external support rack 950, for example, by the use of screws. The floor supports 958 may be used to lift and/or level the external support rack 950 away from the floor and/or to lift the castors of the external support rack 950 off of the floor. In some embodiments, the floor supports 958 may be used to correct the positioning of the external support rack 950 in the case of an uneven floor surface.

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In some embodiments, the external support rack 950 may support additional components external to the outer vacuum chamber 106 of dilution refrigerator 100. For example, the external support rack 950 may house compressors, pumps, and/or cooling equipment configured to support the operation of the dilution refrigerator 100. Alternatively, these external components may be housed in an adjacent (e.g., a different) server rack-type container and/or support rack 950 than the dilution refrigerator 100, in some embodiments.

In some embodiments, the external support rack 950 may include elements configured to provide tool-free assembly and/or disassembly of the vacuum chamber 106 and access to the experimental volume, in accordance with some embodiments described herein. As shown in the example of FIG. 9, the vacuum chamber 106 includes three sections, a first section 106a, a second section 106b suspended from the first section 106a, and a third section 106c suspended from the second section 106b. It should be appreciated that the technology described herein is not limited to three sections, and that a vacuum chamber may have one, two, four, five, or six sections in some embodiments.

In some embodiments, the vacuum chamber 106 may have one or more substantially planar surfaces. In some embodiments, at least one of the one or more substantially planar surfaces may be disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator. As shown in the example of FIG. 9, the sections 106a-106c may each have at least four substantially planar surfaces such that, when assembled, the vacuum chamber 106 is arranged to form a rectangular prism. In some embodiments, the vacuum chamber 106 may include two substantially planar surfaces disposed within a plane parallel to the plane of the floor and arranged to close the rectangular prism formed by the surfaces of the sections 106a-106c. In some embodiments, and as described below, the vacuum chamber 106 may have an opening accessible by a door 1070 in at least one of the substantially planar surfaces.

In some embodiments, the three sections 106a-106c of the vacuum chamber 106 may be partially or fully removable in order to provide access to internal portions of the dilution refrigerator 100. For example, the three sections 106a-106c of the vacuum chamber 106 may comprise removable panels (e.g., side panels, panels attached to a frame, etc.), in some embodiments. The three sections 106a-106c may be configured to allow a user of the dilution refrigerator 100 to be able to remove the vacuum chamber 106 from the dilution refrigerator 100 without needed a large clearance above or below the dilution

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refrigerator 100 (e.g., without needing high ceilings or a pit underneath the dilution refrigerator 100).

In some embodiments, the external support rack 950 may include an integrated lift 956a configured to support the three sections 106a-106c of the vacuum chamber during assembly, disassembly, and/or maintenance of the dilution refrigerator 100. The integrated lift 956a may be configured to raise and/or lower the sections 106a-106c of the vacuum chamber. For example, the integrated lift 956a may be configured to raise and/or lower arms 956b configured to support portions (e.g., the flanges) of the three sections 106a-106c. In some embodiments, the integrated lift 956a may be operated manually (e.g., using screws and/or cables). In some embodiments, the integrated lift 956a may be operated using an electronically-operated machine (e.g., pneumatic or hydraulic devices).

In some embodiments, the external support rack 950 may include one or more carts 957. The carts 957 may be configured to receive one or more of the sections 106a-106c when lowered manually or by using the integrated lift 956a. For example, the integrated lift 956a may be used to lower the third section 106c onto a cart 957. Thereafter, the third section 106c may be transported using the cart 957 along direction C to provide a user of the dilution refrigerator 100 space under the interior components of the dilution refrigerator 100.

In some embodiments, the integrated lift 956a may be removably coupled to the external support rack 950. For example, the integrated lift 956a may be slidably removable from the external support rack 950 (e.g., sliding horizontally outward along the direction C). Removal of the integrated lift 956a may be desired to provide the user with extra space (e.g., during maintenance of the dilution refrigerator 100).

In some embodiments, the three sections 106a-106c of the vacuum chamber 106 may be suspended from one another by integrated clamps and/or cams. Such integrated clamps and/or cams may be configured to enable a user to unclamp or clamp two sections of the three sections 106a-106c together without the use of any additional tools. FIGS. 10A-10C illustrate an example of an integrated cam 1060, with FIG. 10B showing the integrated cam 1060 in an open position and FIG. 10C showing the integrated cam 1060 in a closed position.

In some embodiments, the integrated cam 1060 includes a handle 1062 that enables a user to clamp or unclamp two sections of the three sections 106a-106c together or apart. The handle 1062 is coupled to two latches 1064 that are configured to connect to bars

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1066. The handle 1062 and latches 1064 are hingedly coupled to a section of the vacuum chamber 106 by cams 1068, which provide the requisite range of motion to perform clamping and unclamping motions.

In some embodiments, a compressive layer may be included at the connection points between the three sections 106a-106c of the vacuum chamber 106 to ensure a proper vacuum-safe seal. For example, a rubber O-ring, copper or indium gasket, or other vacuum-safe compressive layer may be placed between sections 106a-106c.

Returning to FIG. 10A, in some embodiments, the vacuum chamber 106 may include an external opening to provide access to an internal volume within the dilution refrigerator 100. For example, the opening may provide access to a sample stage or experimental volume of the dilution refrigerator 100, or any other interior portion of the dilution refrigerator 100. In some embodiments, the opening may be sealed by a hermetic seal. In some embodiments, the opening may be sealed by a door 1070, as shown in the example of FIG. 10A. The door 1070 may be sealed, for example, using a hinge and/or a clamp that may be manually engaged and disengaged. In some embodiments, the door 1070 may be coupled to the opening by a load lock.

In some embodiments, the door 1070 may provide access through all of the inner radiation shields (not shown, and which may be thermally coupled to one or more of the thermal stages 108a-108f) of the dilution refrigerator 100 to allow a user to access the experimental volume. For example, a portion of the inner radiation shields (not shown) may be coupled to the door 1070 such that when a user opens the door 1070, the inner radiation shields slide or otherwise move to provide the user access with the interior portion of the dilution refrigerator. In some embodiments, a portion the inner radiation shields may be removable through the door 1070 and/or slidable through the door 1070.

In some embodiments, the external support rack 950 may be configured to be integrated with a server rack-type container. For example, the external support rack 950 may be configured to integrate the dilution refrigerator 100 with commercial server rack infrastructure (e.g., server racks). In some embodiments, the external support rack 950 may be configured to integrate the dilution refrigerator 100 with 19-inch server racks.

In some embodiments, the external support rack 950 and dilution refrigerator 100 may be housed within an outer housing. An example of an outer housing 1100 is illustrated in FIG. 11. In some embodiments, the outer housing 1100 may include an integrated horizontal surface 1110. For example, the integrated horizontal surface 1110 may be used

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as a desk or support surface when the user interacts with the dilution refrigerator. The integrated horizontal surface 1110 may be configured to be stowed by folding (as shown in the example of FIG. 11) or sliding away when not in use. In some embodiments, the outer housing 1100 may further include one or more storage locations (e.g., drawers, shelves) for the storage of related parts and/or tools for maintenance of the dilution refrigerator 100.

In some embodiments, the outer housing 1100 may further include a door 1125 providing access through an opening 1120 to the experimental volume of the dilution refrigerator 100. For example, the door 1125 may open to provide access to the experimental volume through the vacuum chamber 106 and the radiation shields inside of the vacuum chamber 106. In some embodiments, the vacuum chamber exterior and/or the radiation shields may be coupled to the door 1125 such that when a user opens the door 1125, the user opens the vacuum chamber exterior 106 and/or the radiation shields. In some embodiments, the radiation shields may alternatively be slidably and/or hingedly movable such that the user may move the radiation shields such that they no longer block access to the experimental volume as needed.

In some embodiments, the housing 1100 may further be configured to perform sound dampening. For example, the housing 1100 may include sound dampening materials to perform passive sound dampening. Alternatively or additionally, the housing 1100 may include audio equipment (e.g., speakers) configured to provide active sound dampening through the emission of destructive interference of the sounds generated by functional components of the system.

IV. Inverted Dilution Refrigerator

Conventionally, dilution refrigerators are oriented such that warmer thermal stages are positioned towards the top of the system with the thermal stages getting increasingly colder as the $^3He/^4He$ mixture progresses to the bottom of the dilution refrigerator. The inventors have recognized and appreciated that an inverted geometry, with the coldest stage disposed at the top of the system (e.g., furthest from the floor) may simplify the operation and use of a dilution refrigerator by making the experimental volume more accessible to a user and offer improved thermodynamic qualities compared to a conventional dilution refrigerator. Accordingly, the inventors have developed an inverted, dry dilution refrigerator.

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FIG. 12A is a schematic diagram of an inverted dilution refrigerator 1200, in accordance with some embodiments described herein. The inverted dilution refrigerator 1200 may include a pump system 1202 configured to circulate the $^3He/^4He$ mixture through the dilution refrigerator 1200. The inverted dilution refrigerator 1200 also may include a cryocooler 1204. The cryocooler may be coupled to a cryocooler support (not pictured) as described in connection with cryocooler support 103 herein.

In some embodiments, the inverted dilution refrigerator 1200 may include an outer vacuum chamber 1206 and a series of thermal stages 1208a-1208f disposed inside of the outer vacuum chamber 1206. The series of thermal stages 1208a-1208f may be held at same or similar temperatures as the thermal stages 108a-108f described in connection with FIG. 1 herein.

In some embodiments, the inverted dilution refrigerator 1200 may include an opening in the outer vacuum chamber 1206 and/or through the inner radiation shields to provide ease of access to the coldest stage of the inverted dilution refrigerator 1200. In some embodiments, the opening may comprise hermetic seals and/or an opening mechanism 1225 that may withstand the vacuum within the outer vacuum chamber when the inverted dilution refrigerator 1200 is in operation. For example, the opening mechanism 1225 may include a hinged door and/or a removable panel.

In some embodiments, the inverted dilution refrigerator 1200 may include a number of components arranged along the length of the dilution refrigerator (e.g., from within the vacuum chamber 1206 to within the sixth thermal stage 1208f). The components may be arranged with the coldest thermal stage, the mixing chamber 1224, disposed above warmer thermal stages (e.g., the still 1214, impedance stages 1212 and 1216, heat exchangers 1218, 1219, 1220, etc.).

In some embodiments, the inverted dilution refrigerator 1200 includes a de-mixing chamber 1222 coupled to the mixing chamber 1224. In some embodiments, the de-mixing chamber 1222 may be thermally coupled to the mixing chamber 1224 by a heat exchanger 1223 (e.g., a co-flow heat exchanger). The de-mixing chamber 1222 may be fluidly connected to the mixing chamber 1224 such that ^3He may be transported from the de-mixing chamber 1222 to the mixing chamber 1224 to provide additional cooling to the mixing chamber 1224. The de-mixing chamber 1222 may additionally have ^4He injected into the de-mixing chamber 1222 to provide a co-flow of ^3He and ^4He in order to mitigate a concentration gradient forming between the still 1214 and the mixing chamber 1224.

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FIGs. 12B and 12C are schematic diagrams of exemplary internal components of an inverted dilution refrigerator, in accordance with some embodiments described herein. It should be appreciated that the exemplary components of FIGs. 12B and 12C could be implemented within inverted dilution refrigerator 1200 of FIG. 12A (e.g., within the third thermal stage 1208c).

As shown in the example of FIG. 12B, in some embodiments the inverted dilution refrigerator may include a ^{4}He line 1226 configured to transport ^{4}He from the still 1214 to the de-mixing chamber 1222. In some embodiments, the ^{4}He line 1226 may include a pump 1228 configured to assist in the transportation of the ^{4}He to the de-mixing chamber 1222. The pump 1228 may be, for example, a fountain pump in some embodiments. Alternatively or additionally, the ^{4}He line 1226 may include additional heat exchangers to cool the ^{4}He as it travels to the de-mixing chamber 1222.

As shown in the example of FIG. 12C, in some embodiments, the inverted dilution refrigerator may include a heat exchange stage 1230 configured to cool the incoming ^{3}He/^{4}He mixture prior to the primary impedance stage 1212. As should be appreciated from the description of FIG. 1, such a configuration may increase the efficiency of the first impedance stage and/or eliminate or reduce the need for pressurization of the incoming ^{3}He/^{4}He mixture.

V. Distributed Cooling

Dilution refrigerators generally include an integrated cryocooler (e.g., such as a pulse tube or a Gifford-McMahon cryocooler) to pre-cool the ^{3}He/^{4}He mixture gas below 5 K. Conventionally, a dilution refrigerator is paired with at least one of these cryocoolers, and dilution refrigerators do not share cooling systems. Such small-scale dilution refrigeration systems typically rely on low-power cryocooling systems that are relatively inefficient (e.g., requiring more power for each Watt of cooling power at 4 K) in comparison to larger, higher-power cryocooling systems. The inventors have recognized and appreciated that a single, high-efficiency cooling system may be thermally coupled to multiple cryogenic systems such as dilution refrigerators to distribute this first stage of cooling across multiple cryogenic systems. Such distributed cooling therefore allows for increased cooling efficiency across multiple cryogenic systems.

FIG. 13 is a schematic diagram of a distributed cooling system 1300, in accordance with some embodiments described herein. The distributed cooling system 1300 may

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include multiple housings 1305. In some embodiments, the housings 1305 may be server rack-type containers (e.g., commercial server rack infrastructure, 19-inch server racks).

As shown in the example of FIG. 13, each housing 1305 may contain a cooling system 1310 or a cryogenic device 1320. It should be appreciated that cryogenic devices 1320 and/or cooling systems 1310 may be grouped within housings 1305, in some embodiments. It should further be appreciated that while FIG. 13 shows three cryogenic devices 1320 coupled to the cooling system 1310, in some embodiments, there may be two, four, ten, or many tens of cryogenic devices 1320 coupled to the cooling system 1310, as aspects of this disclosure are not so limited.

In some embodiments, the cooling system 1310 may be a cryocooling system configured to cool a first stage of the cryogenic devices 1320 to a temperature of at least 5 K and/or to a temperature of approximately 4-5 K. In some embodiments, the cooling system 1310 may be a pulse tube. For example, the cooling system 1310 may be a pulse tube, a helium liquefier system, and/or a Brayton cryocooler.

In some embodiments, the cooling system 1310 may be thermally coupled to multiple cryogenic devices 1320. Cooling may be distributed to cryogenic devices 1320 from cooling system 1310 by cooling line 1312. Additionally, heat may be returned from the cryogenic devices 1320 to cooling system by return 1314. The cooling line 1312 and/or return 1314 may be lines configured to transfer liquid and/or gaseous helium. For example, the cooling line 1312 and/or return 1314 may be pipes that are vacuum insulated to maintain the temperature of the transported helium. In some embodiments, the cooling line 1312 and/or return 1314 may be fill lines, heat pipes (e.g., traditional and/or pulsed heat pipes), and/or a superfluid loop.

In some embodiments, the cryogenic devices 1320 may include any suitable refrigeration system configured to reach temperatures at or below 5 K. In some embodiments, cryogenic devices 1320 may include one or more dilution refrigerators (e.g., dilution refrigerator 100 as described herein, configured to reach temperatures below 1 K). Alternatively or additionally, it should be appreciated that cryogenic devices 1320 may include cryogenic systems other than dilution refrigerators (e.g., microscopy systems such as scanning tunneling microscopy or atomic force microscopy systems, ^{3}He refrigeration systems, superconducting CMOS systems, etc.).

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IPR2026-00291 - U.S. Patent No. 12,313,320

In the embodiment shown in FIG. 14, the computer 1400 includes a processing unit 1401 having one or more processors and a non-transitory computer-readable storage medium 1402 that may include, for example, volatile and/or non-volatile memory. The memory 1402 may store one or more instructions to program the processing unit 1401 to perform any of the functions described herein. The computer 1400 may also include other types of non-transitory computer-readable medium, such as storage 1405 (e.g., one or more disk drives) in addition to the system memory 1402. The storage 1405 may also store one or more application programs and/or resources used by application programs (e.g., software libraries), which may be loaded into the memory 1402.

The computer 1400 may have one or more input devices and/or output devices, such as devices 1406 and 1407 illustrated in FIG. 14. These devices can be used, among other things, to present a user interface. Examples of output devices that can be used to provide a user interface include printers or display screens for visual presentation of output and speakers or other sound generating devices for audible presentation of output. Examples of input devices that can be used for a user interface include keyboards and pointing devices, such as mice, touch pads, and digitizing tablets. As another example, the input devices 1407 may include a microphone for capturing audio signals, and the output devices 1406 may include a display screen for visually rendering, and/or a speaker for audibly rendering, recognized text.

As shown in FIG. 14, the computer 1400 may also comprise one or more network interfaces (e.g., the network interface 1410) to enable communication via various networks (e.g., the network 1420). Examples of networks include a local area network or a wide area network, such as an enterprise network or the Internet. Such networks may be based on any suitable technology and may operate according to any suitable protocol and may include wireless networks, wired networks or fiber optic networks. Such networks may include analog and/or digital networks.

Various aspects of the embodiments described above may be used alone, in combination, or in a variety of arrangements not specifically discussed in the embodiments described in the foregoing and is therefore not limited in its application to the details and arrangement of components set forth in the foregoing description or illustrated in the drawings. For example, aspects described in one embodiment may be combined in any manner with aspects described in other embodiments.

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All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

The indefinite articles "a" and "an," as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean "at least one."

The phrase "and/or," as used herein in the specification and in the claims, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, a reference to "A and/or B," when used in conjunction with open-ended language such as "comprising" can refer, in one embodiment, to A only (optionally including elements other than B); in another embodiment, to B only (optionally including elements other than A); in yet another embodiment, to both A and B (optionally including other elements); etc.

As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements); etc.

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IPR2026-00291 - U.S. Patent No. 12,313,320

Use of ordinal terms such as "first," "second," "third," etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another or the temporal order in which acts of a method are performed, but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish the claim elements.

In the claims, as well as in the specification above, all transitional phrases such as "comprising," "including," "carrying," "having," "containing," "involving," "holding," "composed of," and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of" and "consisting essentially of" shall be closed or semi-closed transitional phrases, respectively.

The terms "approximately," "about," and "substantially" may be used to mean within ±20% of a target value in some embodiments, within ±10% of a target value in some embodiments, within ±5% of a target value in some embodiments, within ±2% of a target value in some embodiments. The terms "approximately," "about," and "substantially" may include the target value.

Having thus described several aspects of at least one embodiment, it is to be appreciated that various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure and are intended to be within the spirit and scope of the principles described herein. Accordingly, the foregoing description and drawings are by way of example only.

What is claimed is:

EXHIBIT 1004 – Page 278 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

FEE TRANSMITTAL

Complete if known	
Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban I. Tillemann-Dick
Examiner Name	L. W. Nouketcha
Art Unit	3763
Practitioner Docket No.	M1567.70000US04

[X] Applicant asserts small entity status. See 37 CFR 1.27.

[ ] Applicant certifies micro entity status. See 37 CFR 1.29. Form PTO/SB/15A or B or equivalent must either be enclosed or have been submitted previously.

TOTAL AMOUNT OF PAYMENT ($)56.00

METHOD OF PAYMENT (check all that apply)

[ ] Check [X] Credit Card [ ] Money Order [ ] None [ ] Other (please identify): _____

[X] Deposit Account Deposit Account Number: 23/2825 Deposit Account Name: Wolf, Greenfield & Sacks, P.C.

For the above-identified deposit account, the Director is hereby authorized to (check all that apply):

[ ] Charge fee(s) indicated below

[ ] Charge fee(s) indicated below, **except for the filing fee**

[X] Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17, **except for any excess claims fees or multiple dependent claim fee**

[ ] Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17

[X] Credit any overpayment of fee(s)

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES (U = undiscounted fee; S = small entity fee; M = micro entity fee)

	FILING FEES			SEARCH FEES			EXAMINATION FEES			
Application Type	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**Fees Paid ($)**
Utility	320	128*	64	700	280	140	800	320	160	
Design	220	88	44	160	64	32	640	256	128	
Plant	220	88	44	440	176	88	660	264	132	
Reissue	320	128	64	700	280	140	2,320	928	464	
Provisional	300	120	60	0	0	0	0	0	0	

* The $128 small entity status filing fee for a utility application is further reduced to $64 for a small entity applicant who files the application via Patent Center or EFS-Web.

2. EXCESS CLAIM FEES

Fee Description	**Undiscounted Fee ($)**	**Small Entity Fee ($)**	**Micro Entity Fee ($)**
Each claim over 20 (including Reissues)	100	40	20
Each independent claim over 3 (including Reissues)	480	192	96
Multiple dependent claims	860	344	172

Total Claims		**Extra Claims**	**Fee ($)**		**Fee Paid ($)**
20	- 20 or HP =		x	=	

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims		**Extra Claims**	**Fee ($)**		**Fee Paid ($)**
1	- 3 or HP =		x	=	

HP = highest number of independent claims paid for, if greater than 3.

Multiple Dependent Claims	
Fee ($)	**Fee Paid ($)**

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $420 ($168 for small entity) ($84 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets		**Extra Sheets**		**Number of each additional 50 or fraction thereof**	**Fee ($)**	**Fee Paid ($)**
	- 100 =		/50 =	(round **up** to a whole number) x		=

4. OTHER FEE(S)

	Fees Paid ($)
Non-English specification, $140 fee ($56 small entity) ($28 for micro entity)	
Non-electronic filing fee under 37 CFR 1.16(t) for a utility application, $400 fee ($200 small or micro entity)	
Other (e.g., late filing surcharge): 2830 Processing fee, except in provisional applications	56.00

SUBMITTED BY

Signature	/Sarah C. C. Schlotter/	Registration No. (Attorney/Agent)	79,027	Telephone	617.646.8000
Name (Print/Type)	Sarah C.C. Schlotter, PhD			Date	April 15, 2024

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: April 15, 2024 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

12331831.1

Docket No.: M1567.70000US04
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	L. W. Nouketcha
Art Unit:	3763

Certificate of Electronic Filing under 37 C.F.R. § 1.8
I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: April 15, 2024 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

REQUEST TO CORRECT INVENTORSHIP UNDER 37 C.F.R. 1.48(f)

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Commissioner:

Applicant hereby requests correction of the inventorship for the above-identified patent application pursuant to 37 C.F.R. § 1.48(f) to correct the name of inventors Tillemann-Dick, Thompson and Choo. Inventor Corban Tillemann-Dick's name should be updated to Corban I. Tillemann-Dick. Inventor Kyle Thompson's name should be updated to Kyle J. Thompson. Inventor Bryan Choo's name should be updated to Bryan J. Choo.

The inventors on this Application, as amended, are Corban I. Tillemann-Dick, Kyle J. Thompson, Bryan J. Choo, John Ogando Dos Santos Allan, and Jonathan Michael Byars.

Applicant submits herewith a Corrected Application Data Sheet showing the requested change to inventorship. Applicant requests that an updated Filing Receipt be issued and that all

pertinent U.S. Patent and Trademark Office records regarding the present Application be updated to reflect this change in inventorship.

Please charge our Credit Card in the amount of $56.00 covering the fee set forth in 37 C.F.R. § 1.17(i). The Director is hereby authorized to charge any deficiency in the fees filed, asserted to be filed or which should have been filed with this Request to our Deposit Account No. 23/2825, under Docket No. M1567.70000US04.

Dated: April 15, 2024

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
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EXHIBIT 1004 – Page 281 of 510
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IPR2026-00291 - U.S. Patent No. 12,313,320

UNITED STATES
PATENT AND TRADEMARK OFFICE

P.O. Box 1450
Alexandria, VA 22313 - 1450
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ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**04/15/2024 12:23:06 PM Z ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Morgan Ryan
PATENT CENTER #	65092361	FILING DATE	07/08/2022
CUSTOMER #	23628	FIRST NAMED INVENTOR	Corban Tillemann-Dick
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	Sarah Schlotter

Documents

TOTAL DOCUMENTS: 10

DOCUMENT	PAGES	DESCRIPTION	SIZE (KB)
M156770000US04-TRN-SCS.pdf	1	Miscellaneous Incoming Letter	25 KB
M156770000US04-CADS-SCS.pdf	8	Application Data Sheet	62 KB
Warning: This is not a USPTO supplied ADS fillable form. Data in the form cannot be automatically loaded to other USPTO systems.			
M156770000US04-FEE-SCS.pdf	1	Fee Worksheet (SB06)	33 KB
M156770000US04-INVDEC-SCS.pdf	2	Oath or Declaration filed	1199 KB

M156770000US04-RTCI-SCS.pdf		2	Request under Rule 48 correcting inventorship	26 KB
M156770000US04-PAMN-SCS.pdf		3	-	29 KB
M156770000US04-PAMN-SCS-A.PE.pdf	(1-1)	1	Preliminary Amendment	24 KB
M156770000US04-PAMN-SCS-SPEC.pdf	(2-2)	1	Specification	23 KB
M156770000US04-PAMN-SCS-REM.pdf	(3-3)	1	Applicant Arguments/Remarks Made in an Amendment	23 KB
M156770000US04-MUSPEC-SCS.pdf		33	Specification	137 KB
M156770000US04-SUBSPEC-SCS.pdf		33	Specification	136 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
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M156770000US04-INVDEC-	400DBE5DE9592F70659D48061F3AB955C2028C3C9BAE79B22

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M156770000US04-PAMN-SCS-A.PE.pdf	867F8C587F42549981F7BE3741205EE66568D00F9084235F9E580600284CDB0C4B0A9D7D256874388625A0E7AD3AF1F1AD58AEC788165E1519E7E64812181AC2
M156770000US04-PAMN-SCS-SPEC.pdf	E0C2C26FDC2D8AEBF22A85AAA5B06B160572519DD5FC5701E732E6BB2DBBCD7135408D0BAD224C25C2D82C10C687BC2C4B87ED761DDE06391AA2504526A99493
M156770000US04-PAMN-SCS-REM.pdf	E44B236E4F509F156C4EE0E136DD87BB505FC3AFF463E5918FFF777AD3FBCEFF8BC87C87128303A9B8EE7CF7404E9330FBFE4509C6C1B75DC43FD1E75EDEA763
M156770000US04-MUSPEC-SCS.pdf	2E3942DF6486DC9B265C8CDEB14E44DB623280950EAD6C0EF90613D373B1A574E6BFD2D8D76EEA79139748C72D4802B829E8BBBBF9587354F16AAC228DC9BB472
M156770000US04-SUBSPEC-SCS.pdf	4ECC8B1C023248343B7B2F7360501327435F813A3743289B8C214AEFA8A778F10F17D256FAD8CFA1D54B2E1D9049CE46153FFDE7F9A4822CF2D3B7EAD59F3346

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage

submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

FORM PTO-1449/A and B (modified PTO/SB/08)	APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
	FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet 1 of 2	GROUP ART UNIT: Not Yet Assigned	EXAMINER: Not Yet Assigned

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	U.S. Patent Document Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		4,296,609		Severijns et al.	10-27-1981
		4,672,823		Benoit et al.	06-16-1987
		4,986,077	A	Shao et al.	01-22-1991
		5,172,554	A	Swift et al.	12-22-1992
		5,207,674	A	Hamilton	05-04-1993
		2004-0223300	A1	Fink et al.	11-11-2004
		2005-0223714	A1	Li et al.	10-13-2015
		2009-0275476	A1	Atrey	11-05-2009
		2015-0160702	A1	Franz	06-11-2015
		2018-0051937	A1	Thiers et al.	02-22-2018
		2019-0226724	A1	Kotsubo et al.	07-25-2019
		2020-0370792	A1	Matthews	11-26-2020
		2021-0076530	A1	Hart et al.	03-11-2021
		2021-0402407	A1	Hoehne	12-30-2021
		2021-0402407	A1	Hoehne	12-30-2021
		2022-0221108	A1	Corcoles-Gonzalez et al.	07-14-2022

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Foreign Patent Document Number	Foreign Patent Document Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		CN	111089436	A	Csic Pride Nanjing Cryogenic Tech Co., Ltd .	05-01-2020	Y; Abstract Only
		FR	2 184 536	A1	Anvar	12-28-1973	Y; Abstract Only
		GB	2 282 437	A	Hitachi Europe Limited	04-05-1995	
		WO	2015-004904	A1	Denso Corp.	01-15-2015	Y; Abstract Only

EXAMINER:	DATE CONSIDERED:

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

11455735.1

FORM PTO-1449/A and B (modified PTO/SB/08) **INFORMATION DISCLOSURE STATEMENT BY APPLICANT**				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban I. Tillemann-Dick	
Sheet	2	of	2	GROUP ART UNIT: Not Yet Assigned	EXAMINER: Not Yet Assigned

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)
		SMITH et al., Flexible Coaxial Ribbon Cable for High-Density Superconducting Microwave Device Arrays. arXiv. 2020 July 13:6 pages.	

[NOTE – No copies of U.S. patents, published U.S. patent applications, or pending, unpublished patent applications stored in the USPTO's Image File Wrapper (IFW) system, are included. See 37 CFR § 1.98 and 1287OG163. Copies of all other patent(s), publication(s), unpublished, pending U.S. patent applications, or other information listed are provided as required by 37 CFR § 1.98 unless 1) such copies were provided in an IDS in an earlier application that complies with 37 CFR § 1.98, and 2) the earlier application is relied upon for an earlier filing date under 35 U.S.C. § 120.]

EXAMINER:	DATE CONSIDERED:

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

11455735.1

UNITED STATES PATENT AND TRADEMARK OFFICE
P.O. Box 1450
Alexandria, VA 22313 - 1450
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ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
17/860,950	**07/13/2023 05:11:51 PM ET**	**M1567.70000US04**

Title of Invention

INTEGRATED DILUTION REFRIGERATORS

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	9208	FILED BY	Jennifer Weaver
PATENT CENTER #	62438701	FILING DATE	07/08/2022
CUSTOMER #	23628	FIRST NAMED INVENTOR	Corban Tillemann-Dick
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	Sarah Schlotter

Documents

TOTAL DOCUMENTS: 8

DOCUMENT	PAGES	DESCRIPTION	SIZE (KB)
M156770000US04-TRN-SCS.pdf	1	Miscellaneous Incoming Letter	25 KB
M156770000US04-IDSBODY-SCS.pdf	3	Letter specifying the conditions for filing under 37 CFR 1.97	29 KB
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FR2184536A1_w_engabs_FOR.pdf	13	Foreign Reference	1453 KB
GB2282437A_FOR.pdf	15	Foreign Reference	1542 KB
CN111089436A_w_engabs_FOR.pdf	11	Foreign Reference	1983 KB
WO2015004904A1_w_engabs_FOR.pdf	70	Foreign Reference	8215 KB

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New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Espacenet

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VEHICLE AIR CONDITIONING DEVICE

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Applicant(s): DENSO CORP [JP] ± (DENSO CORPORATION)

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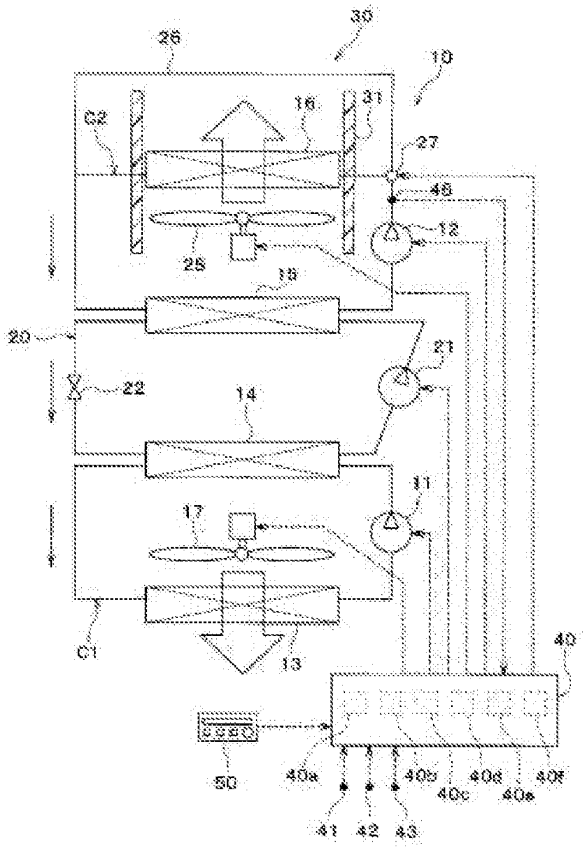
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Abstract of WO2015004904 (A1)

This vehicle air conditioning device is provided with: a blower (25) that generates air blown to the vehicle interior; a compressor (21) that takes in and discharges a refrigerant; a heating medium-heating heat exchanger (15) that exchanges heat between the refrigerant discharged from the compressor (21) and a heating medium, and heats the heating medium; an air-heating heat exchanger (16) that exchanges heat between the blown air and the heating medium heated by the heating medium-heating heat exchanger (15), and heats the blown air; and an air flow control unit (40e). When the temperature (Tw2) of the heating medium is determined to be below a prescribed value (α), the air flow control unit (40e) reduces the amount of blown air that flows through the air-heating heat exchanger (16) relative to the amount when the temperature (Tw2) of the heating medium is determined to be at or above the prescribed value (α). Because this configuration reduces the amount of blown air that flows through the air-heating heat exchanger when the temperature of the heating medium is determined to be below a prescribed value, the transfer of heat between the heating medium and the blown air in the air-heating heat exchanger is suppressed, the

temperature of the heating medium is increased, and the refrigerant pressure in the heating medium-heating heat exchanger is increased, whereby the impact of the temperature of the blown air is reduced and sufficient performance is exhibited, even if the temperature of the blown air that enters the air-heating heat exchanger is low.



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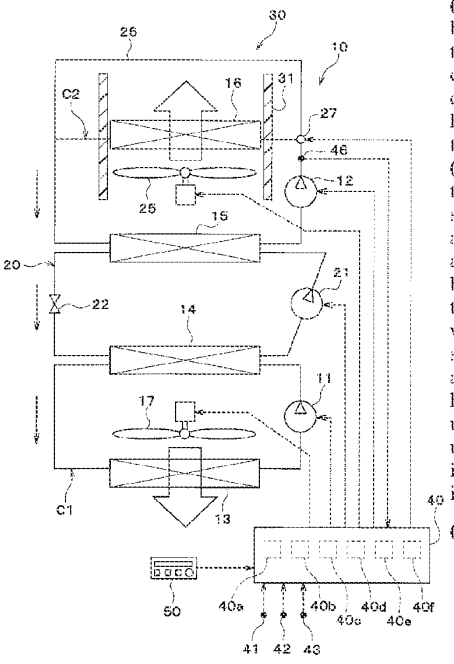
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(54) Title: VEHICLE AIR CONDITIONING DEVICE

(54) 発明の名称 : 車両用空調装置



(57) Abstract: This vehicle air conditioning device is provided with: a blower (25) that generates air blown to the vehicle interior; a compressor (21) that takes in and discharges a refrigerant; a heating medium-heating heat exchanger (15) that exchanges heat between the refrigerant discharged from the compressor (21) and a heating medium, and heats the heating medium; an air-heating heat exchanger (16) that exchanges heat between the blown air and the heating medium heated by the heating medium-heating heat exchanger (15), and heats the blown air; and an air flow control unit (40e). When the temperature (Tw2) of the heating medium is determined to be below a prescribed value (α), the air flow control unit (40e) reduces the amount of blown air that flows through the air-heating heat exchanger (16) relative to the amount when the temperature (Tw2) of the heating medium is determined to be at or above the prescribed value (α). Because this configuration reduces the amount of blown air that flows through the air-heating heat exchanger when the temperature of the heating medium is determined to be below a prescribed value, the transfer of heat between the heating medium and the blown air in the air-heating heat exchanger is suppressed, the temperature of the heating medium is increased, and the refrigerant pressure in the heating medium-heating heat exchanger is increased, whereby the impact of the temperature of the blown air is reduced and sufficient performance is exhibited, even if the temperature of the blown air that enters the air-heating heat exchanger is low.

(57) 要約:

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SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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— 国際調査報告（条約第 21 条(3)）

車両用空調装置は、車室内への送風空気を発生させる送風機（２５）と、冷媒を吸入して吐出する圧縮機（２１）と、前記圧縮機（２１）から吐出された冷媒と熱媒体とを熱交換させて前記熱媒体を加熱する熱媒体加熱用熱交換器（１５）と、前記熱媒体加熱用熱交換器（１５）で加熱された前記熱媒体と前記送風空気とを熱交換させて前記送風空気を加熱する空気加熱用熱交換器（１６）と、空気流量制御部（４０ｅ）とを備える。空気流量制御部（４０ｅ）は、前記熱媒体の温度（Ｔｗ２）が所定値（α）未満であると判断される場合、前記熱媒体の温度（Ｔｗ２）が前記所定値（α）以上であると判断される場合と比較して、前記空気加熱用熱交換器（１６）を流れる前記送風空気の流量を減少させる。上記構成により、熱媒体の温度が所定値未満であると判断される場合、空気加熱用熱交換器を流れる送風空気の風量を減少させるので、空気加熱用熱交換器における熱媒体と送風空気との熱交換が抑制され、熱媒体の温度が上昇して、熱媒体加熱用熱交換器における冷媒圧力を上昇させることができるので、空気加熱用熱交換器に導入される送風空気が低温であっても、送風空気の温度の影響を小さくして十分な性能を発揮させることができる。

明　細　書

発明の名称 ： 車両用空調装置

関連出願の相互参照

[0001] 本出願は、２０１３年７月９日に出願された日本出願番号２０１３－１４３２０５号、２０１４年１月２８日に出願された日本出願番号２０１４－１３０５７号と、２０１４年６月２日に出願された日本出願番号２０１４－１１３９３０号に基づくもので、ここにそれらの記載内容を援用する。

技術分野

[0002] 本開示は、車両に用いられる空調装置に関する。

背景技術

[0003] 従来、特許文献１には、圧縮機から吐出された高温高圧の気相冷媒を、室内熱交換器で車室内への送風空気と熱交換させて車室内への送風空気を加熱する車両用空調装置が記載されている。

[0004] この従来技術では、室内熱交換器から流出した冷媒が吸熱することなく圧縮機に戻される、いわゆるホットガスサイクルを構成している。

先行技術文献

特許文献

[0005] 特許文献1：特許第３９６８８４１号公報

発明の概要

[0006] ホットガスサイクルは、サイクル高圧が高いほど良い性能が得られる。すなわち、サイクル高圧が高いと吸入密度が高くなって冷媒流量が増加し、ひいてはエンタルピ差が大きくなる。

[0007] しかるに、上記従来技術によると、冬期には室内熱交換器に導入される送風空気が低温になるので、低温の送風空気が室内熱交換器で冷媒と熱交換することとなる。そのため、サイクル高圧の上昇が抑制され、十分な性能を得ることができなくなる。

[0008] この課題は、ホットガスサイクルのみならず、室内熱交換器から流出した

冷媒が吸熱した後に圧縮機に戻される、いわゆるヒートポンプサイクルにおいても同様に発生する。

[0009] 本開示は、車室内への送風空気を加熱する熱交換器に導入される送風空気が低温であっても十分な性能を発揮できる車両用空調装置を提供することを目的とする。

[0010] 本開示の一形態において、車両用空調装置は、車室内への送風空気を発生させる送風機と、冷媒を吸入して吐出する圧縮機と、圧縮機から吐出された冷媒と熱媒体とを熱交換させて熱媒体を加熱する熱媒体加熱用熱交換器と、熱媒体加熱用熱交換器で加熱された熱媒体と送風空気とを熱交換させて送風空気を加熱する空気加熱用熱交換器と、熱媒体の温度が所定値未満であると判断される場合、熱媒体の温度が所定値以上であると判断される場合と比較して、空気加熱用熱交換器を流れる送風空気の流量を減少させる空気流量制御部とを備える。

[0011] これによると、熱媒体の温度が所定値未満であると判断される場合、空気加熱用熱交換器を流れる送風空気の風量を減少させるので、空気加熱用熱交換器における熱媒体と送風空気との熱交換が抑制され、熱媒体の温度が上昇する。

[0012] そのため、熱媒体加熱用熱交換器における冷媒圧力を上昇させることができるので、空気加熱用熱交換器に導入される送風空気が低温であっても、送風空気の温度の影響を小さくして十分な性能を発揮させることができる。

[0013] 本開示の一形態において、車両用空調装置は、冷媒を吸入して吐出する圧縮機と、圧縮機から吐出された冷媒と熱媒体とを熱交換させて熱媒体を加熱する熱媒体加熱用熱交換器と、熱媒体加熱用熱交換器で加熱された熱媒体と車室内へ流れる空気とを熱交換させて空気を加熱する空気加熱用熱交換器と、空気加熱用熱交換器を流れる空気の流量を制御する空気流量制御部とを備える。熱媒体の温度が所定値未満であると判断される場合、熱媒体の温度が所定値以上であると判断される場合と比較して、空気加熱用熱交換器を流れる空気の流量を空気流量制御部で減少させることによって、冷媒の熱を利用

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して熱媒体の蓄熱量を増加させる。

[0014] これによると、熱媒体の温度が所定値未満であると判断される場合、空気加熱用熱交換器における熱媒体と空気との熱交換を抑制することによって、圧縮機から吐出された冷媒の熱を利用して熱媒体の蓄熱量を増加させるので、圧縮機から吐出された冷媒の温度を過度に上昇させることなく熱媒体の温度を上昇させて熱媒体加熱用熱交換器における冷媒圧力を上昇させることができる。

[0015] したがって、圧縮機から吐出された冷媒の温度が過度に上昇して圧縮機の効率が低下することを抑制できるので、冷凍サイクルの効率を向上でき、ひいては十分な性能を発揮できる。

図面の簡単な説明

[0016] [図1]第１実施形態における車両用空調装置の全体構成図である。

[図2]第１実施形態における車両用空調装置の制御装置が実行する制御処理を示すフローチャートである。

[図3]第１実施形態における車両用空調装置をホットガスサイクルにした場合のモリエル線図を示している。

[図4]第１実施形態における車両用空調装置の冷却水温度と加熱能力との関係を示すグラフである。

[図5]第２実施形態における車両用空調装置の全体構成図である。

[図6]第２実施形態における補助ヒータ等の構成図である。

[図7]第２実施形態における車両用空調装置の電気制御部を示すブロック図である。

[図8]第２実施形態における車両用空調装置の制御装置が実行する制御処理を示すフローチャートである。

[図9]第２実施形態における車両用空調装置の通常暖房モードの作動を示す全体構成図である。

[図10]第２実施形態における車両用空調装置の制御装置がウォームアップ暖房モード時に実行する制御処理を示すフローチャートである。

[図11]第２実施形態における車両用空調装置のヒータコアバイパスウォームアップ暖房モードの作動を示す全体構成図である。

[図12]第２実施形態における車両用空調装置の廃熱利用ウォームアップ暖房モードの作動を示す全体構成図である。

[図13]第２実施形態における車両用空調装置の制御処理において、補助ヒータ通過風量の算出に用いられる制御特性図である。

[図14]第２実施形態における車両用空調装置の制御装置において、ブロワレベルの算出に用いられる制御特性図である。

[図15]第３実施形態における車両用空調装置の全体構成図である。

[図16]第４実施形態における冷却水加熱用熱交換器の模式図である。

[図17]第５実施形態における車両用空調装置の制御装置が実行する制御処理を示すフローチャートである。

[図18]第６実施形態における車両用空調装置の制御装置が実行する制御処理を示すフローチャートである。

[図19]第７実施形態における車両用空調装置の制御装置が実行する制御処理を示すフローチャートである。

発明を実施するための形態

[0017] 以下、実施形態について図に基づいて説明する。なお、以下の各実施形態相互において、互いに同一もしくは均等である部分には、図中、同一符号を付してある。

[0018] （第１実施形態）

第１実施形態を図１～図４に基づいて説明する。図１に示す車両用熱管理装置１０は、車両が備える各種機器や車室内を適切な温度に調整するために用いられる。本実施形態では、車両用熱管理装置１０を、エンジン（内燃機関）および走行用電動モータから車両走行用の駆動力を得るハイブリッド自動車に適用している。

[0019] 本実施形態のハイブリッド自動車は、車両停車時に外部電源（商用電源）から供給された電力を、車両に搭載された電池（車載バッテリ）に充電可能

なプラグインハイブリッド自動車として構成されている。電池としては、例えばリチウムイオン電池を用いることができる。

[0020] エンジンから出力される駆動力は、車両走行用として用いられるのみならず、発電機を作動させるためにも用いられる。そして、発電機にて発電された電力および外部電源から供給された電力を電池に蓄わえることができ、電池に蓄えられた電力は、走行用電動モータのみならず、車両用熱管理装置１０を構成する電動式構成機器をはじめとする各種車載機器に供給される。

[0021] 車両用熱管理装置１０は、第１ポンプ１１、第２ポンプ１２、室外熱交換器１３、冷却水冷却用熱交換器１４、冷却水加熱用熱交換器１５およびヒータコア１６を備えている。

[0022] 第１ポンプ１１および第２ポンプ１２は、冷却水（熱媒体）を吸入して吐出する電動ポンプである。冷却水は、熱媒体としての流体である。本実施形態では、冷却水として、少なくともエチレングリコール、ジメチルポリシロキサンもしくはナノ流体を含む液体、または不凍液体が用いられている。

[0023] 室外熱交換器１３、冷却水冷却用熱交換器１４、冷却水加熱用熱交換器１５およびヒータコア１６は、冷却水が流通する冷却水流通機器（熱媒体流通機器）である。

[0024] 室外熱交換器１３は、冷却水と外気（車室外空気）とを熱交換する冷却水外気熱交換器（熱媒体外気熱交換器）である。室外熱交換器１３は、車両の最前部に配置されている。室外熱交換器１３には、室外送風機１７によって外気が送風される。車両の走行時には室外熱交換器１３に走行風を当てることができるようになっている。

[0025] 室外送風機１７は、室外熱交換器１３へ向けて外気を送風する送風部である。室外送風機１７は、ファンを電動モータにて駆動する電動送風機である。

[0026] 室外熱交換器１３を流通する冷却水の温度が外気の温度よりも低い場合、室外熱交換器１３は、外気の熱を冷却水に吸熱させる吸熱器として機能する。室外熱交換器１３を流通する冷却水の温度が外気の温度よりも高い場合、

室外熱交換器１３は、冷却水の熱を外気に放熱させる放熱器として機能する。

[0027] 冷却水冷却用熱交換器１４は、冷凍サイクル２０の低圧側冷媒と冷却水とを熱交換させることによって冷却水を冷却する低圧側熱交換器（熱媒体冷却用熱交換器）である。冷却水冷却用熱交換器１４では冷却水を外気の温度よりも低温まで冷却することができる。

[0028] 冷却水加熱用熱交換器１５は、冷凍サイクル２０の高圧側冷媒と冷却水とを熱交換させることによって冷却水を加熱する高圧側熱交換器（熱媒体加熱用熱交換器）である。

[0029] 冷凍サイクル２０は、圧縮機２１、冷却水加熱用熱交換器１５、膨張弁２２および冷却水冷却用熱交換器１４を備える蒸気圧縮式冷凍機である。本実施形態の冷凍サイクル２０では、冷媒としてフロン系冷媒を用いており、高圧側冷媒圧力が冷媒の臨界圧力を超えない亜臨界冷凍サイクルを構成している。

[0030] 圧縮機２１は、電池から供給される電力によって駆動される電動圧縮機、またはベルトによって駆動される可変容量圧縮機であり、冷凍サイクル２０の冷媒を吸入して圧縮して吐出する。冷却水加熱用熱交換器１５は、圧縮機２１から吐出された高圧側冷媒と冷却水とを熱交換させることによって高圧側冷媒を凝縮させる凝縮器である。

[0031] 膨張弁２２は、冷却水加熱用熱交換器１５から流出した液相冷媒を減圧膨張させる減圧部である。冷却水冷却用熱交換器１４は、膨張弁２２で減圧膨張された低圧冷媒と冷却水とを熱交換させることによって低圧冷媒を蒸発させる蒸発器である。冷却水冷却用熱交換器１４で蒸発した気相冷媒は圧縮機２１に吸入されて圧縮される。

[0032] ヒータコア１６は、冷却水と車室内への送風空気とを熱交換させて車室内への送風空気を加熱する空気加熱用熱交換器（熱媒体空気熱交換器）である。ヒータコア１６では、冷却水が顕熱変化にて送風空気に放熱する。すなわち、ヒータコア１６では、冷却水が送風空気に放熱しても冷却水が液相のま

まで相変化しない。ヒータコア１６には、室内送風機２５によって内気、外気、または内気と外気との混合空気が送風される。

[0033] 室内送風機２５は、車室内へ向けて送風される送風空気を発生する送風部である。室内送風機２５は、遠心多翼ファン（シロッコファン）を電動モータ（ブロワモータ）にて駆動する電動送風機である。

[0034] 第１ポンプ１１、冷却水冷却用熱交換器１４および室外熱交換器１３は、第１冷却水回路Ｃ１（第１熱媒体回路）に配置されている。第１冷却水回路Ｃ１は、冷却水（第１熱媒体）が第１ポンプ１１→冷却水冷却用熱交換器１４→室外熱交換器１３→第１ポンプ１１の順に循環するように構成されている。

[0035] 第２ポンプ１２、冷却水加熱用熱交換器１５およびヒータコア１６は、第２冷却水回路Ｃ２（第２熱媒体回路）に配置されている。第２冷却水回路Ｃ２は、冷却水（第２熱媒体）が第２ポンプ１２→ヒータコア１６→冷却水加熱用熱交換器１５→第２ポンプ１２の順に循環するように構成されている。

[0036] 第２冷却水回路Ｃ２には、バイパス流路２６および流量調整弁２７が設けられている。バイパス流路２６は、冷却水がヒータコア１６をバイパスして流れる流路である。流量調整弁２７は、バイパス流路２６を流れる冷却水の流量を調整する電磁弁である。

[0037] ヒータコア１６および室内送風機２５は、車両用空調装置の室内空調ユニット３０のケーシング３１に収容されている。室内空調ユニット３０は、車室内最前部の計器盤（インストルメントパネル）の内側に配置されている。ケーシング３１は、室内空調ユニット３０の外殻を形成している。

[0038] ケーシング３１は、車室内に送風される車室内送風空気の空気通路を形成しており、ある程度の弾性を有し、強度的にも優れた樹脂（例えば、ポリプロピレン）にて成形されている。

[0039] ケーシング３１内の車室内送風空気流れ最上流側には、内気導入口および外気導入口が形成されている。内気導入口は、ケーシング３１内に内気を導入させる内気導入部である。外気導入口は、ケーシング３１内に外気を導入

させる外気導入部である。

[0040] ケーシング３１の空気流れ最下流部には、車室内へ空調風を吹き出すための開口部が形成されている。開口部の空気流れ下流側は、空気通路を形成するダクトを介して、車室内に設けられた吹出口（図示せず）に接続されている。

[0041] 制御装置４０は、ＣＰＵ、ＲＯＭおよびＲＡＭ等を含む周知のマイクロコンピュータとその周辺回路から構成され、そのＲＯＭ内に記憶された空調制御プログラムに基づいて各種演算、処理を行い、出力側に接続された第１ポンプ１１、第２ポンプ１２、圧縮機２１、室外送風機１７、室内送風機２５、流量調整弁２７等の作動を制御する制御部である。

[0042] 制御装置４０は、その出力側に接続された各種制御対象機器を制御する制御部が一体に構成されたものであるが、それぞれの制御対象機器の作動を制御する構成（ハードウェアおよびソフトウェア）が、それぞれの制御対象機器の作動を制御する制御部を構成している。

[0043] 制御装置４０のうち第１ポンプ１１の作動を制御する構成（ハードウェアおよびソフトウェア）は、第１冷却水流量制御部４０ａ（第１熱媒体流量制御部）を構成している。第１冷却水流量制御部４０ａは、制御装置４０に対して別体で構成されていてもよい。

[0044] 制御装置４０のうち第２ポンプ１２の作動を制御する構成（ハードウェアおよびソフトウェア）は、第２冷却水流量制御部４０ｂ（第２熱媒体流量制御部）を構成している。第２冷却水流量制御部４０ｂは、制御装置４０に対して別体で構成されていてもよい。

[0045] 制御装置４０のうち圧縮機２１の作動を制御する構成（ハードウェアおよびソフトウェア）は、冷媒流量制御部４０ｃを構成している。冷媒流量制御部４０ｃは、制御装置４０に対して別体で構成されていてもよい。

[0046] 制御装置４０のうち室外送風機１７の作動を制御する構成（ハードウェアおよびソフトウェア）は、空気流量制御部４０ｄを構成している。空気流量制御部４０ｄは、制御装置４０に対して別体で構成されていてもよい。

[0047] 制御装置４０のうち室内送風機２５の作動を制御する構成（ハードウェアおよびソフトウェア）は、送風機制御部４０ｅを構成している。送風機制御部４０ｅは、ヒータコア１６を流れる送風空気の流量を制御する空気流量制御部である。空気流量制御部４０ｅは、制御装置４０に対して別体で構成されていてもよい。

[0048] 制御装置４０のうち流量調整弁２７の作動を制御する構成（ハードウェアおよびソフトウェア）は、流量調整弁制御部４０ｆを構成している。流量調整弁制御部４０ｆは、バイパス流路２６および流量調整弁２７とともに、ヒータコア１６を流れる冷却水の流量を制御する冷却水流量制御部（熱媒体流量制御部）を構成している。流量調整弁制御部４０ｆは、制御装置４０に対して別体で構成されていてもよい。

[0049] 制御装置４０の入力側には、内気センサ４１、外気センサ４２、日射センサ４３、冷却水温度センサ４６等のセンサ群の検出信号が入力される。

[0050] 内気センサ４１は、内気温（車室内温度）を検出する検出部（内気温度検出部）である。外気センサ４２は、外気温（車室外温度）を検出する検出部（外気温度検出部）である。日射センサ４３は、車室内の日射量を検出する検出部(日射量検出部）である。

[0051] 冷却水温度センサ４６は、第２冷却水回路Ｃ２の冷却水温度を検出する検出部(熱媒体温度検出部）である。冷却水温度センサ４６は、第２冷却水回路Ｃ２の任意の場所に設置すればよい。

[0052] なお、内気温、外気温、日射量、第２冷却水回路Ｃ２の冷却水温度を、種々の物理量の検出値に基づいて推定するようにしてもよい。

[0053] 制御装置４０の入力側には、空調操作パネル５０の操作部材からの種々な空調操作信号が入力される。空調操作パネル５０は、車室内の計器盤付近に配置されている。空調操作パネル５０には、車室内の設定温度を設定する温度設定スイッチ、圧縮機２１の作動・停止を切り替えるエアコンスイッチ、室内送風機２５の風量を切り替える風量切替スイッチ等が設けられている。

[0054] 次に、上記構成における作動を説明する。制御装置４０が第１ポンプ１１

、第２ポンプ１２および圧縮機２１を作動させると、冷凍サイクル２０に冷媒が循環し、第１冷却水回路Ｃ１に冷却水が循環し、第２冷却水回路Ｃ２に冷却水が循環する。

[0055] 冷却水冷却用熱交換器１４では、冷凍サイクル２０の冷媒が第１冷却水回路Ｃ１の冷却水から吸熱するので、第１冷却水回路Ｃ１の冷却水が冷却される。冷却水冷却用熱交換器１４で吸熱した冷媒は、冷却水加熱用熱交換器１５で第２冷却水回路Ｃ２の冷却水へ放熱する。これにより、第２冷却水回路Ｃ２の冷却水が加熱される。冷却水加熱用熱交換器１５で加熱された第２冷却水回路Ｃ２の冷却水は、ヒータコア１６で車室内への送風空気に放熱する。これにより、車室内への送風空気が加熱される。

[0056] 冷却水冷却用熱交換器１４で冷却された第１冷却水回路Ｃ１の冷却水は、室外熱交換器１３で外気から吸熱する。

[0057] 室外熱交換器１３で吸熱した外気の熱は、冷凍サイクル２０の冷媒を介して冷却水冷却用熱交換器１４で第２冷却水回路Ｃ２の冷却水に放熱されるので、外気から吸熱するヒートポンプ運転を実現できる。

[0058] ヒートポンプ運転時の作動に対して第１ポンプ１１および室外送風機１７の少なくとも一方を停止させた場合、外気から吸熱しないホットガスサイクルにすることができる。

[0059] 制御装置４０は、図２のフローチャートに示す制御処理を実行する。ステップＳ１００では、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値αを下回っているか否かを判定する。所定値αは、予め制御装置４０に記憶されている固定値である。制御装置４０は、所定値αを少なくとも外気温度に基づいて算出してもよい。換言すれば、制御装置４０は、所定値αを算出する算出部を構成していてもよい。

[0060] 例えば、所定値αを、目標吹出温度ＴＡＯと同じ値にしてもよい。目標吹出温度ＴＡＯは、以下の数式により算出される。

[0061] ＴＡＯ＝Ｋｓｅｔ×Ｔｓｅｔ－Ｋｒ×Ｔｒ－Ｋａｍ×Ｔａｍ－Ｋｓ×Ｔｓ＋Ｃ

Ｔｓｅｔは車室内温度設定スイッチによって設定された車室内設定温度、Ｔｒは内気センサ４１によって検出された車室内温度（内気温）、Ｔａｍは外気センサ４２によって検出された外気温、Ｔｓは日射センサ４３によって検出された日射量である。Ｋｓｅｔ、Ｋｒ、Ｋａｍ、Ｋｓは制御ゲインであり、Ｃは補正用の定数である。

[0062] 目標吹出温度ＴＡＯは、車室内を所望の温度に保つために車両用空調装置が生じさせる必要のある熱量に相当するもので、車両用空調装置に要求される空調熱負荷（冷房負荷および暖房負荷）として捉えることができる。すなわち、車両用空調装置に要求される冷房負荷が高い場合、目標吹出温度ＴＡＯは低温域になり、車両用空調装置に要求される暖房負荷が高い場合、目標吹出温度ＴＡＯは高温域になる。

[0063] ステップＳ１００において第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値αを下回っていると判定した場合、ステップＳ１１０へ進み、室内送風機２５を停止させる。これにより、ヒータコア１６で冷却水と車室内への送風空気とが熱交換されないので、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が上昇する。

[0064] ステップＳ１００において第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値αを下回っていないと判定した場合、ステップＳ１２０へ進み、室内送風機２５を作動させる。これにより、ヒータコア１６で冷却水と車室内への送風空気とが熱交換されるので、車室内への送風空気が加熱されて暖房が行われる。

[0065] 図３は、第１ポンプ１１および室外送風機１７の少なくとも一方を停止させてホットガスサイクルにした場合のモリエル線図を示している。図３は、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が高いほど、サイクル高圧が上昇することを示している。

[0066] ホットガスサイクルは、サイクル高圧が高いほど良い性能が得られる。すなわち、サイクル高圧が高いと吸入密度が高くなって冷媒流量が増加し、ひいてはエンタルピ差が大きくなる。そのため、図４に示すように、第２冷却

水回路Ｃ２の冷却水の温度Ｔｗ２が高いほど、高い加熱能力が得られる。

[0067] 第１ポンプ１１および室外送風機１７を作動させてヒートポンプサイクルにした場合も、ホットガスサイクルにした場合と同様に、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が高いほど、高い加熱能力が得られる。

[0068] 制御装置４０は、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αに近づくように、ヒータコア１６を流れる送風空気の風量を制御するようにしてもよい。例えば、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αよりも低い場合、ヒータコア１６を流れる送風空気の風量を減少させ、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αよりも高い場合、ヒータコア１６を流れる送風空気の風量を増加させるようにすればよい。

[0069] ヒータコア１６を流れる送風空気の風量の増減は、室内送風機２５の送風能力（回転数）を制御することによって行うことができる。ヒータコア１６を流れる送風空気の風量の増減は、エアミックスドア（図示せず）の開度を制御することによっても行うことができる。

[0070] エアミックスドアは、ヒータコア１６を流れる送風空気の風量と、ヒータコア１６を迂回して流れる送風空気の風量との風量割合を調整する風量割合調整部である。エアミックスドアは、ヒータコア１６を流れる送風空気の風量を制御する空気流量制御部である。

[0071] 制御装置４０は、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αに近づくように、ヒータコア１６を流れる冷却水の流量を制御するようにしてもよい。例えば、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αよりも低い場合、ヒータコア１６を流れる冷却水の流量を減少させ、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αよりも高い場合、ヒータコア１６を流れる冷却水の流量を増加させるようにすればよい。

[0072] ヒータコア１６を流れる冷却水の流量の増減は、流量制御弁２７の開度を制御することによって行うことができる。ヒータコア１６を流れる冷却水の流量の増減は、第２ポンプ１２の冷却水吐出能力（回転数）を制御することによっても行うことができる。

[0073] 本実施形態では、制御装置４０は、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度α未満であると判断される場合、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度α以上であると判断される場合と比較して、ヒータコア１６を流れる送風空気の流量を減少させる。

[0074] これによると、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度α未満であると判断される場合、ヒータコア１６を流れる送風空気の風量を減少させるので、ヒータコア１６における冷却水と送風空気との熱交換が抑制され、冷却水の温度Ｔｗ２が上昇する。そのため、冷却水加熱用熱交換器１５における冷媒圧力を上昇させることができるので、送風空気の温度の影響を小さくして十分な性能を発揮させることができる。

[0075] また、ヒータコア１６における冷却水と送風空気との熱交換が抑制されるので、圧縮機２１から吐出された冷媒の熱を利用して第２冷却水回路Ｃ２の冷却水の蓄熱量を増加させることができる。

[0076] そのため、圧縮機２１から吐出された冷媒の温度を過度に上昇させることなく冷却水の温度Ｔｗ２を上昇させて冷却水加熱用熱交換器１５における冷媒圧力を上昇させることができる。

[0077] したがって、圧縮機２１から吐出された冷媒の温度が過度に上昇して圧縮機２１の効率が低下することを抑制できるので、冷凍サイクル２０の効率を向上できる。その結果、十分な性能を発揮できるので、暖房効率を向上できる。

[0078] 具体的には、制御装置４０は、冷却水の温度Ｔｗ２が所定温度α未満であると判断される場合、送風機２５を停止させ、冷却水の温度Ｔｗ２が所定温度α以上であると判断される場合、送風機２５を作動させる。

[0079] 制御装置４０は、冷却水の温度Ｔｗ２が所定温度α未満であると判断される場合、送風機２５の送風能力（回転数）を減少させ、冷却水の温度Ｔｗ２が所定温度α以上であると判断される場合、送風機２５の送風能力（回転数）を増加させるようにしてもよい。

[0080] これにより、冷却水加熱用熱交換器１５における冷媒圧力を確実に上昇さ

せることができるので、十分な性能を確実に発揮させることができる。

[0081] 特に、冷媒が外部から吸熱することなく循環するホットガスサイクルにしている場合、性能を顕著に向上できる。

[0082] 本実施形態において、制御装置４０は、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αに近づくように、ヒータコア１６を流れる送風空気の流量を制御してもよい。これにより、高い性能を安定して発揮できる。

[0083] 本実施形態において、制御装置４０は、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αに近づくように、ヒータコア１６を流れる冷却水の流量を制御してもよい。これにより、高い性能を安定して発揮できる。特に、冷却水は、空気よりも温度変動が少ないため、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２を良好に制御できる。

[0084] 例えば、ヒータコア１６を流れる冷却水の流量の制御を流量制御弁２７によって行えば、第２冷却水回路Ｃ２の全体の冷却水流量を変化させることなくヒータコア１６を流れる冷却水の流量を制御できる。

[0085] 本実施形態において、制御装置４０は、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度αに近づくように、圧縮機２１から吐出される冷媒の流量を制御してもよい。これにより、高い性能を安定して発揮できる。

[0086] 具体的には、圧縮機２１の回転数（冷媒吐出能力）を制御することによって、圧縮機２１から吐出される冷媒の流量を制御できる。

[0087] 本実施形態において、制御装置４０は、所定温度αを、少なくとも外気温度に基づいて算出してもよい。これにより、外気温度等の環境条件の変化に応じて十分な性能を発揮させることが可能になる。

[0088] （第２実施形態）

図５に示すように、本実施形態の熱管理システム１０は、クーラコア５１、インバータ５２、電池温調用熱交換器５３、冷却水冷却水熱交換器５４、第１切替弁５５および第２切替弁５６を備えている。

[0089] クーラコア５１は、冷却水が流通する冷却水流通機器（熱媒体流通機器）である。クーラコア５１は、冷却水と車室内への送風空気とを熱交換させて

車室内への送風空気を冷却する空気冷却用熱交換器（熱媒体空気熱交換器）である。

[0090] クーラコア５１では、冷却水が顕熱変化にて送風空気から吸熱する。すなわち、クーラコア５１では、冷却水が送風空気から吸熱しても冷却水が液相のままで相変化しない。クーラコア５１には、室内送風機２５によって内気、外気、または内気と外気との混合空気が送風される。

[0091] インバータ５２、電池温調用熱交換器５３および冷却水冷却水熱交換器５４は、冷却水が流通する流路を有し、冷却水との間で熱授受が行われる熱授受機器（温度調整対象機器）である。

[0092] インバータ５２は、電池から供給された直流電力を交流電圧に変換して走行用電動モータに出力する電力変換装置である。インバータ５２は、作動に伴って発熱する発熱機器である。

[0093] 電池温調用熱交換器５３は、電池と冷却水とを熱交換する熱交換器である。電池温調用熱交換器５３は、電池に接触配置されていて、電池との間で熱伝導が行われる熱交換器である。電池温調用熱交換器５３は、電池への送風経路に配置されていて、送風空気と冷却水とを熱交換する熱交換器（空気熱媒体熱交換器）であってもよい。

[0094] 冷却水冷却水熱交換器５４は、車両用熱管理システム１０の冷却水（第１ポンプ１１または第２ポンプ１２によって循環される冷却水）と、エンジン冷却回路７０の冷却水（エンジン用熱媒体）とを熱交換する熱交換器（熱媒体熱媒体熱交換器）である。

[0095] 第１ポンプ１１は、第１ポンプ用流路６１に配置されている。第１ポンプ用流路６１において第１ポンプ１１の吐出側には、冷却水冷却用熱交換器１４が配置されている。

[0096] 第２ポンプ１２は、第２ポンプ用流路６２に配置されている。第２ポンプ用流路６２において第２ポンプ１２の吐出側には、冷却水加熱用熱交換器１５が配置されている。

[0097] 室外熱交換器１３は、室外熱交換器用流路６３に配置されている。クーラ

コア５１は、クーラコア用流路６４に配置されている。ヒータコア１６は、ヒータコア用流路６５に配置されている。

[0098] インバータ５２は、インバータ用流路６６に配置されている。電池温調用熱交換器５３は、電池温調用流路６７に配置されている。冷却水冷却水熱交換器５４は、冷却水冷却水熱交換器用流路６８に配置されている。

[0099] 第１ポンプ用流路６１、第２ポンプ用流路６２、室外熱交換器用流路６３、クーラコア用流路６４、ヒータコア用流路６５、インバータ用流路６６、電池温調用流路６７および冷却水冷却水熱交換器用流路６８は、第１切替弁５５および第２切替弁５６に接続されている。第１切替弁５５および第２切替弁５６は、冷却水の流れを切り替える切替部である。

[0100] 第１切替弁５５は、冷却水の入口として第１入口５５ａおよび第２入口５５ｂを有し、冷却水の出口として第１出口５５ｃ、第２出口５５ｄ、第３出口５５ｅ、第４出口５５ｆ、第５出口５５ｇ、第６出口５５ｈ、第７出口５５ｉを有している。

[0101] 第２切替弁５６は、冷却水の出口として第１出口５６ａおよび第２出口５６ｂを有し、冷却水の入口として第１入口５６ｃ、第２入口５６ｄ、第３入口５６ｅ、第４入口５６ｆ、第５入口５６ｇ、第６入口５６ｈ、第７入口５６ｉを有している。

[0102] 第１切替弁５５の第１入口５５ａには、第１ポンプ用流路６１の一端が接続されている。換言すれば、第１切替弁５５の第１入口５５ａには、冷却水冷却用熱交換器１４の冷却水出口側が接続されている。

[0103] 第１切替弁５５の第２入口５５ｂには、第２ポンプ用流路６２の一端が接続されている。換言すれば、第１切替弁５５の第２入口５５ｂには、冷却水加熱用熱交換器１５の冷却水出口側が接続されている。

[0104] 第１切替弁５５の第１出口５５ｃには、室外熱交換器用流路６３の一端が接続されている。換言すれば、第１切替弁５５の第１出口５５ｃには室外熱交換器１３の冷却水入口側が接続されている。

[0105] 第１切替弁５５の第２出口５５ｄには、クーラコア用流路６４の一端が接

続されている。換言すれば、第１切替弁５５の第２出口５５ｄにはクーラコア５１の冷却水入口側が接続されている。

[0106] 第１切替弁５５の第３出口５５ｅには、ヒータコア用流路６５の一端が接続されている。換言すれば、第１切替弁５５の第３出口５５ｅにはヒータコア１６の冷却水入口側が接続されている。

[0107] 第１切替弁５５の第４出口５５ｆには、インバータ用流路６６の一端が接続されている。換言すれば、第１切替弁５５の第４出口５５ｆにはインバータ５２の冷却水入口側が接続されている。

[0108] 第１切替弁５５の第５出口５５ｇには、電池温調用流路６７の一端が接続されている。換言すれば、第１切替弁５５の第５出口５５ｇには電池温調用熱交換器５３の冷却水入口側が接続されている。

[0109] 第１切替弁５５の第６出口５５ｈには、冷却水冷却水熱交換器用流路６８の一端が接続されている。換言すれば、第１切替弁５５の第６出口５５ｈには冷却水冷却水熱交換器５４の冷却水入口側が接続されている。

[0110] 第１切替弁５５の第７出口５５ｉには、バイパス流路２６の一端が接続されている。

[0111] 第２切替弁５６の第１出口５６ａには、第１ポンプ用流路６１の他端が接続されている。換言すれば、第２切替弁５６の第１出口５６ａには、第１ポンプ１１の冷却水吸入側が接続されている。

[0112] 第２切替弁５６の第２出口５６ｂには、第２ポンプ用流路６２の他端が接続されている。換言すれば、第２切替弁５６の第２出口５６ｂには、第２ポンプ１２の冷却水吸入側が接続されている。

[0113] 第２切替弁５６の第１入口５６ｃには、室外熱交換器用流路６３の他端が接続されている。換言すれば、第２切替弁５６の第１入口５６ｃには室外熱交換器１３の冷却水出口側が接続されている。

[0114] 第２切替弁５６の第２入口５５ｄには、クーラコア用流路６４の他端が接続されている。換言すれば、第２切替弁５６の第２入口５５ｄにはクーラコア５１の冷却水出口側が接続されている。

[0115] 第２切替弁５６の第３入口５５ｅには、ヒータコア用流路６５の他端が接続されている。換言すれば、第２切替弁５６の第３入口５５ｅにはヒータコア１６の冷却水出口側が接続されている。

[0116] 第２切替弁５６の第４入口５５ｆには、インバータ用流路６６の他端が接続されている。換言すれば、第２切替弁５６の第４入口５５ｆにはインバータ５２の冷却水出口側が接続されている。

[0117] 第２切替弁５６の第５入口５５ｇには、電池温調用流路６７の他端が接続されている。換言すれば、第２切替弁５６の第５入口５５ｇには電池温調用熱交換器５３の冷却水出口側が接続されている。

[0118] 第２切替弁５６の第６入口５５ｈには、冷却水冷却水熱交換器用流路６８の他端が接続されている。換言すれば、第２切替弁５６の第６入口５５ｈには冷却水冷却水熱交換器５４の冷却水出口側が接続されている。

[0119] 第２切替弁５６の第７入口５５ｉには、バイパス流路２６の他端が接続されている。

[0120] 第１切替弁５５および第２切替弁５６は、各入口と各出口との連通状態を任意または選択的に切り替え可能な構造になっている。

[0121] 具体的には、第１切替弁５５は、室外熱交換器１３、クーラコア５１、ヒータコア１６、インバータ５２、電池温調用熱交換器５３、冷却水冷却水熱交換器５４およびバイパス流路２６のそれぞれについて、第１ポンプ１１から吐出された冷却水が流入する状態と、第２ポンプ１２から吐出された冷却水が流入する状態と、第１ポンプ１１から吐出された冷却水および第２ポンプ１２から吐出された冷却水が流入しない状態とを切り替える。

[0122] 第２切替弁５６は、室外熱交換器１３、クーラコア５１、ヒータコア１６、インバータ５２、電池温調用熱交換器５３、冷却水冷却水熱交換器５４およびバイパス流路２６のそれぞれについて、第１ポンプ１１へ冷却水が流出する状態と、第２ポンプ１２へ冷却水が流出する状態と、第１ポンプ１１および第２ポンプ１２へ冷却水が流出しない状態とを切り替える。

[0123] 第１切替弁５５および第２切替弁５６は、弁開度を調整可能になっている

。これにより、室外熱交換器１３、クーラコア５１、ヒータコア１６、インバータ５２、電池温調用熱交換器５３、冷却水冷却水熱交換器５４およびバイパス流路２６を流れる冷却水の流量を調整できる。

[0124] したがって、第１切替弁５５および第２切替弁５６は、各冷却水流通機器１３、１６、５１、５２、５３、５４およびバイパス流路２６を流れる冷却水の流量を調整する流量調整弁である。

[0125] 第１切替弁５５および第２切替弁５６は、第１ポンプ１１から吐出された冷却水と、第２ポンプ１２から吐出された冷却水とを任意の流量割合で混合して、室外熱交換器１３、クーラコア５１、ヒータコア１６、インバータ５２、電池温調用熱交換器５３、冷却水冷却水熱交換器５４およびバイパス流路２６に流入させることが可能になっている。

[0126] クーラコア５１およびヒータコア１６は、車両用空調装置の室内空調ユニット３０のケーシング３１に収容されている。

[0127] ケーシング３１内の空気流れ最上流側には、内外気切替箱３２が配置されている。内外気切替箱３２は、内気（車室内空気）と外気（車室外空気）とを切替導入する内外気導入部である。

[0128] 内外気切替箱３２には、ケーシング３１内に内気を導入させる内気吸込口３２ａ、および外気を導入させる外気吸込口３２ｂが形成されている。内外気切替箱３２の内部には、内外気切替ドア３３が配置されている。

[0129] 内外気切替ドア３３は、ケーシング３１内に導入される内気と外気との風量割合を変化させる風量割合変更部である。具体的には、内外気切替ドア３３は、内気吸込口３２ａおよび外気吸込口３２ｂの開口面積を連続的に調整して、内気の風量と外気の風量との風量割合を変化させる。内外気切替ドア３３は、電動アクチュエータ（図示せず）によって駆動される。

[0130] 内外気切替箱３２の空気流れ下流側には、室内送風機２５（ブロワ）が配置されている。室内送風機２５は、内外気切替箱３２を介して吸入した空気（内気および外気）を車室内へ向けて送風する送風部である。

[0131] ケーシング３１内において室内送風機２５の空気流れ下流側には、クーラ

コア５１およびヒータコア１６が配置されている。

[0132] ケーシング３１の内部においてクーラコア５１の空気流れ下流側部位には、ヒータコアバイパス通路３１ａが形成されている。ヒータコアバイパス通路３１ａは、クーラコア５１を通過した空気を、ヒータコア１６を通過させずに流す空気通路である。

[0133] ケーシング３１の内部においてクーラコア５１とヒータコア１６との間には、エアミックスドア３５が配置されている。

[0134] エアミックスドア３５は、ヒータコア１６へ流入させる空気と、ヒータコアバイパス通路３１ａへ流入させる空気との風量割合を連続的に変化させる風量割合調整部である。エアミックスドア３５は、回動可能な板状ドアや、スライド可能なドア等であり、電動アクチュエータ（図示せず）によって駆動される。

[0135] ヒータコア１６を通過する空気とヒータコアバイパス通路３１ａを通過する空気との風量割合によって、車室内へ吹き出される吹出空気の温度が変化する。したがって、エアミックスドア３５は、車室内へ吹き出される吹出空気の温度を調整する温度調整部である。

[0136] ケーシング３１の空気流れ最下流部には、空調対象空間である車室内へ送風空気を吹き出す吹出口３１ｂが配置されている。この吹出口３１ｂとしては、具体的には、デフロスタ吹出口、フェイス吹出口およびフット吹出口が設けられている。

[0137] デフロスタ吹出口は、車両前面窓ガラスの内側の面に向けて空調風を吹き出す。フェイス吹出口は、乗員の上半身に向けて空調風を吹き出す。フット吹出口は、乗員の足元に向けて空調風を吹き出す。

[0138] 吹出口３１ｂの空気流れ上流側には、吹出口モードドア（図示せず）が配置されている。吹出口モードドアは、吹出口モードを切り替える吹出口モード切替部である。吹出口モードドアは、電動アクチュエータ(図示せず)によって駆動される。

[0139] 吹出口モードドアによって切り替えられる吹出口モードとしては、例えば

、フェイスモード、バイレベルモード、フットモードおよびフットデフロスタモードがある。

[0140] フェイスモードは、フェイス吹出口を全開してフェイス吹出口から車室内乗員の上半身に向けて空気を吹き出す吹出口モードである。バイレベルモードは、フェイス吹出口とフット吹出口の両方を開口して車室内乗員の上半身と足元に向けて空気を吹き出す吹出口モードである。

[0141] フットモードは、フット吹出口を全開するとともにデフロスタ吹出口を小開度だけ開口して、フット吹出口から主に空気を吹き出す吹出口モードである。フットデフロスタモードは、フット吹出口およびデフロスタ吹出口を同程度開口して、フット吹出口およびデフロスタ吹出口の双方から空気を吹き出す吹出口モードである。

[0142] エンジン冷却回路７０は、エンジン７１を冷却するための冷却水循環回路である。エンジン冷却回路７０は、エンジン冷却水（第２熱媒体）が循環する循環流路７２を有している。循環流路７２には、エンジン７１、第３ポンプ７３、エンジン用ラジエータ７４および冷却水冷却水熱交換器５４が配置されている。

[0143] 第３ポンプ７３は、エンジン冷却水を吸入して吐出する電動ポンプである。第３ポンプ７３は、エンジン７１から出力される動力によって駆動される機械式ポンプであってもよい。

[0144] エンジン用ラジエータ７４は、エンジン冷却水と外気とを熱交換することによって冷却水の熱を外気に放熱させる放熱用の熱交換器（空気熱媒体熱交換器）である。

[0145] 循環流路７２には、ラジエータバイパス流路７５が接続されている。ラジエータバイパス流路７５は、エンジン冷却水がエンジン用ラジエータ７４をバイパスして流れる流路である。

[0146] ラジエータバイパス流路７５と循環流路７２との接続部にはサーモスタット７６が配置されている。サーモスタット７６は、温度によって体積変化するサーモワックス（感温部材）によって弁体を変位させて冷却水流路を開閉

する機械的機構で構成される冷却水温度応動弁である。

[0147] 具体的には、サーモスタット７６は、エンジン冷却水の温度が所定温度を上回っている場合（例えば８０℃以上）、ラジエータバイパス流路７５を閉じ、冷却水の温度が所定温度を下回っている場合（例えば８０℃未満）、ラジエータバイパス流路７５を開ける。

[0148] 循環流路７２には、エンジン補機用流路７７が接続されている。エンジン補機用流路７７は、エンジン冷却水が冷却水冷却水熱交換器５４と並列に流れる流路である。エンジン補機用流路７７にはエンジン補機７８が配置されている。冷却水冷却水熱交換器５４は、冷却エンジン補機用流路７７に配置されて、エンジン補機７８と直列に冷却水が流れるようになってもよい。

[0149] エンジン補機７８は、オイル熱交換器、ＥＧＲクーラ、スロットルクーラ（ウォーマ）、ターボクーラ、エンジン補助モータ等である。オイル熱交換器は、エンジンオイルまたはトランスミッションオイルとエンジン冷却水とを熱交換してオイルの温度を調整する熱交換器である。

[0150] ＥＧＲクーラは、エンジンの排気ガスの一部を吸気側に還流させてスロットルバルブで発生するポンピングロスを低減させるＥＧＲ（排気ガス再循環）装置を構成する熱交換器であって、還流ガスとエンジン冷却水とを熱交換させて還流ガスの温度を調整する熱交換器である。

[0151] スロットルクーラ（ウォーマ）は、スロットルバルブを冷却（加熱）するためにスロットル内部に設けたウォータジャケットである。

[0152] ターボクーラはターボチャージャで発生する熱とエンジン冷却水とを熱交換させてターボチャージャを冷却するための冷却器である。

[0153] エンジン補助モータは、エンジン停止中でもエンジンベルトを回せるようにするための大型モータであり、エンジンベルトで駆動される圧縮機やウォータポンプなどをエンジン７１の駆動力が無い状態でも作動させたり、エンジン７１の始動時に利用される。

[0154] エンジン用ラジエータ７４にはエンジン用リザーブタンク７９が接続されている。エンジン用リザーブタンク７９は、エンジン冷却水を貯留する大気

開放式の容器（熱媒体貯留部）である。したがって、エンジン用リザーブタンク７９に蓄えているエンジン冷却水の液面における圧力は大気圧になる。

[0155] エンジン用リザーブタンク７９は、エンジン用リザーブタンク７９に蓄えているエンジン冷却水の液面における圧力が所定圧力（大気圧とは異なる圧力）になるように構成されていてもよい。

[0156] エンジン用リザーブタンク７９に余剰冷却水を貯留しておくことによって、各流路を循環するエンジン冷却水の液量の低下を抑制することができる。エンジン用リザーブタンク７９は、エンジン冷却水に混入した気泡を気液分離する機能を有している。

[0157] 室外熱交換器用流路６３にはリザーブタンク８０が接続されている。リザーブタンク８０の構造および機能はエンジン用リザーブタンク７９と同様である。

[0158] 室内空調ユニット３０のケーシング３１の内部においてヒータコア１６の空気流れ下流側部位には、補助ヒータ８１が配置されている。補助ヒータ８１は、送風空気を加熱する空気加熱部である。補助ヒータ８１は、ＰＴＣ素子（正特性サーミスタ）を有し、このＰＴＣ素子に電力が供給されることによって発熱して空気を加熱するＰＴＣヒータ（電気ヒータ）である。補助ヒータ８１は、ニクロム線などの電熱線を有し、電熱線に電力が供給されることによって空気を加熱する方式の電熱ヒータでもよい。

[0159] 図６に示すように、補助ヒータ８１には、電池８２から電力が供給される。電池８２および補助ヒータ８１で構成される電流回路には、リレー８３およびヒューズ８４が配置されている。

[0160] リレー８３は、補助ヒータ８１への通電をオン・オフする通電制御部である。リレー８３が補助ヒータ８１への通電をオン・オフすることによって、補助ヒータ８１の発熱量が制御される。リレー８３の作動（発熱量）は、制御装置４０によって制御される。ヒューズ８４は、電流回路に過電流が流れた場合に通電を遮断する通電遮断部である。

[0161] 次に、熱管理システム１０の電気制御部を図７に基づいて説明する。制御

装置４０のうち第１切替弁５５および第２切替弁５６の作動を制御する構成（ハードウェアおよびソフトウェア）は、切替弁制御部４０ｇ（流量調整弁制御部）を構成している。切替弁制御部４０ｇを制御装置４０に対して別体で構成してもよい。

[0162] 切替弁制御部４０ｇは、第１切替弁５５および第２切替弁５６とともに、各冷却水流通機器１３、１６、５１、５２、５３、５４およびバイパス流路２６を流れる冷却水の流量を制御する冷却水流量制御部（熱媒体流量制御部）を構成している。

[0163] 制御装置４０のうち、ケーシング３１の内部に配置された各種ドア（内外気切替ドア３３、エアミックスドア３５、吹出口モードドア等）の作動を制御する構成（ハードウェアおよびソフトウェア）は、空調切替制御部４０ｈを構成している。空調切替制御部４０ｈを制御装置４０に対して別体で構成してもよい。

[0164] エアミックスドア３５および空調切替制御部４０ｈは、クーラコア５１で冷却された送風空気のうちヒータコア１６を流れる送風空気とヒータコア１６を迂回して流れる送風空気との風量割合を調整する風量割合調整部である。

[0165] 内外気切替ドア３３および空調切替制御部４０ｈは、車室内へ吹き出される送風空気のうち内気と外気との割合を調整する内外気割合調整部である。

[0166] 制御装置４０のうち補助ヒータ８１（具体的には補助ヒータ用リレー８３）の作動を制御する構成（ハードウェアおよびソフトウェア）は、補助ヒータ制御部４０ｉ（電気ヒータ制御部）を構成している。補助ヒータ制御部４０ｉは、補助ヒータ８１による空気の加熱を制御する空気加熱制御部である。

[0167] 制御装置４０のうちインバータ５２の作動を制御する構成（ハードウェアおよびソフトウェア）は、インバータ制御部４０ｊを構成している。

[0168] 制御装置４０の入力側には、内気温度センサ４１、内気湿度センサ８５、外気温度センサ４２、日射センサ４３、第１水温センサ８６、第２水温セン

サ４６、ラジエータ水温センサ８７、クーラコア温度センサ８８、ヒータコア温度センサ８９、エンジン水温センサ９０、インバータ温度センサ９１、電池温度センサ９２、冷媒温度センサ９３、９４および冷媒圧力センサ９５、９６等のセンサ群の検出信号が入力される。

[0169] 内気温度センサ４１は、内気の温度（車室内温度）を検出する検出部（内気温度検出部）である。内気湿度センサ８５は、内気の湿度を検出する検出部（内気湿度検出部）である。

[0170] 外気温度センサ４２は、外気の温度（車室外温度）を検出する検出部（外気温度検出部）である。日射センサ４３は、車室内の日射量を検出する検出部(日射量検出部）である。

[0171] 第１水温センサ８６は、第１ポンプ用流路６１を流れる冷却水の温度（例えば第１ポンプ１１に吸入される冷却水の温度）を検出する検出部（第１熱媒体温度検出部）である。

[0172] 第２水温センサ４６は、第２ポンプ用流路６２を流れる冷却水の温度（例えば第２ポンプ１２に吸入される冷却水の温度）を検出する検出部（第２熱媒体温度検出部）である。

[0173] ラジエータ水温センサ８７は、ラジエータ用流路６３を流れる冷却水の温度（例えばラジエータ１３から流出した冷却水の温度）を検出する検出部（機器側熱媒体温度検出部）である。

[0174] クーラコア温度センサ８８は、クーラコア５１の表面温度を検出する検出部（クーラコア温度検出部）である。クーラコア温度センサ８８は、例えば、クーラコア５１の熱交換フィンの温度を検出するフィンサーミスタや、クーラコア５１を流れる冷却水の温度を検出する水温センサ等である。

[0175] ヒータコア温度センサ８９は、ヒータコア１６の表面温度を検出する検出部（ヒータコア温度検出部）である。ヒータコア温度センサ８９は、例えば、ヒータコア１６の熱交換フィンの温度を検出するフィンサーミスタや、ヒータコア１６を流れる冷却水の温度を検出する水温センサ等である。

[0176] エンジン水温センサ９０は、エンジン冷却回路７０を循環する冷却水の温

度（例えばエンジン７１の内部を流れる冷却水の温度）を検出する検出部（エンジン熱媒体温度検出部）である。

[0177] インバータ温度センサ９１は、インバータ用流路６６を流れる冷却水の温度（例えばインバータ５２から流出した冷却水の温度）を検出する検出部（機器側熱媒体温度検出部）である。

[0178] 電池温度センサ９２は、電池熱交換用流路６７を流れる冷却水の温度（例えば電池温調用熱交換器５３に流入する冷却水の温度）を検出する検出部（機器側熱媒体温度検出部）である。

[0179] 冷媒温度センサ９３、９４は、圧縮機２１から吐出された冷媒の温度を検出する吐出側冷媒温度センサ９３、および圧縮機２１に吸入される冷媒の温度を検出する吸入側冷媒温度センサ９４である。

[0180] 冷媒圧力センサ９５、９６は、圧縮機２１から吐出された冷媒の圧力を検出する吐出側冷媒圧力センサ９５、および圧縮機２１に吸入される冷媒の圧力を検出する吸入側冷媒温度センサ９６である。

[0181] 次に、上記構成における作動を説明する。制御装置４０が第１ポンプ１１、第２ポンプ１２、圧縮機２１、第１切替弁５５および第２切替弁５６等の作動を制御することによって、種々の作動モードに切り替えられる。

[0182] 例えば、第１ポンプ１１によって吸入されて吐出された冷却水が、冷却水冷却用熱交換器１４と、ラジエータ１３、クーラコア５１、ヒータコア１６、インバータ５２、電池温調用熱交換器５３および冷却水冷却水熱交換器５４のうち少なくとも１つの機器との間で循環する低温側冷却水回路（低温側熱媒体回路）が形成され、第２ポンプ１２によって吸入されて吐出された冷却水が、冷却水加熱用熱交換器１５と、ラジエータ１３、クーラコア５１、ヒータコア１６、インバータ５２、電池温調用熱交換器５３および冷却水冷却水熱交換器５４のうち少なくとも１つの機器との間で循環する高温側冷却水回路（高温側熱媒体回路）が形成される。

[0183] ラジエータ１３、クーラコア５１、ヒータコア１６、インバータ５２、電池温調用熱交換器５３および冷却水冷却水熱交換器５４のそれぞれについて

、低温側冷却水回路に接続される場合と、高温側冷却水回路に接続される場合とを状況に応じて切り替えることによって、ラジエータ１３、クーラコア５１、ヒータコア１６、インバータ５２、電池温調用熱交換器５３および冷却水冷却水熱交換器５４を状況に応じて適切な温度に調整できる。

[0184] ラジエータ１３が低温側冷却水回路に接続された場合、冷凍サイクル３１のヒートポンプ運転を行うことができる。すなわち、低温側冷却水回路では、冷却水冷却用熱交換器１４で冷却された冷却水がラジエータ１３を流れるので、ラジエータ１３で冷却水が外気から吸熱する。

[0185] そして、ラジエータ１３にて外気から吸熱した冷却水は、冷却水冷却用熱交換器１４で冷凍サイクル３１の冷媒と熱交換して放熱する。したがって、冷却水冷却用熱交換器１４では、冷凍サイクル３１の冷媒が冷却水を介して外気から吸熱する。

[0186] 冷却水冷却用熱交換器１４にて外気から吸熱した冷媒は、冷却水加熱用熱交換器１５にて高温側冷却水回路の冷却水と熱交換して放熱する。したがって、外気の熱を汲み上げるヒートポンプ運転を実現できる。

[0187] ラジエータ１３が高温側冷却水回路に接続された場合、冷却水加熱用熱交換器１５で加熱された冷却水がラジエータ１３を流れるので、ラジエータ１３で冷却水の熱を外気に放熱できる。

[0188] クーラコア５１が低温側冷却水回路に接続された場合、冷却水冷却用熱交換器１４で冷却された冷却水がクーラコア５１を流れるので、クーラコア５１で車室内への送風空気を冷却できる。すなわち車室内を冷房できる。

[0189] ヒータコア１６が高温側冷却水回路に接続された場合、冷却水加熱用熱交換器１５で加熱された冷却水がヒータコア１６を流れるので、ヒータコア１６で車室内への送風空気を加熱できる。すなわち車室内を暖房できる。

[0190] インバータ５２が低温側冷却水回路に接続された場合、冷却水冷却用熱交換器１４で冷却された冷却水がインバータ５２を流れるのでインバータ５２を冷却できる。換言すれば、インバータ５２の廃熱を汲み上げるヒートポンプ運転を実現できる。

[0191] インバータ５２が高温側冷却水回路に接続された場合、冷却水加熱用熱交換器１５で加熱された冷却水がインバータ５２を流れるのでインバータ５２を加熱(暖機)できる。

[0192] 電池温調用熱交換器５３が低温側冷却水回路に接続された場合、冷却水冷却用熱交換器１４で冷却された冷却水が電池温調用熱交換器５３を流れるので電池を冷却できる。換言すれば、電池の廃熱を汲み上げるヒートポンプ運転を実現できる。

[0193] 電池温調用熱交換器５３が高温側冷却水回路に接続された場合、冷却水加熱用熱交換器１５で加熱された冷却水が電池温調用熱交換器５３を流れるので電池を加熱（暖機）できる。

[0194] 冷却水冷却水熱交換器５４が低温側冷却水回路に接続された場合、冷却水冷却用熱交換器１４で冷却された冷却水が冷却水冷却水熱交換器５４を流れるのでエンジン冷却水を冷却できる。換言すれば、冷却水冷却水熱交換器５４で低温側冷却水回路の冷却水がエンジン冷却水から吸熱できるので、エンジン７１の廃熱を汲み上げるヒートポンプ運転を実現できる。

[0195] 冷却水冷却水熱交換器５４が高温側冷却水回路に接続された場合、冷却水加熱用熱交換器１５で加熱された冷却水が冷却水冷却水熱交換器５４を流れるのでエンジン冷却水を加熱できる。したがって、エンジン７１を加熱（暖機）できる。

[0196] 空調モードが暖房モードに設定された場合、制御装置４０は、図８のフローチャートに示す制御処理を実行する。暖房モードは、ヒータコア１６で送風空気を加熱して車室内へ吹き出す空調モードである。例えば、暖房モードは、内気の温度が目標吹出空気温度ＴＡＯよりも低い場合に設定される。

[0197] ステップＳ２００では、第２冷却水回路の冷却水温度Ｔｗ２（第２ポンプ用流路６２を流れる冷却水の温度）が所定値α未満であるか否かを判定する。所定値αは、定常運転時における第２冷却水回路の冷却水温度よりも低い温度値である。

[0198] 第２冷却水回路の冷却水温度Ｔｗ２が所定値α未満である場合とは、第２

冷却水回路の冷却水が冷えていて、第２冷却水回路の冷却水の温度を早期に上昇させる必要がある場合のことである。

[0199] 第２冷却水回路の冷却水温度Ｔｗ２が所定値α未満でないと判定した場合、ステップＳ２１０へ進み、図９に示す通常暖房モードを実施する。通常暖房モードでは、ラジエータ１３が低温側冷却水回路Ｃ１に接続され、ヒータコア１６が高温側冷却水回路Ｃ２に接続される。

[0200] これにより、冷却水加熱用熱交換器１５で加熱された冷却水がヒータコア１６を流れるので、ヒータコア１６で車室内への送風空気を加熱できる。すなわち車室内を暖房できる。

[0201] 一方、第２冷却水回路の冷却水温度Ｔｗ２が所定値α未満であると判定した場合、ステップＳ２２０へ進み、図１０に示すウォームアップ暖房モードの制御処理を実施する。

[0202] ウォームアップ暖房モードの制御処理のステップＳ２２１では、インバータ５２の発熱量Ｑｅが所定量以上であるか否かを判定する。所定量は、例えば、冷却水加熱用熱交換器１５での放熱量（冷却水加熱量）である。

[0203] インバータ５２の発熱量が所定量以上でないと判定した場合、ステップＳ２２２へ進み、図１１に示すヒータコアバイパスウォームアップ暖房モードの冷却水回路に切り替える。

[0204] ヒータコアバイパスウォームアップ暖房モードでは、ラジエータ１３が低温側冷却水回路Ｃ１に接続され、高温側冷却水回路Ｃ２の冷却水がヒータコア１６を流れずにバイパス流路２６を流れて循環する。

[0205] これにより、冷却水加熱用熱交換器１５で加熱された冷却水がヒータコア１６で送風空気に放熱されないので、第２冷却水回路Ｃ２の冷却水温度Ｔｗ２を速やかに上昇させることができる。

[0206] 一方、インバータ５２の発熱量が所定量以上であると判定した場合、ステップＳ２２３へ進み、図１２に示す廃熱利用ウォームアップ暖房モードの冷却水回路に切り替える。

[0207] 廃熱利用ウォームアップ暖房モードでは、ラジエータ１３が低温側冷却水

回路Ｃ１に接続され、高温側冷却水回路Ｃ２にヒータコア１６が接続されずインバータ５２が接続される。

[0208] これにより、冷却水加熱用熱交換器１５で加熱された冷却水がヒータコア１６で送風空気に放熱されないので、第２冷却水回路Ｃ２の冷却水温度Ｔｗ２を速やかに上昇させることができる。さらに、インバータ５２の廃熱で高温側冷却水回路Ｃ２の冷却水が加熱されるので、インバータ５２の廃熱を利用して第２冷却水回路Ｃ２の冷却水温度Ｔｗ２を速やかに上昇させることができる。

[0209] 廃熱利用ウォームアップ暖房モードでは、制御装置４０がインバータ５２の作動効率を意図的に低下させることによって、インバータ５２の発熱量（廃熱量）を増やすようにしてもよい。

[0210] ステップＳ２２０に続くステップＳ２３０では、ＴＡＶ＝ＴＡＯとなるような補助ヒータ吹出目標温度ＴＡＯ＿ＡＨを算出する。ＴＡＶは、室内空調ユニット３０から吹き出される空気の温度である。補助ヒータ吹出目標温度ＴＡＯ＿ＡＨは、以下の数式を用いて算出される。

[0211] ＴＡＯ＝Ａ／１００×ＴＡＯ＿ＡＨ＋Ｂ／１００×Ｔ＿ｉｎ

Ａは、室内送風機２５から送風された空気のうち、補助ヒータ８１を通過する空気の風量割合を百分率（％）で表したものである。Ｂは、室内送風機２５から送風された空気のうち、補助ヒータ８１をバイパスして流れる空気の風量割合を百分率（％）で表したものである。Ｔ＿ｉｎは、補助ヒータ８１に流入する空気の温度である。

[0212] ステップＳ２３０で用いられる各温度ＴＡＶ、ＴＡＯ、ＴＡＯ＿ＡＨ、Ｔ＿ｉｎは、絶対温度（Ｋ）で表されたものである。

[0213] 続くステップＳ２４０では、ＴＡＶ＿ＡＨ＝ＴＡＯ＿ＡＨとなる補助ヒータ通過風量Ｌを、予め制御装置４０に記憶された制御マップを参照して算出する。補助ヒータ通過風量Ｌは、補助ヒータ８１を通過する空気の風量である。ＴＡＶ＿ＡＨは、補助ヒータ８１から吹き出される空気の温度（補助ヒータ後吹出空気温度）である。

[0214] 図１３は、ステップＳ２４０で用いられる制御マップの例を示している。制御マップは、補助ヒータ通過風量Ｌと補助ヒータ後吹出空気温度ＴＡＶ＿ＡＨとの関係を補助ヒータ流入空気温度Ｔ＿ｉｎ毎に表したものである。

[0215] 図１３は、補助ヒータ流入空気温度Ｔ＿ｉｎが０℃の場合と１０℃の場合の制御マップの例を示しているが、実際には補助ヒータ流入空気温度Ｔ＿ｉｎが０℃と１０℃以外の場合についても制御マップが複数作成されている。

[0216] 図１３は、補助ヒータ８１の加熱能力が１ｋＷである場合の制御マップの例を示しているが、補助ヒータ８１の加熱能力毎に制御マップが複数作成されている。

[0217] 続くステップＳ２５０では、ステップＳ２４０で算出した補助ヒータ通過風量Ｌが所定風量（例えば１５０ｍ３／ｈ）以上であるか否かを判定する。

[0218] ステップＳ２４０で算出した補助ヒータ通過風量Ｌが所定風量以上であると判定した場合、ステップＳ２６０へ進み、ステップＳ２４０で算出した補助ヒータ通過風量Ｌが得られる室内送風機２５の駆動レベルを、予め制御装置４０に記憶された制御マップを参照して決定し、決定した駆動レベルで室内送風機２５を駆動する。

[0219] 図１４は、ステップＳ２６０で用いられる制御マップの例を示している。制御マップは、室内空調ユニット３０の風路状態（空調ユニット作動モード）と、室内送風機２５の駆動レベル（ブロワ駆動レベル）と、補助ヒータ通過風量Ｌとの関係を表したものである。

[0220] 図１４の制御マップにおいて、縦軸は、室内空調ユニット３０の風路状態（空調ユニット作動モード）であり、横軸は、室内送風機２５の駆動レベル（ブロワ駆動レベル）であり、制御マップ内の数値は、補助ヒータ通過風量Ｌである。

[0221] 図１４の制御マップにおいて、室内空調ユニット３０の風路状態は、吸込口モード（内外気切替ドア３３の切替状態）、エアミックスドア３５の作動状態、および吹出口モード（吹出口モードドアの切替状態）に応じて区分されている。

[0222] 室内送風機２５の駆動レベルは、室内送風機２５の電動モータに印加される電圧に対応する値である。制御装置４０は、ステップＳ２６０で決定されたブロワ駆動レベルに基づいて、実際に室内送風機２５の電動モータに印加される電圧を決定する。

[0223] 続くステップＳ２７０では、補助ヒータ８１の通電をオンする。これにより、補助ヒータ８１で加熱された送風空気が車室内に吹き出されて車室内が暖房される。このとき、ステップＳ２６０で決定した駆動レベルで室内送風機２５を駆動するので、補助ヒータ８１を通過する風量は、ステップＳ２４０で算出した補助ヒータ通過風量Ｌとなる。そのため、車室内に吹き出される吹出空気は、目標吹出温度ＴＡＯに近い温度となる。

[0224] 一方、ステップＳ２５０において、ステップＳ２４０で算出した補助ヒータ通過風量Ｌが所定風量以上でないと判定した場合、ステップＳ２８０へ進む。所定風量は、室内送風機２５の最低送風量以下の風量であり、予め制御装置４０に記憶されている。

[0225] ステップＳ２８０では、室内送風機２５を所定駆動力（最低駆動力）で駆動して、ステップＳ２７０へ進む。

[0226] これにより、補助ヒータ８１で加熱された送風空気が車室内に吹き出されて車室内が暖房される。このとき、補助ヒータ８１を通過する空気の風量は最低風量になるので、車室内に吹き出される吹出空気の温度が極力高くなって、目標吹出温度ＴＡＯに極力近い温度となる。

[0227] 本実施形態では、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値α未満であると判断される場合、制御装置４０は、冷却水の温度Ｔｗ２が所定値α以上であると判断される場合と比較して、ヒータコア１６を流れる冷却水の流量を減少し、かつバイパス流路２６を流れる冷却水の流量が増加するように第１切替弁５５および第２切替弁５６の作動を制御する。

[0228] これによると、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が低い場合、冷却水加熱用熱交換器１５を流れる冷却水の流量を確保しつつ、ヒータコア１６における冷却水から送風空気への放熱量を低減できるので、第２冷却水回

路Ｃ２の冷却水の温度Ｔｗ２を冷却水加熱用熱交換器１５によって早期に上昇させることができる。

[0229] さらに、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値α未満であると判断される場合、制御装置４０は、送風空気が加熱されるように補助ヒータ８１の作動を制御するとともに、冷却水の温度Ｔｗ２が所定値α以上であると判断される場合と比較して、補助ヒータ８１流れる送風空気の流量を減少させる。

[0230] これにより、補助ヒータ８１から吹き出される送風空気の温度を高めることができるので、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２を早期に上昇させるためにヒータコア１６における送風空気への放熱量を低減させても、車室内に吹き出される送風空気の温度が低下することを抑制できる。そのため、乗員の暖房感を極力確保することができる。

[0231] （第３実施形態）

上記第２実施形態では、室内空調ユニット３０のケーシング３１の内部に補助ヒータ８１が配置されているが、本実施形態では、図１５に示すように、補助ヒータ８１の代わりに補助ヒータコア１００が配置されている。

[0232] 補助ヒータコア１００は、車室内への送風空気と、エンジン冷却回路７０のエンジン冷却水（第２熱媒体）とを熱交換して送風空気を加熱する空気加熱用熱交換器（第２空気加熱用熱交換器）である。すなわち、補助ヒータコア１００は、エンジン７１（熱媒体加熱部）で加熱されたエンジン冷却水を利用して、車室内への送風空気を加熱する空気加熱部である。

[0233] 補助ヒータコア１００は、エンジン冷却回路７０において循環流路７２に配置されている。ラジエータバイパス流路７５と循環流路７２との接続部には三方弁１０１が配置されている。

[0234] 三方弁１０１は、エンジン冷却水が補助ヒータコア１００を流れる状態と流れない状態とを切り替える冷却水流れ切替部（冷却水流れ切替部）である。三方弁１０１の作動は、制御装置４０によって制御される。

[0235] 三方弁１０１によって、エンジン冷却水が補助ヒータコア１００を流れる

状態に切り替えられた場合、補助ヒータコア１００で送風空気が加熱される。三方弁１０１によって、エンジン冷却水が補助ヒータコア１００を流れない状態に切り替えられた場合、補助ヒータコア１００で送風空気が加熱されない。

[0236] したがって、制御装置４０のうち、三方弁１０１の作動を制御する構成（ハードウェアおよびソフトウェア）は、空気加熱制御部を構成している。空気加熱制御部は、制御装置４０に対して別体で構成されていてもよい。

[0237] 空調モードが暖房モードに設定された場合、制御装置４０は、図８のフローチャートと同様の制御処理を実行する。

[0238] 具体的には、図８のフローチャートのステップＳ２４０～Ｓ２６０において、補助ヒータ通過風量Ｌの代わりに補助ヒータコア１００を通過する空気の風量を用い、ステップＳ２７０において、補助ヒータ８１の通電をオンする代わりに、エンジン冷却水が補助ヒータコア１００を流れるように三方弁１０１の作動を制御する。

[0239] ステップＳ２４０では、補助ヒータ８１の加熱能力毎に作成された制御マップ（図１３）の代わりに、エンジン７１の加熱能力毎に作成された制御マップを用いる。エンジン７１の加熱能力は、エンジン冷却回路７０を循環する冷却水の温度から推定することができる。

[0240] 本実施形態においても、上記第２実施形態と同様の作用効果を奏することができる。

[0241] （第４実施形態）

図１６に示すように、冷却水加熱用熱交換器１５は、冷媒の流れ方向Ｒ１と冷却水の流れ方向Ｗ１とが対向する構造になっている。これにより、冷却水加熱用熱交換器１５の内部には、冷媒の流れ方向Ｒ１に沿って、気相域Ａ１、気液二相域Ａ２、過冷却域Ａ３が形成される。

[0242] 図１６では、気相域Ａ１、気液二相域Ａ２、過冷却域Ａ３を模式的に示している。気相域Ａ１は図１６の破線ハッチング領域であり、気液二相域Ａ２は図１６の一点鎖線ハッチング領域であり、過冷却域Ａ３は図１６の実線ハ

ッチング領域である。

[0243] 気相域Ａ１では、冷媒が気相状態になっている。気液二相域Ａ２では、冷媒が気相二相状態になっている。過冷却域Ａ３では、冷媒が過冷却状態になっている。

[0244] 本実施形態によると、冷却水加熱用熱交換器１５において冷媒の流れ方向Ｒ１と冷却水の流れ方向Ｗ１とが対向するので、冷却水加熱用熱交換器１５に流入した冷却水の全部が過冷却域Ａ３、気液二相域Ａ２、気相域Ａ１の順に流れる。

[0245] そのため、冷媒の流れ方向Ｒ１と冷却水の流れ方向Ｗ１とが直交している場合、すなわち冷却水加熱用熱交換器１５に流入した冷却水の一部のみが気相域Ａ１を流れる場合と比較して、気相域Ａ１の気相冷媒を冷却水で効果的に冷却できる。

[0246] その結果、圧縮機２１から吐出された冷媒の温度を低く抑えることができるので、圧縮機２１の効率、冷凍サイクル２０の効率、および暖房効率を向上できる。

[0247] （第５実施形態）

上記第１実施形態では、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度α未満であると判断される場合、ヒータコア１６を流れる送風空気の流量を減少させるが、本実施形態ではさらに、図１７に示すように、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度α未満であると判断される場合、冷却水加熱用熱交換器１５を流れる冷却水の流量を減少させる。

[0248] 具体的には、ステップＳ１００において第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値αを下回っていると判定した場合、ステップＳ１１５へ進み、第２ポンプ１２の回転数を低回転にする。

[0249] これにより、第２ポンプ１２から吐出される冷却水の流量が低流量になるので、冷却水加熱用熱交換器１５を流れる冷却水の流量も低流量になる。その結果、冷却水加熱用熱交換器１５における冷却水と冷媒との熱交換が抑制されるので、冷却水加熱用熱交換器１５における冷媒圧力を速やかに上昇さ

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せることができる。

[0250] ステップＳ１００において第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値αを下回っていないと判定した場合、ステップＳ１２５へ進み、第２ポンプ１２の回転数を高回転にする。

[0251] これにより、第２ポンプ１２から吐出される冷却水の流量が高流量になるので、冷却水加熱用熱交換器１５を流れる冷却水の流量も高流量になる。そのため、冷却水加熱用熱交換器１５における冷却水と冷媒との熱交換が促進される。

[0252] 本実施形態では、制御装置４０は、冷却水の温度Ｔｗ２が所定値α未満であると判断される場合、冷却水の温度Ｔｗ２が所定値α以上であると判断される場合と比較して、冷却水加熱用熱交換器１５を流れる冷却水の流量を減少させる。

[0253] これによると、冷却水の温度Ｔｗ２が所定値α未満であると判断される場合、第２ポンプ１２から吐出される冷却水の流量を低流量にするので、冷却水加熱用熱交換器１５における冷却水と冷媒との熱交換が抑制される。そのため、冷却水加熱用熱交換器１５における冷媒圧力を速やかに上昇させることができるので、速やかに十分な性能を発揮させることができる。

[0254] （第６実施形態）

上記第１実施形態では、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度α未満であると判断される場合、ヒータコア１６を流れる送風空気の流量を減少させるが、本実施形態ではさらに、図１８に示すように、第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定温度α未満であると判断される場合、ヒータコア１６を流れる冷却水の流量を冷却水加熱用熱交換器１５を流れる冷却水の流量よりも少なくさせる。

[0255] 具体的には、ステップＳ１００において第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値αを下回っていると判定した場合、ステップＳ１１８へ進み、流量調整弁２７でバイパス流路２６を開く。

[0256] これにより、バイパス流路２６に冷却水が流れるので、ヒータコア１６を

流れる冷却水の流量が冷却水加熱用熱交換器１５を流れる冷却水の流量よりも少なくなる。そのため、ヒータコア１６における冷却水と送風空気との熱交換が抑制されるので、圧縮機２１から吐出された冷媒の熱を利用して第２冷却水回路Ｃ２の冷却水の蓄熱量を増加させることができる。

[0257] ステップＳ１００において第２冷却水回路Ｃ２の冷却水の温度Ｔｗ２が所定値αを下回っていないと判定した場合、ステップＳ１２８へ進み、流量調整弁２７でバイパス流路２６を閉じる。

[0258] これにより、ヒータコア１６における冷却水と送風空気との熱交換が促進されるので、車室内への送風空気が加熱されて暖房が行われる。

[0259] 本実施形態では、制御装置４０は、冷却水の温度Ｔｗ２が所定値α未満であると判断される場合、ヒータコア１６を流れる冷却水の流量を、冷却水加熱用熱交換器１５を流れる冷却水の流量よりも少なくさせる。

[0260] これにより、ヒータコア１６における冷却水と送風空気との熱交換が抑制されるので、圧縮機２１から吐出された冷媒の熱を利用して第２冷却水回路Ｃ２の冷却水の蓄熱量を増加させることができる。

[0261] （第７実施形態）

本実施形態では、図１９に示すように、圧縮機２１から吐出された冷媒の温度ＴＲ１が第２所定値β以上であると判断される場合、圧縮機２１から吐出された冷媒の温度ＴＲ１が第２所定値β未満であると判断される場合と比較して、冷却水加熱用熱交換器１５を流れる冷却水の流量を多くさせる。

[0262] 具体的には、ステップＳ１００、Ｓ１１０に続くステップＳ１３０では、圧縮機２１から吐出された冷媒の温度ＴＲ１が第２所定値βを下回っているか否かを判定する。第２所定値βは、予め制御装置４０に記憶されている固定値である。

[0263] 圧縮機２１から吐出された冷媒の温度ＴＲ１は、吐出側冷媒温度センサによって検出される。制御装置４０は、圧縮機２１から吐出された冷媒の温度ＴＲ１を、冷却水の温度Ｔｗ２や圧縮機２１から吐出された冷媒の圧力等に基づいて算出してもよい。

[0264] ステップＳ１３０において圧縮機２１から吐出された冷媒の温度ＴＲ１が第２所定値βを下回っていると判定した場合、ステップＳ１４０へ進み、第２ポンプ１２の回転数を低回転にする。

[0265] これにより、第２ポンプ１２から吐出される冷却水の流量が低流量になるので、冷却水加熱用熱交換器１５を流れる冷却水の流量も低流量になる。その結果、冷却水加熱用熱交換器１５における冷却水と冷媒との熱交換が抑制されるので、冷却水加熱用熱交換器１５における冷媒圧力を速やかに上昇させることができる。

[0266] ステップＳ１３０において圧縮機２１から吐出された冷媒の温度ＴＲ１が第２所定値βを下回っていないと判定した場合、ステップＳ１５０へ進み、第２ポンプ１２の回転数を高回転にする。

[0267] これにより、第２ポンプ１２から吐出される冷却水の流量が高流量になるので、冷却水加熱用熱交換器１５を流れる冷却水の流量も高流量になる。そのため、冷却水加熱用熱交換器１５において冷媒から冷却水に与えられる熱量が一定なら、冷却水加熱用熱交換器１５における冷却水の温度上昇が抑制される。これは、次の関係式から明らかである。

[0268] （数１）

Ｑ＝Ｃｐ・Ｇｗ・（Ｔｏｕｔ－Ｔｉｎ）

この数式において、Ｑは、冷却水加熱用熱交換器１５において冷媒から冷却水に与えられる熱量である。Ｃｐは、冷却水の比熱である。Ｇｗは、冷却水加熱用熱交換器１５を流れる冷却水の流量である。Ｔｏｕｔは、冷却水加熱用熱交換器１５の冷却水出口における冷却水の温度である。Ｔｉｎは、冷却水加熱用熱交換器１５の冷却水入口における冷却水の温度である。

[0269] このように冷却水加熱用熱交換器１５における冷却水の温度上昇が抑制されるので、圧縮機２１から吐出された冷媒の温度ＴＲ１の上昇を抑制できる。

[0270] 本実施形態では、制御装置４０は、圧縮機２１から吐出された冷媒の温度ＴＲ１が第２所定値β以上であると判断される場合、圧縮機２１から吐出さ

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れた冷媒の温度ＴＲ１が第２所定値β未満であると判断される場合と比較して、冷却水加熱用熱交換器１５を流れる冷却水の流量を多くさせる。

[0271] これによると、冷却水加熱用熱交換器１５における冷却水の温度が低下するので、圧縮機２１から吐出された冷媒の温度ＴＲ１の上昇を抑制できる。そのため、圧縮機２１から吐出された冷媒の温度が過度に上昇して圧縮機２１の効率が低下することを抑制できるので、冷凍サイクル２０の効率を向上でき、ひいては暖房効率を向上できる。

[0272] （他の実施形態）

上記実施形態を適宜組み合わせ可能である。上記実施形態を例えば以下のように種々変形可能である。

[0273] 上記実施形態において、ヒータコア１６の代わりに、冷却水が顕熱変化にて吸熱する種々の冷却水流通機器（熱媒体流通機器）が設けられていてもよい。例えば、電池を冷却する電池冷却器が設けられていてもよい。

[0274] 上記実施形態において、冷却水加熱用熱交換器１５の代わりに、冷凍サイクル２０の高圧側冷媒と外気とを熱交換させることによって高圧側冷媒の熱を外気に放熱する冷媒用放熱器が設けられていてもよい。

[0275] 上記第１実施形態において、第１冷却水回路Ｃ１および第２冷却水回路Ｃ２に、冷却水によって温度調整（冷却・加熱）される種々の温度調整対象機器（冷却対象機器・加熱対象機器）が配置されていてもよい。

[0276] さらに、第１冷却水回路Ｃ１および第２冷却水回路Ｃ２が切替弁を介して接続され、切替弁が、第１冷却水回路Ｃ１および第２冷却水回路Ｃ２に配置された複数個の熱媒体流通機器のそれぞれに対して、第１ポンプ１１によって吸入・吐出される冷却水が循環する場合と、第２ポンプ１２によって吸入・吐出される冷却水が循環する場合とを切り替えるようにしてもよい。

[0277] 上記実施形態では、ヒータコア１６を流れる熱媒体として冷却水を用いているが、油などの各種媒体を熱媒体として用いてもよい。熱媒体として、エチレングリコール系の不凍液、水、または一定の温度以上に維持された空気等を用いてもよい。

[0278] 熱媒体として、ナノ流体を用いてもよい。ナノ流体とは、粒子径がナノメートルオーダーのナノ粒子が混入された流体のことである。ナノ粒子を熱媒体に混入させることで、エチレングリコールを用いた冷却水（いわゆる不凍液）のように凝固点を低下させる作用効果に加えて、次のような作用効果を得ることができる。

[0279] すなわち、特定の温度帯での熱伝導率を向上させる作用効果、熱媒体の熱容量を増加させる作用効果、金属配管の防食効果やゴム配管の劣化を防止する作用効果、および極低温での熱媒体の流動性を高める作用効果を得ることができる。

[0280] このような作用効果は、ナノ粒子の粒子構成、粒子形状、配合比率、付加物質によって様々に変化する。

[0281] これによると、熱伝導率を向上させることができるので、エチレングリコールを用いた冷却水と比較して少ない量の熱媒体であっても同等の冷却効率を得ることが可能になる。

[0282] また、熱媒体の熱容量を増加させることができるので、熱媒体自体の蓄冷熱量（顕熱による蓄冷熱）を増加させることができる。

[0283] 蓄冷熱量を増加させることにより、圧縮機２１を作動させない状態であっても、ある程度の時間は蓄冷熱を利用した機器の冷却、加熱の温調が実施できるため、車両用熱管理装置１０の省動力化が可能になる。

[0284] ナノ粒子のアスペクト比は５０以上であるのが好ましい。十分な熱伝導率を得ることができるからである。なお、アスペクト比は、ナノ粒子の縦×横の比率を表す形状指標である。

[0285] ナノ粒子としては、Ａｕ、Ａｇ、ＣｕおよびＣのいずれかを含むものを用いることができる。具体的には、ナノ粒子の構成原子として、Ａｕナノ粒子、Ａｇナノワイヤー、ＣＮＴ（カーボンナノチューブ）、グラフェン、グラファイトコアシェル型ナノ粒子（上記原子を囲むようにカーボンナノチューブ等の構造体があるような粒子体）、およびＡｕナノ粒子含有ＣＮＴなどを用いることができる。

[0286] 上記実施形態では、冷凍サイクル２０の蒸発器１４で低圧側冷媒と第１冷却水回路Ｃ１の冷却水とを熱交換させるようになっているが、冷凍サイクル２０の蒸発器１４で低圧側冷媒と外気とを熱交換させるようにしてもよい。

[0287] 上記実施形態の冷凍サイクル２０では、冷媒としてフロン系冷媒を用いているが、冷媒の種類はこれに限定されるものではなく、二酸化炭素等の自然冷媒や炭化水素系冷媒等を用いてもよい。

[0288] また、上記実施形態の冷凍サイクル２０は、高圧側冷媒圧力が冷媒の臨界圧力を超えない亜臨界冷凍サイクルを構成しているが、高圧側冷媒圧力が冷媒の臨界圧力を超える超臨界冷凍サイクルを構成していてもよい。

[0289] 上記実施形態では、車両用熱管理装置１０をハイブリッド自動車に適用した例を示したが、エンジンを備えず走行用電動モータから車両走行用の駆動力を得る電気自動車等に車両用熱管理装置１０を適用してもよい。

[0290] 上記第２実施形態では、発熱機器としてインバータ５２を備えているが、インバータ５２の他に種々の発熱機器を備えていてもよい。発熱機器の他の例としては、走行用電動モータや各種エンジン機器などが挙げられる。

[0291] 各種エンジン機器としては、ターボチャージャ、インタークーラ、ＥＧＲクーラ、ＣＶＴクーラ（ウォーマ）、排気熱回収器などが挙げられる。

[0292] ターボチャージャは、エンジンの吸入空気（吸気）を過給する過給機である。インタークーラは、ターボチャージャで圧縮されて高温になった過給吸気と冷却水とを熱交換して過給吸気を冷却する吸気冷却器（吸気熱媒体熱交換器）である。

[0293] ＥＧＲクーラは、エンジンの吸気側に戻されるエンジン排気ガス（排気）と冷却水とを熱交換して排気を冷却する排気冷却水熱交換器（排気熱媒体熱交換器）である。

[0294] ＣＶＴクーラ（ウォーマ）は、ＣＶＴ（無段変速機）を潤滑する潤滑油（ＣＶＴオイル）と冷却水とを熱交換してＣＶＴオイルを冷却（加熱）する潤滑油冷却水熱交換器（潤滑油熱媒体熱交換器）である。

[0295] 排気熱回収器は、排気と冷却水とを熱交換して冷却水に排気の熱を吸熱さ

せる排気冷却水熱交換器（排気熱媒体熱交換器）である。

[0296] 上記第２実施形態のステップＳ２２１～Ｓ２２３では、インバータ５２の発熱量Ｑｅが所定量以上でないと判定した場合、ヒータコアバイパスウォームアップ暖房モードを実施し、インバータ５２の発熱量Ｑｅが所定量以上であると判定した場合、廃熱利用ウォームアップ暖房モードを実施するが、以下の数式の条件を満たす場合、廃熱利用ウォームアップ暖房モードを実施し、以下の数式の条件を満たさない場合、ヒータコアバイパスウォームアップ暖房モードを実施するようにしてもよい。

[0297] （Ｈｍ／Ｑｅ）×ΔＴ≦ｔｂ

上記数式において、Ｈｍは、インバータ５２およびインバータ用流路６６の熱容量と、それらの中に含まれる冷却水の熱容量との和である。ΔＴは、第２冷却水回路の冷却水温度の目標温度から、現状の第２冷却水回路の冷却水温度Ｔｗ２を減じた温度差である。

[0298] 上記数式において、ｔｂは、ヒータコアバイパスウォームアップ暖房モードの冷却水回路構成において第２冷却水回路の冷却水温度が目標温度に到達するまでの時間である。ｔｂは、各温度条件に対して予め測定した値であり、制御装置４０に記憶されている。

[0299] これにより、インバータ５２の発熱量Ｑｅに応じて、廃熱利用ウォームアップ暖房モードおよびヒータコアバイパスウォームアップ暖房モードのうち、第２冷却水回路の冷却水温度Ｔｗ２が目標温度に到達するまでの時間が短くなる方のモードを選択できる。

[0300] 上記第３実施形態では、補助ヒータコア１００はエンジン冷却回路７０に配置されているが、補助ヒータコア１００は、燃料電池を冷却するための冷却水循環回路に配置されていてもよい。これにより、燃料電池で加熱された冷却水（第２熱媒体）によって送風空気を加熱できる。

[0301] 補助ヒータコア１００は、インバータ５２を冷却するための冷却水循環回路に配置されていてもよい。これにより、インバータ５２で加熱された冷却水（第２熱媒体）によって送風空気を加熱できる。

[0302] 補助ヒータコア１００には、電気ヒータで加熱された冷却水（第２熱媒体）が循環するようになっていてもよい。これにより、電気ヒータで加熱された冷却水によって送風空気を加熱できる。

[0303] 補助ヒータコア１００には、燃焼式ヒータで加熱された冷却水（第２熱媒体）が循環するようになっていてもよい。燃焼式ヒータは、ガソリンなどの液体燃料を燃焼させて得られる熱を冷却水へと伝熱することによって冷却水を加熱する冷却水加熱部である。これにより、燃焼式ヒータで加熱された冷却水によって送風空気を加熱できる。

請求の範囲

[請求項1] 車室内への送風空気を発生させる送風機（２５）と、

冷媒を吸入して吐出する圧縮機（２１）と、

前記圧縮機（２１）から吐出された冷媒と熱媒体とを熱交換させて前記熱媒体を加熱する熱媒体加熱用熱交換器（１５）と、

前記熱媒体加熱用熱交換器（１５）で加熱された前記熱媒体と前記送風空気とを熱交換させて前記送風空気を加熱する空気加熱用熱交換器（１６）と、

前記熱媒体の温度（Ｔｗ２）が所定値（α）未満であると判断される場合、前記熱媒体の温度（Ｔｗ２）が前記所定値（α）以上であると判断される場合と比較して、前記空気加熱用熱交換器（１６）を流れる前記送風空気の流量を減少させる空気流量制御部（４０ｅ）とを備える車両用空調装置。

[請求項2] 冷媒を吸入して吐出する圧縮機（２１）と、

前記圧縮機（２１）から吐出された冷媒と熱媒体とを熱交換させて前記熱媒体を加熱する熱媒体加熱用熱交換器（１５）と、

前記熱媒体加熱用熱交換器（１５）で加熱された前記熱媒体と車室内へ流れる空気とを熱交換させて前記空気を加熱する空気加熱用熱交換器（１６）と、

前記空気加熱用熱交換器（１６）を流れる前記空気の流量を制御する空気流量制御部（２５、３５、４０ｅ、４０ｈ）とを備え、

前記熱媒体の温度（Ｔｗ２）が所定値（α）未満であると判断される場合、前記熱媒体の温度（Ｔｗ２）が前記所定値（α）以上であると判断される場合と比較して、前記空気加熱用熱交換器（１６）を流れる前記空気の流量を前記空気流量制御部（２５、３５、４０ｅ、４０ｈ）で減少させることによって、前記冷媒の熱を利用して前記熱媒体の蓄熱量を増加させる車両用空調装置。

[請求項3] 前記空気流量制御部（４０ｅ）は、前記熱媒体の温度（Ｔｗ２）が

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前記所定値（α）未満であると判断される場合、前記送風機（２５）を停止させ、前記熱媒体の温度（Ｔｗ２）が前記所定値（α）以上であると判断される場合、前記送風機（２５）を作動させる送風機制御部である請求項１または２に記載の車両用空調装置。

[請求項4] 前記熱媒体加熱用熱交換器（１５）は、前記冷媒の流れ方向と前記熱媒体の流れ方向とが対向する構造になっている請求項１ないし３のいずれか１つに記載の車両用空調装置。

[請求項5] 前記熱媒体の温度（Ｔｗ２）が前記所定値（α）未満であると判断される場合、前記熱媒体の温度（Ｔｗ２）が前記所定値（α）以上であると判断される場合と比較して、前記熱媒体加熱用熱交換器（１５）を流れる前記熱媒体の流量を減少させる熱媒体流量制御部（１１、１２、２６、２７、４０、５５、５６）とを備える請求項１ないし４のいずれか１つに記載の車両用空調装置。

[請求項6] 前記熱媒体の温度（Ｔｗ２）が前記所定値（α）未満であると判断される場合、前記空気加熱用熱交換器（１６）を流れる前記熱媒体の流量を、前記熱媒体加熱用熱交換器（１５）を流れる前記熱媒体の流量よりも少なくさせる熱媒体流量制御部（１１、１２、２６、２７、４０、５５、５６）とを備える請求項１ないし４のいずれか１つに記載の車両用空調装置。

[請求項7] 前記熱媒体流量制御部（１１、１２、２６、２７、４０、５５、５６）は、前記圧縮機（２１）から吐出された前記冷媒の温度（ＴＲ１）が第２所定値（β）以上であると判断される場合、前記圧縮機（２１）から吐出された前記冷媒の温度（ＴＲ１）が前記第２所定値（β）未満であると判断される場合と比較して、前記熱媒体加熱用熱交換器（１５）を流れる前記熱媒体の流量を多くさせる請求項５に記載の車両用空調装置。

[請求項8] 前記圧縮機（２１）および前記熱媒体加熱用熱交換器（１５）は、冷媒が外部から吸熱することなく循環するホットガスサイクルを構成

している請求項１ないし７のいずれか１つに記載の車両用空調装置。

[請求項9] 前記熱媒体は、エチレングリコール系の不凍液、水、または一定の温度以上に維持された空気である請求項１ないし８のいずれか１つに記載の車両用空調装置。

[請求項10] 前記空気流量制御部（４０ｅ）は、前記熱媒体の温度（Ｔｗ２）が前記所定値（α）に近づくように、前記空気加熱用熱交換器（１６）を流れる前記送風空気の流量を制御する請求項１ないし９のいずれか１つに記載の車両用空調装置。

[請求項11] 前記熱媒体の温度（Ｔｗ２）が前記所定値（α）に近づくように、前記空気加熱用熱交換器（１６）を流れる前記熱媒体の流量を制御する熱媒体流量制御部（２６、２７、４０ｆ、４０ｇ、５５、５６）を備える請求項１ないし４のいずれか１つに記載の車両用空調装置。

[請求項12] 前記熱媒体の温度（Ｔｗ２）が前記所定値（α）に近づくように、前記圧縮機（２１）から吐出される前記冷媒の流量を制御する冷媒流量制御部（４０ｃ）を備える請求項１ないし４のいずれか１つに記載の車両用空調装置。

[請求項13] 前記熱媒体流量制御部は、前記熱媒体が前記空気加熱用熱交換器（１６）をバイパスして流れるバイパス流路（２６）と、前記バイパス流路（２６）を流れる前記熱媒体の流量を調整する流量調整弁（２７、５５、５６）とを有している請求項５ないし７および１１のいずれか１つに記載の車両用空調装置。

[請求項14] 前記送風空気を加熱する空気加熱部（８１、１００）と、

前記空気加熱部（８１、１００）の作動を制御する空気加熱制御部（４０ｉ）と、

前記流量調整弁（５５、５６）の作動を制御する流量調整弁制御部（４０ｇ）とを備え、

前記熱媒体の温度（Ｔｗ２）が所定値（α）未満であると判断される場合、

前記流量調整弁制御部（４０ｇ）は、前記熱媒体の温度（Ｔｗ２）が前記所定値（α）以上であると判断される場合と比較して、前記空気加熱用熱交換器（１６）を流れる前記熱媒体の流量を減少し、かつ前記バイパス流路（２６）を流れる前記熱媒体の流量が増加するように前記流量調整弁（５５、５６）の作動を制御し、

前記空気加熱制御部（４０ｉ）は、前記送風空気が加熱されるように前記空気加熱部（８１、１００）の作動を制御し、

前記空気流量制御部（４０ｅ）は、前記熱媒体の温度（Ｔｗ２）が前記所定値（α）以上であると判断される場合と比較して、前記空気加熱部（８１、１００）を流れる前記送風空気の流量を減少させる請求項１３に記載の車両用空調装置。

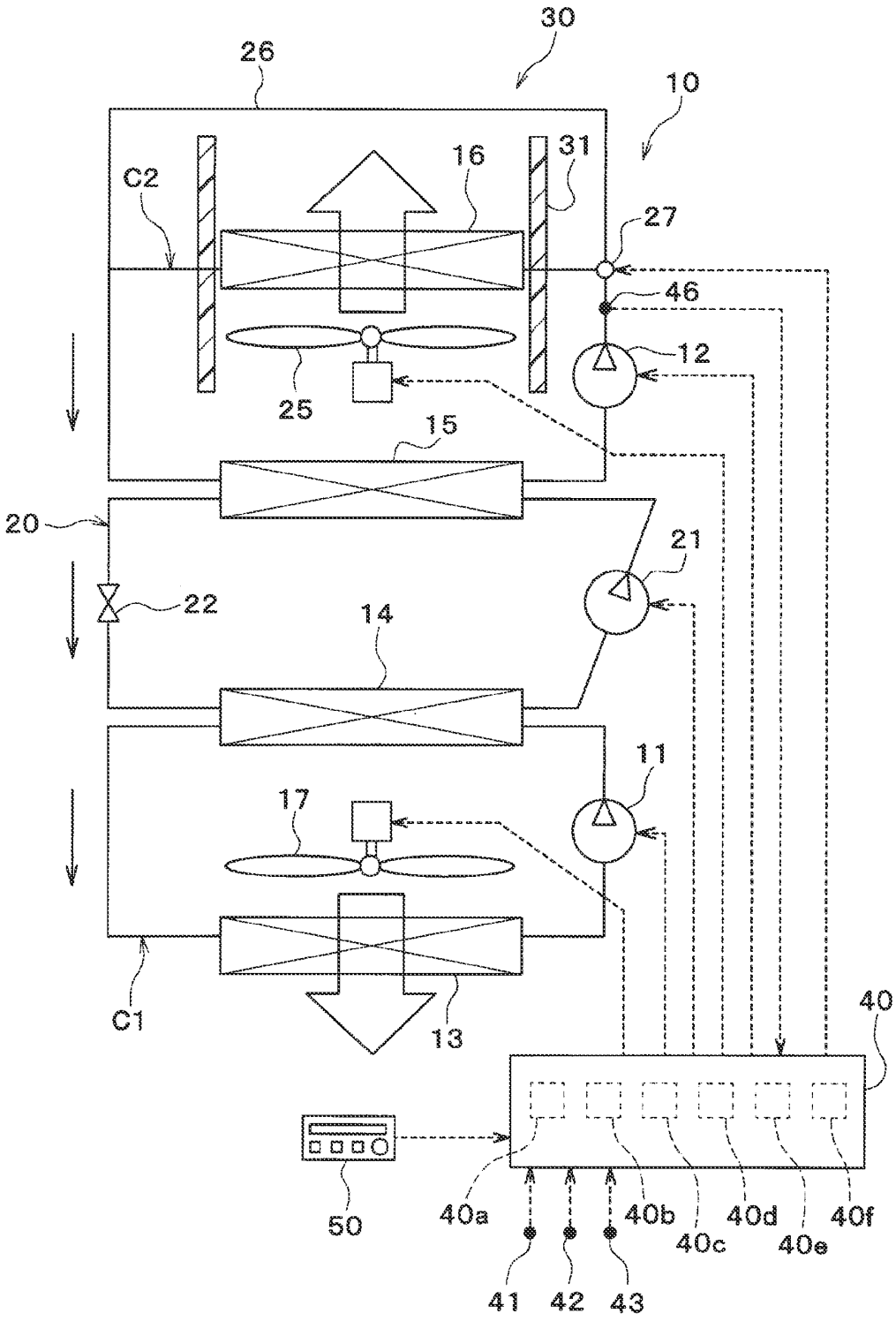
[請求項15] 前記空気加熱部は、通電されると発熱する電気ヒータ（８１）である請求項１４に記載の車両用空調装置。

[請求項16] 第２熱媒体を加熱する熱媒体加熱部（７１）を備え、

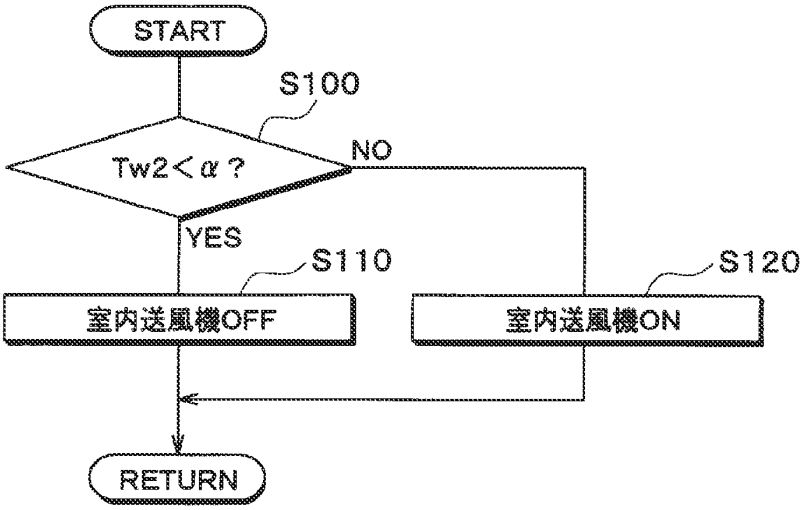
前記空気加熱部は、前記熱媒体加熱部（７１）で加熱された前記第２熱媒体と前記送風空気とを熱交換させて前記送風空気を加熱する第２空気加熱用熱交換器（１００）である請求項１４に記載の車両用空調装置。

[請求項17] 前記所定値（α）を、少なくとも外気温度に基づいて算出する算出部（４０）を備える請求項１ないし１６のいずれか１つに記載の車両用空調装置。

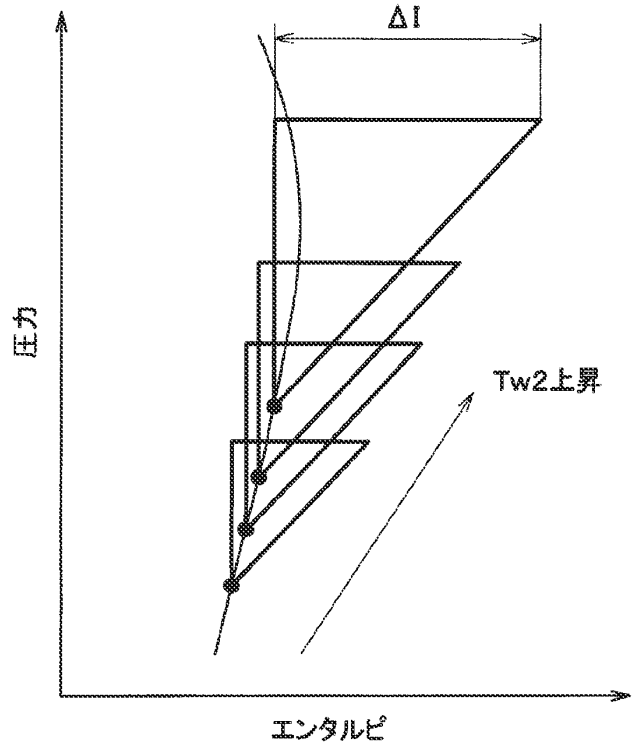
[図1]


30
26
10
C2
16
31
27
46
12
25
15
20
21
22
14
11
17
C1
13
40
50
40a
40b
40c
40d
40e
40f
41
42
43

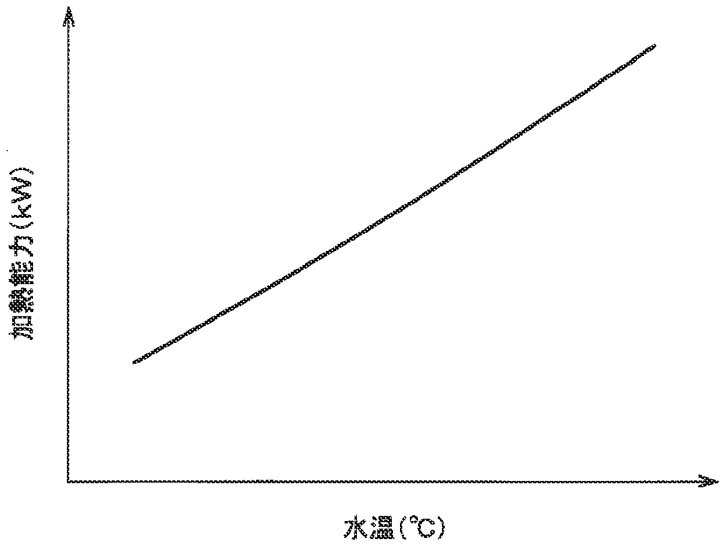
[図2]


START
S100
Tw2＜α？
NO
YES
S110
S120
室内送風機OFF
室内送風機ON
RETURN

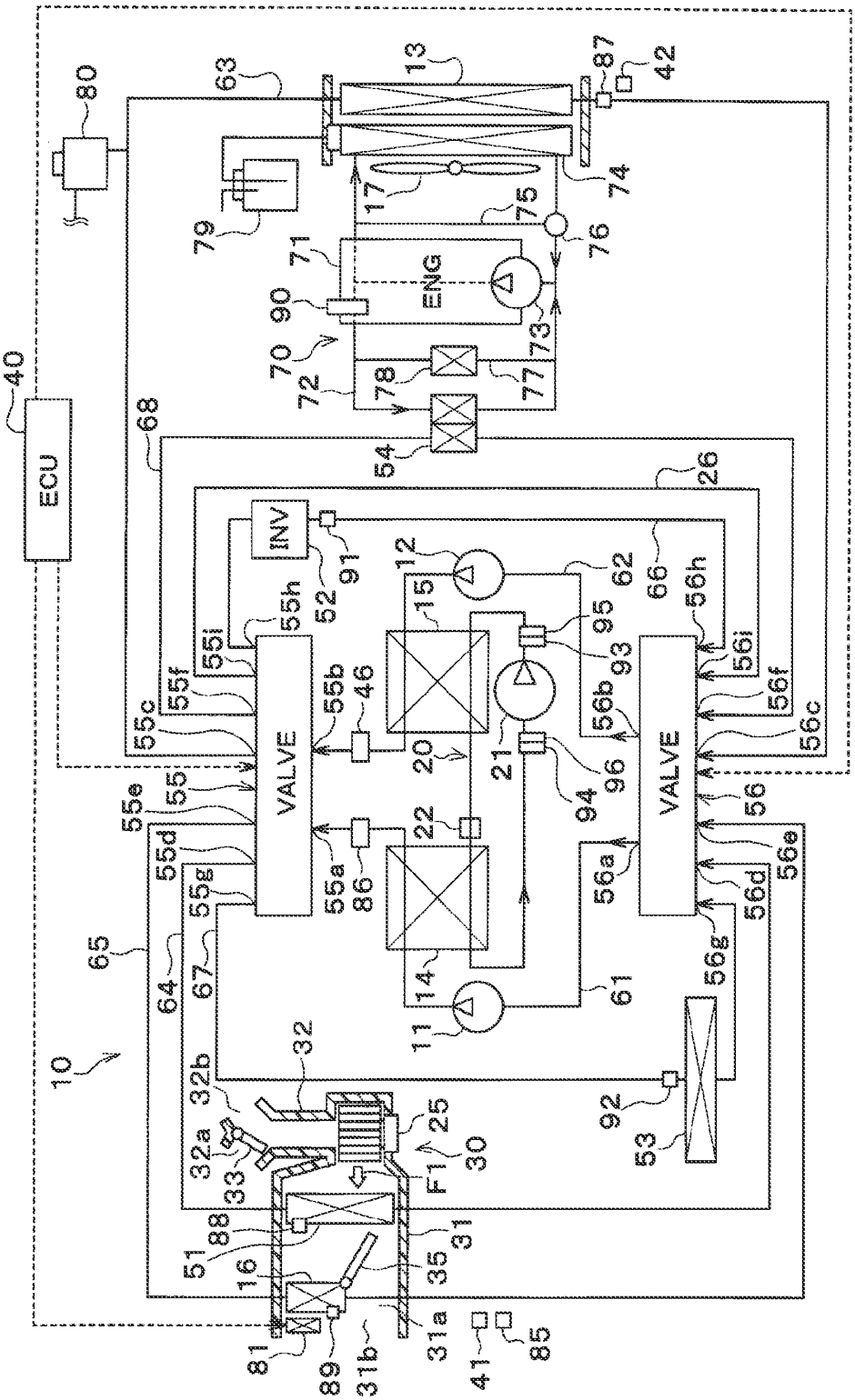
[図3]


ΔI
圧力
Tw2上昇
エンタルピ

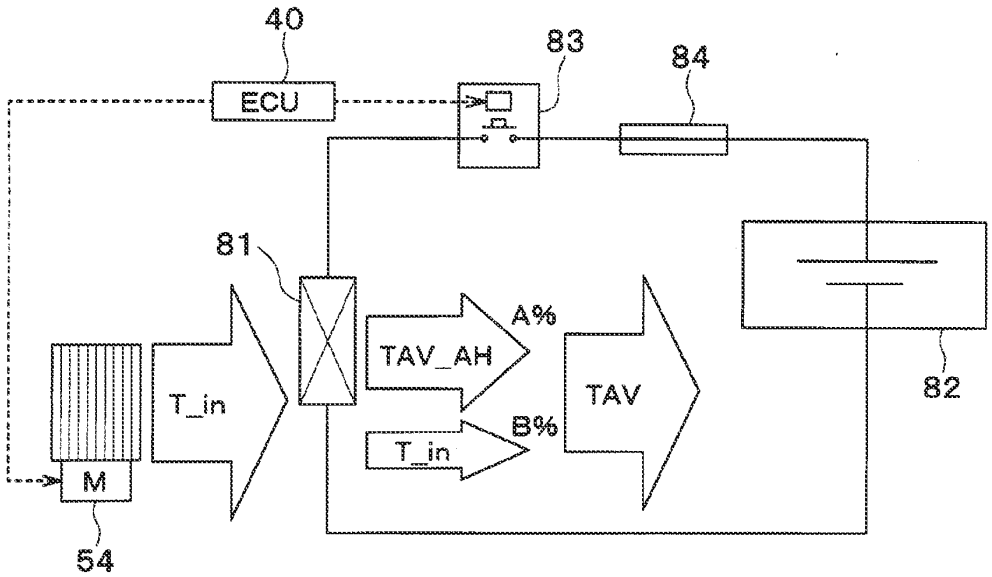
[図4]



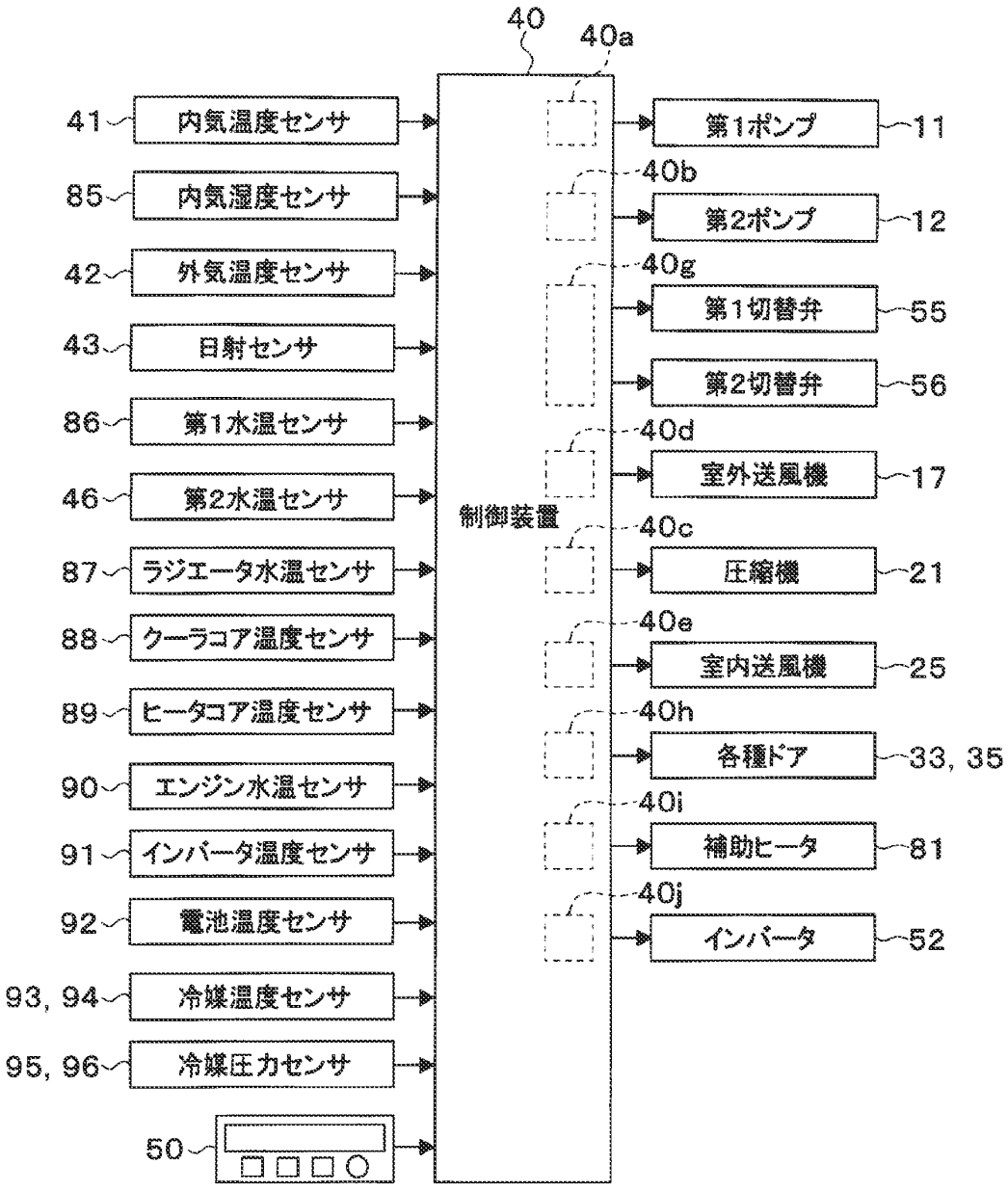
[図5]



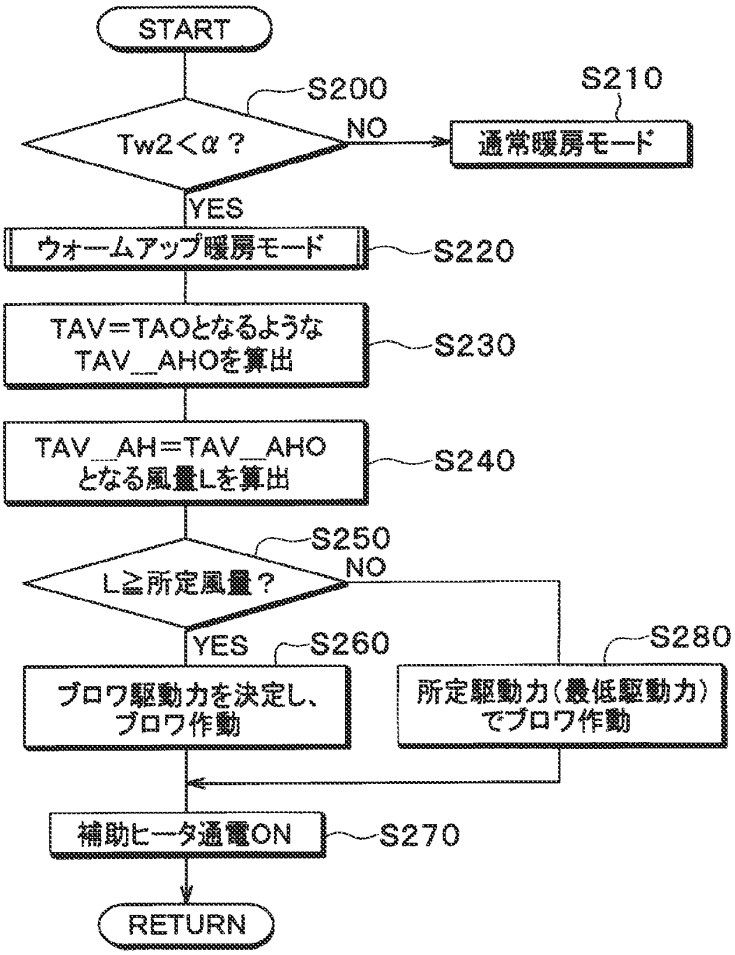
[図6]



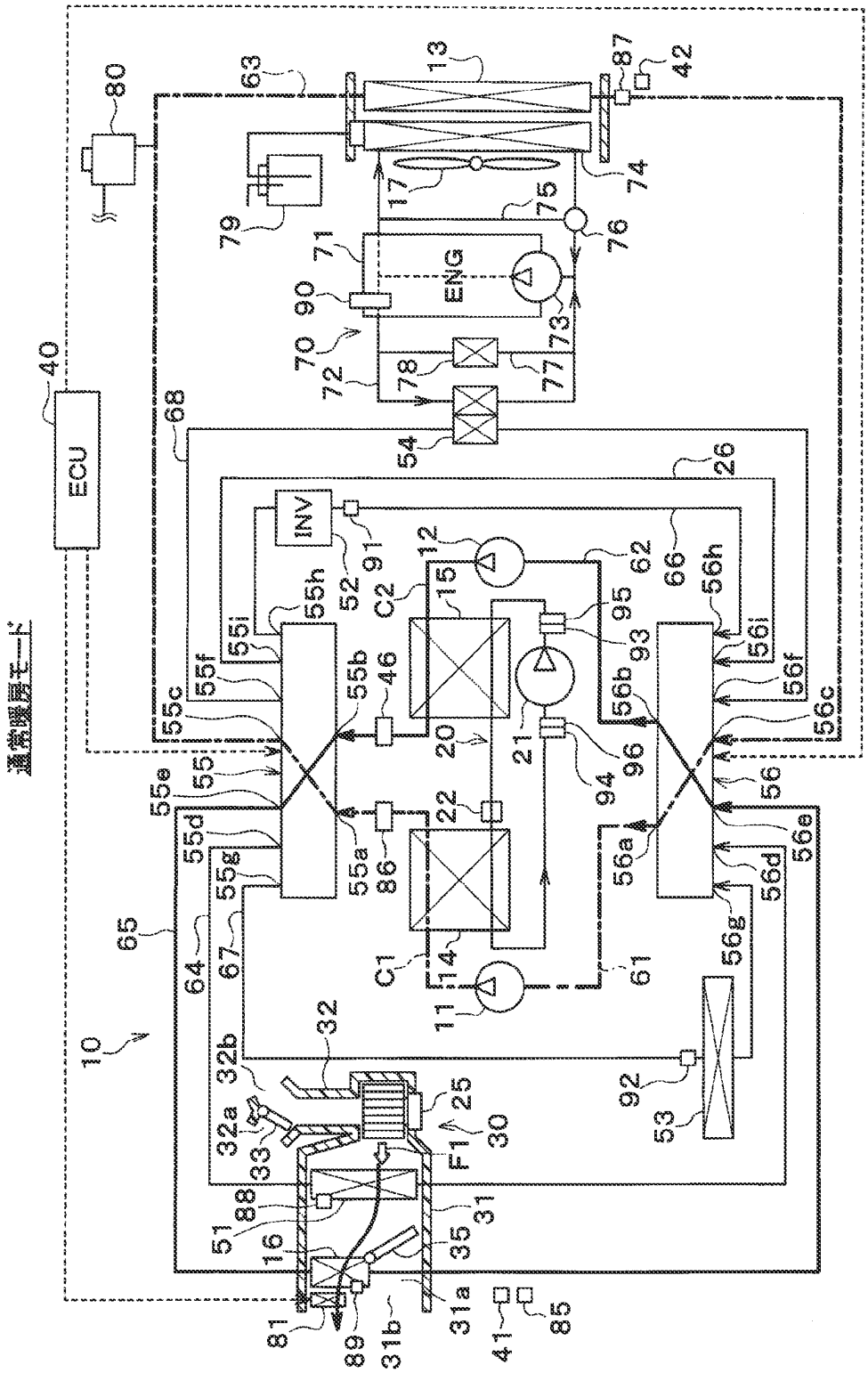
[図7]


40
40a
41
内気温度センサ
85
内気湿度センサ
42
外気温度センサ
43
日射センサ
86
第1水温センサ
46
第2水温センサ
87
ラジエータ水温センサ
88
クーラコア温度センサ
89
ヒータコア温度センサ
90
エンジン水温センサ
91
インバータ温度センサ
92
電池温度センサ
93, 94
冷媒温度センサ
95, 96
冷媒圧力センサ
50
制御装置
第1ポンプ
11
40b
第2ポンプ
12
40g
第1切替弁
55
第2切替弁
56
40d
室外送風機
17
40c
圧縮機
21
40e
室内送風機
25
40h
各種ドア
33, 35
40i
補助ヒータ
81
40j
インバータ
52

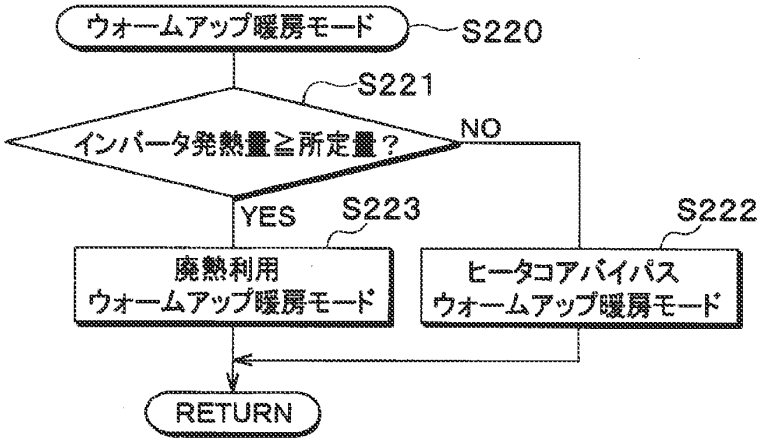
[図8]


START
S200
Tw2＜α？
NO
S210
通常暖房モード
YES
ウォームアップ暖房モード
S220
TAV＝TAOとなるような
TAV_AHOを算出
S230
TAV_AH＝TAV_AHO
となる風量Lを算出
S240
S250
L≧所定風量？
NO
YES
S260
ブロワ駆動力を決定し、
ブロワ作動
S280
所定駆動力（最低駆動力）
でブロワ作動
補助ヒータ通電ON
S270
RETURN

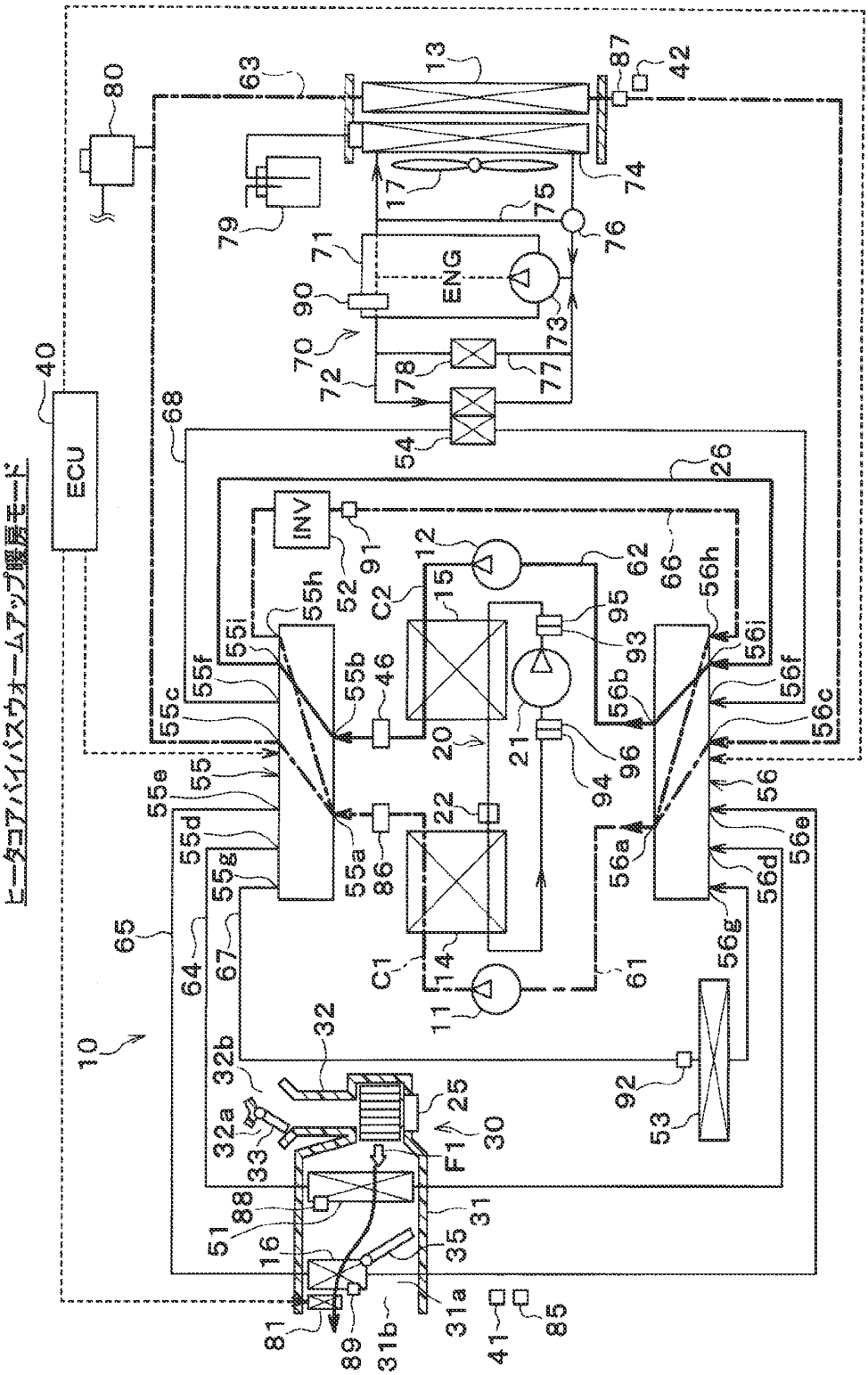
[図9]


通常暖房モード
ECU
INV
ENG
10
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31a
31b
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32a
32b
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55a
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55c
55d
55e
55f
55g
55h
55i
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56a
56b
56c
56d
56e
56f
56g
56h
56i
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C1
C2
F1

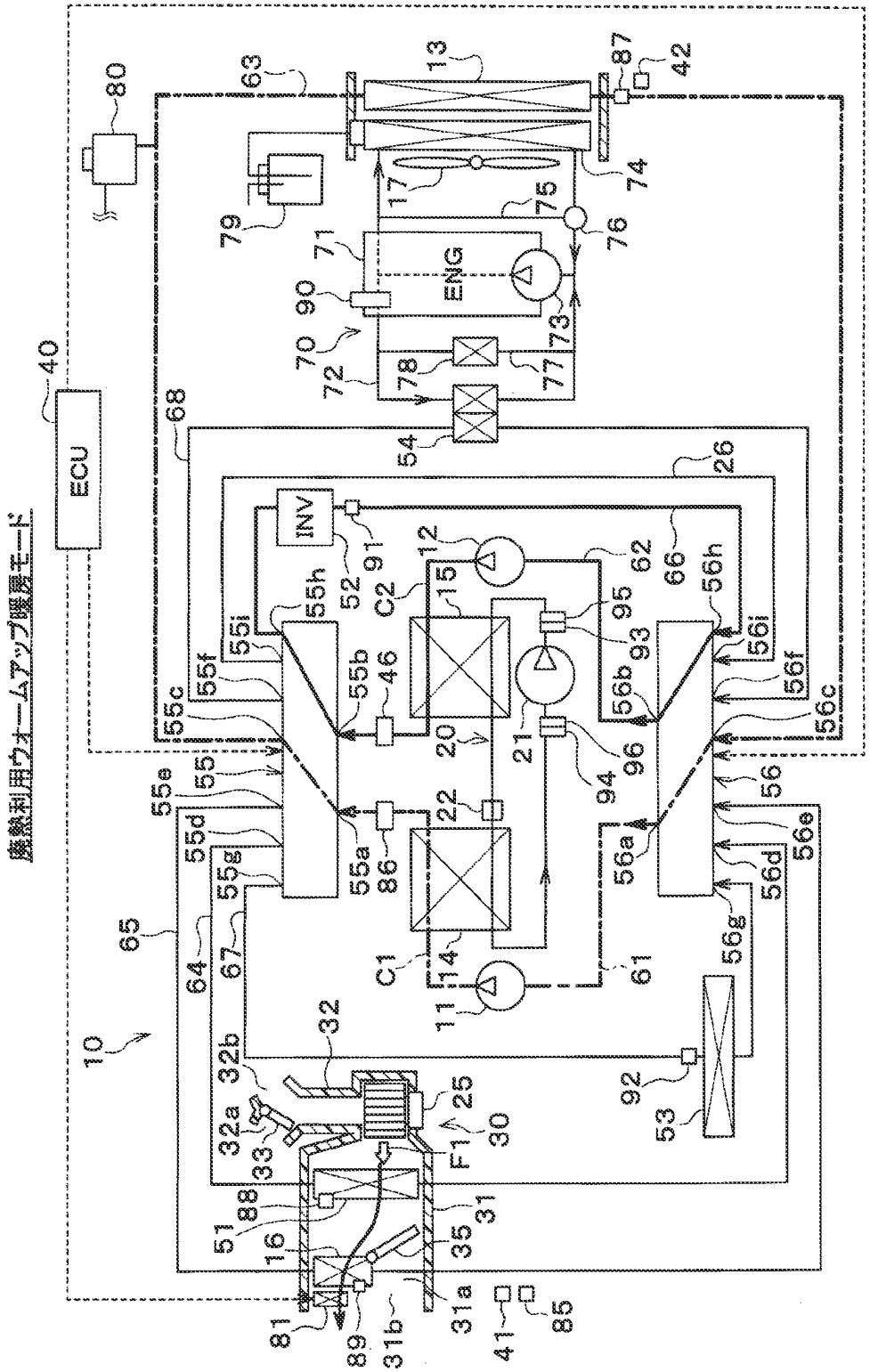
[図10]


ウォームアップ暖房モード
S220
S221
インバータ発熱量≧所定量？
NO
YES
S223
S222
廃熱利用
ウォームアップ暖房モード
ヒータコアバイパス
ウォームアップ暖房モード
RETURN

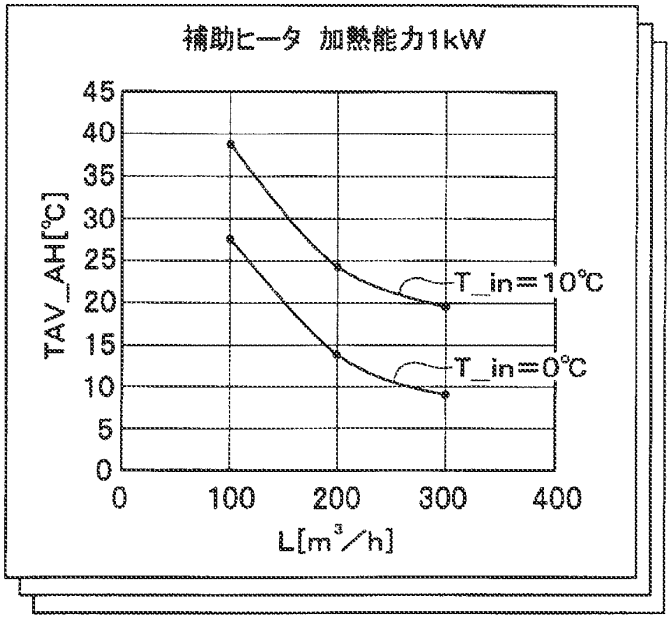
[図11]


ヒータコアバイパスウォームアップ暖房モード
ECU
INV
ENG
10
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31a
31b
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32a
32b
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C1
C2
F1

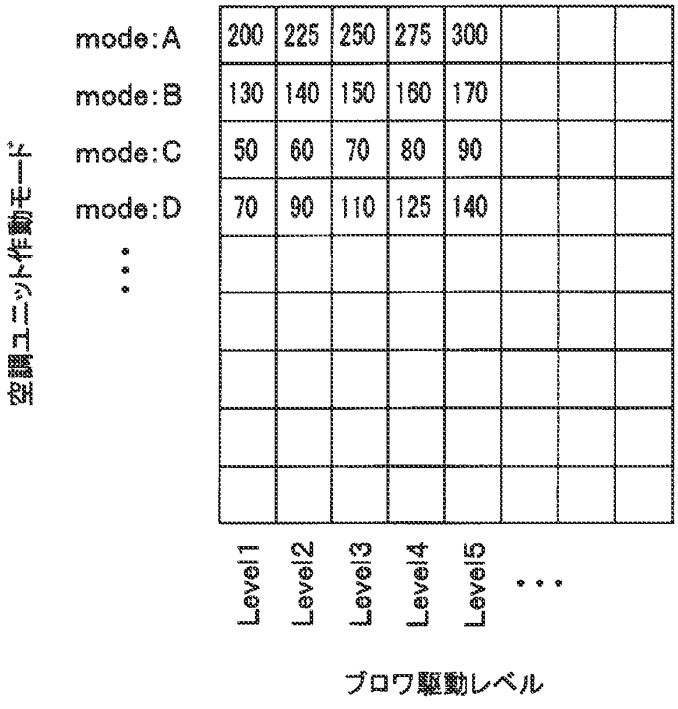
[図12]



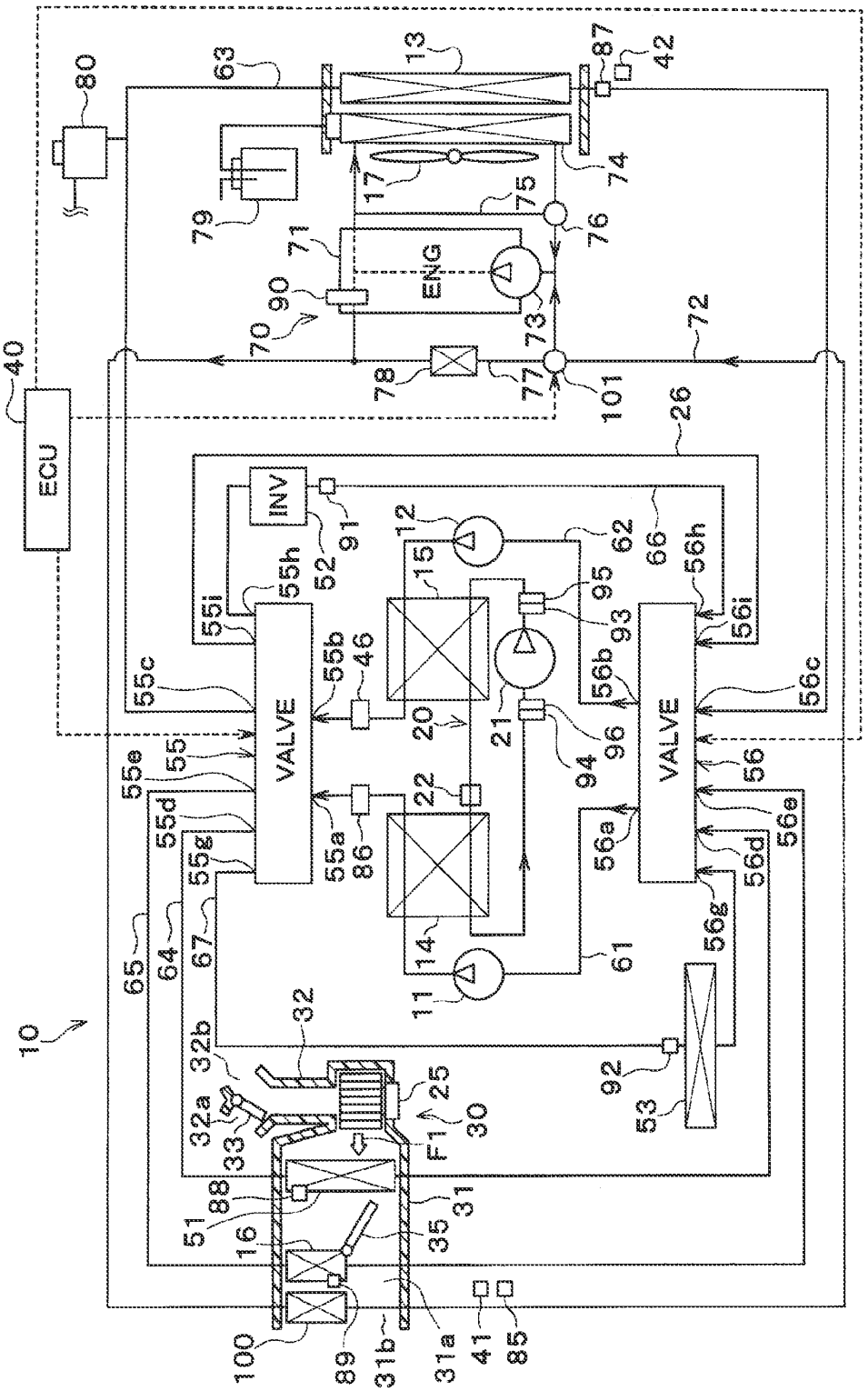
[図13]


補助ヒータ 加熱能力1kW
TAV_AH[℃]
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
L[m³/h]
T_in＝10℃
T_in＝0℃

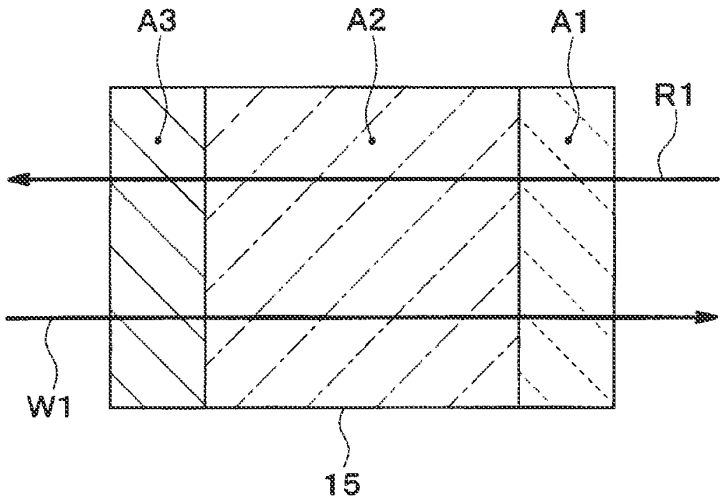
[図14]


空調ユニット作動モード
mode:A
mode:B
mode:C
mode:D
200 225 250 275 300
130 140 150 160 170
50 60 70 80 90
70 90 110 125 140
Level1
Level2
Level3
Level4
Level5
ブロワ駆動レベル

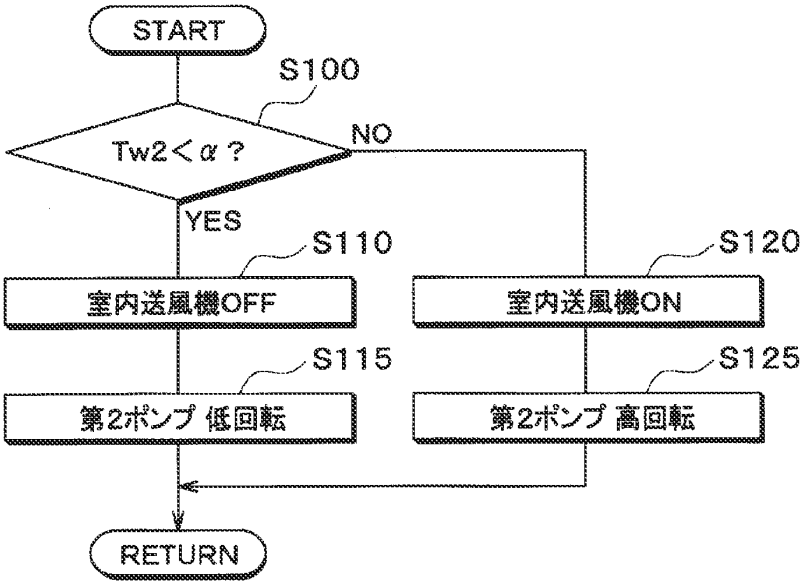
[図15]


ECU
INV
VALVE
VALVE
ENG
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100
101
F1

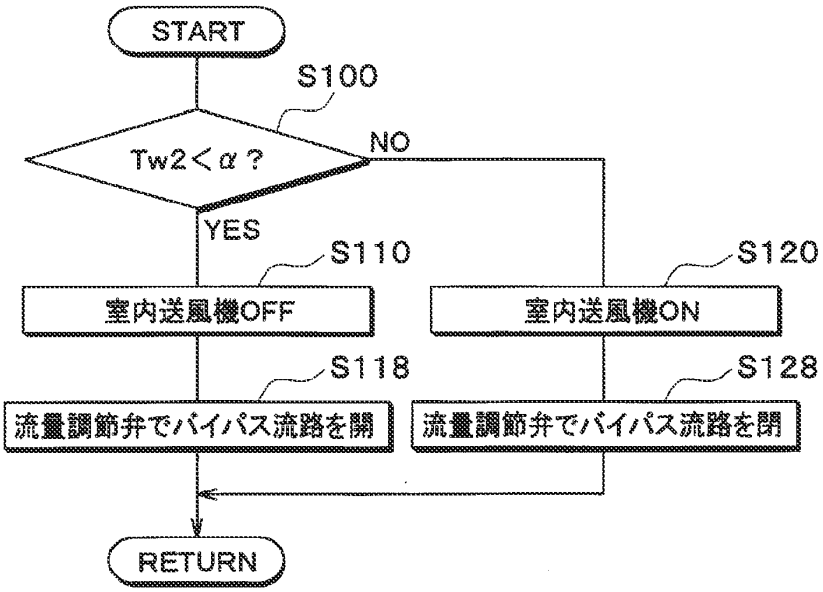
[図16]


A3
A2
A1
R1
W1
15

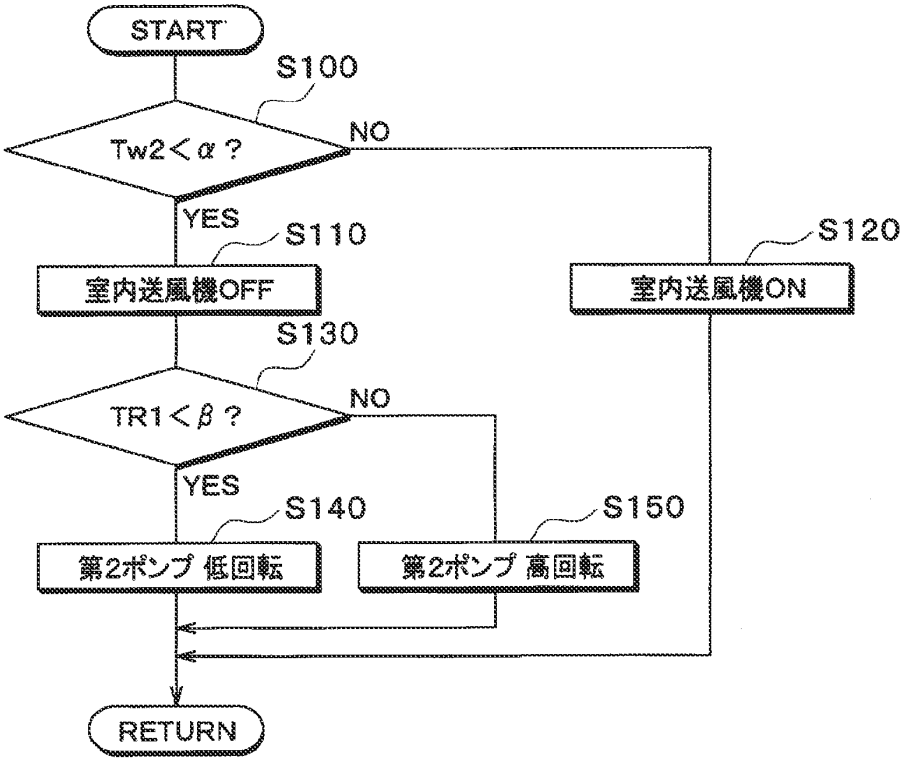
[図17]


START
S100
Tw2＜α？
NO
YES
S110
室内送風機OFF
S120
室内送風機ON
S115
第2ポンプ 低回転
S125
第2ポンプ 高回転
RETURN

[図18]


START
S100
Tw2＜α？
NO
YES
S110
室内送風機OFF
S120
室内送風機ON
S118
流量調節弁でバイパス流路を開
S128
流量調節弁でバイパス流路を閉
RETURN

[図19]


START
S100
Tw2＜α？
NO
YES
S110
室内送風機OFF
S120
室内送風機ON
S130
TR1＜β？
NO
YES
S140
第2ポンプ 低回転
S150
第2ポンプ 高回転
RETURN

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/003609

A. CLASSIFICATION OF SUBJECT MATTER
B60H1/22(2006.01)i, *B60H1/00*(2006.01)i, *B60H1/03*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B60H1/22, B60H1/00, B60H1/03

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2014
Kokai Jitsuyo Shinan Koho 1971-2014 Toroku Jitsuyo Shinan Koho 1994-2014

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	WO 2012/143119 A1 (VALEO SYSTEMS THERMIQUES), 26 October 2012 (26.10.2012), column 7, line 24 to column 19, line 19; fig. 1 to 3 & WO 2012/143119 A1 & CN 103732427 A	1-4,6,8-17 5,7
Y A	JP 2012-11927 A (Panasonic Corp.), 19 January 2012 (19.01.2012), paragraphs [0008] to [0010], [0062] to [0067]; fig. 1 to 2 (Family: none)	1-4,6,8-17 5,7

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 October, 2014 (07.10.14)	21 October, 2014 (21.10.14)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/003609

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2004-50873 A (Toyota Motor Corp.), 19 February 2004 (19.02.2004), paragraphs [0018] to [0031], [0042] to [0048]; fig. 1 to 4 & US 2006/0032623 A1 & EP 1533154 A1 & WO 2004/007224 A1 & DE 60321005 D & BR 312713 A & PL 373097 A & KR 10-2005-0048588 A & CN 1738727 A & AU 2003241839 A	2,4,16
Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 80520/1991(Laid-open No. 32021/1993) (Calsonic Corp.), 27 April 1993 (27.04.1993), paragraph [0002]; fig. 4 (Family: none)	3,10
Y	JP 2006-321389 A (Denso Corp.), 30 November 2006 (30.11.2006), paragraphs [0067] to [0068]; fig. 1 (Family: none)	11-16
Y	JP 2012-11928 A (Panasonic Corp.), 19 January 2012 (19.01.2012), paragraphs [0054] to [0068]; fig. 1 to 2 (Family: none)	14
Y	JP 2003-136945 A (Japan Climate Systems Corp.), 14 May 2003 (14.05.2003), paragraphs [0037] to [0038]; fig. 1 to 2 (Family: none)	15
Y	JP 2013-86728 A (Denso Corp.), 13 May 2013 (13.05.2013), paragraphs [0004], [0085] to [0092]; fig. 10 (Family: none)	17
A	JP 2010-1013 A (Valeo System Thermiques), 07 January 2010 (07.01.2010), paragraphs [0031] to [0046]; fig. 1 to 2 & US 2009/0314462 A1 & EP 2135759 A1 & FR 2932720 A & ES 2400037 T	1-17

EXHIBIT 1004 – Page 358 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

国際調査報告

国際出願番号　ＰＣＴ／ＪＰ２０１４／００３６０９

Ａ．　発明の属する分野の分類（国際特許分類（ＩＰＣ））

Int.Cl.　B60H1/22(2006.01)i, B60H1/00(2006.01)i, B60H1/03(2006.01)i

Ｂ．　調査を行った分野

調査を行った最小限資料（国際特許分類（ＩＰＣ））

Int.Cl.　B60H1/22, B60H1/00, B60H1/03

最小限資料以外の資料で調査を行った分野に含まれるもの

日本国実用新案公報	１９２２－１９９６年
日本国公開実用新案公報	１９７１－２０１４年
日本国実用新案登録公報	１９９６－２０１４年
日本国登録実用新案公報	１９９４－２０１４年

国際調査で使用した電子データベース（データベースの名称、調査に使用した用語）

Ｃ．　関連すると認められる文献

引用文献のカテゴリー＊	引用文献名　及び一部の箇所が関連するときは、その関連する箇所の表示	関連する請求項の番号
Y A	WO 2012/143119 A1 (VALEO SYSTEMS THERMIQUES) 2012.10.26, 第７欄第２４行－第１９欄第１９行, 第１－３図 & WO 2012/143119 A1 & CN 103732427 A	1-4,6,8-17 5,7
Y A	JP 2012-11927 A (パナソニック株式会社) 2012.01.19, 段落０００８－００１０, 段落００６２－００６７, 第１－２図 (ファミリーなし)	1-4,6,8-17 5,7

☑　Ｃ欄の続きにも文献が列挙されている。　　☐　パテントファミリーに関する別紙を参照。

＊　引用文献のカテゴリー
「A」特に関連のある文献ではなく、一般的技術水準を示すもの
「E」国際出願日前の出願または特許であるが、国際出願日以後に公表されたもの
「L」優先権主張に疑義を提起する文献又は他の文献の発行日若しくは他の特別な理由を確立するために引用する文献（理由を付す）
「O」口頭による開示、使用、展示等に言及する文献
「P」国際出願日前で、かつ優先権の主張の基礎となる出願の日の後に公表された文献
「T」国際出願日又は優先日後に公表された文献であって出願と矛盾するものではなく、発明の原理又は理論の理解のために引用するもの
「X」特に関連のある文献であって、当該文献のみで発明の新規性又は進歩性がないと考えられるもの
「Y」特に関連のある文献であって、当該文献と他の１以上の文献との、当業者にとって自明である組合せによって進歩性がないと考えられるもの
「&」同一パテントファミリー文献

国際調査を完了した日 ０７．１０．２０１４	国際調査報告の発送日 ２１．１０．２０１４
国際調査機関の名称及びあて先 日本国特許庁（ＩＳＡ／ＪＰ） 郵便番号１００－８９１５ 東京都千代田区霞が関三丁目４番３号	特許庁審査官（権限のある職員）　３Ｍ　３５３２ 田中　一正 電話番号　０３－３５８１－１１０１　内線　３３７７

様式ＰＣＴ／ＩＳＡ／２１０（第２ページ）（２００９年７月）

Ｃ（続き）．　関連すると認められる文献

引用文献のカテゴリー＊	引用文献名　及び一部の箇所が関連するときは、その関連する箇所の表示	関連する請求項の番号
Ｙ	JP 2004-50873 A（トヨタ自動車株式会社）2004.02.19，段落００１８－００３１，段落００４２－００４８，第１－４図 & US 2006/0032623 A1 & EP 1533154 A1 & WO 2004/007224 A1 & DE 60321005 D & BR 312713 A & PL 373097 A & KR 10-2005-0048588 A & CN 1738727 A & AU 2003241839 A	2,4,16
Ｙ	日本国実用新案登録出願3-80520号（日本国実用新案登録出願公開5-32021号）の願書に添付した明細書及び図面の内容を撮影したマイクロフィルム（カルソニック株式会社）1993.04.27，段落０００２，第４図（ファミリーなし）	3,10
Ｙ	JP 2006-321389 A（株式会社デンソー）2006.11.30，段落００６７－００６８，第１図（ファミリーなし）	11-16
Ｙ	JP 2012-11928 A（パナソニック株式会社）2012.01.19，段落００５４－００６８，第１－２図（ファミリーなし）	14
Ｙ	JP 2003-136945 A（株式会社日本クライメイトシステムズ）2003.05.14，段落００３７－００３８，第１－２図（ファミリーなし）	15
Ｙ	JP 2013-86728 A（株式会社デンソー）2013.05.13，段落０００４，段落００８５－００９２，第１０図（ファミリーなし）	17
Ａ	JP 2010-1013 A（ヴァレオ　システム　テルミク）2010.01.07，段落００３１－００４６，第１－２図 & US 2009/0314462 A1 & EP 2135759 A1 & FR 2932720 A & ES 2400037 T	1-17

EXHIBIT 1004 – Page 360 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

DOCKET NO.: M1567.70000US04

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban I. Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	Not Yet Assigned
Art Unit:	Not Yet Assigned

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I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: July 13, 2023 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

MAIL STOP AMENDMENT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

STATEMENT FILED PURSUANT TO THE DUTY OF DISCLOSURE UNDER 37 C.F.R. §§ 1.56, 1.97 AND 1.98

Commissioner:

Pursuant to the duty of disclosure under 37 C.F.R. §§ 1.56, 1.97 and 1.98, the undersigned requests consideration of this Information Disclosure Statement.

PART I: Compliance with 37 C.F.R. § 1.97

This Information Disclosure Statement has been filed before the mailing of a first Office Action on the merits.

No fee or certification is required.

PART II: Information Cited

The undersigned hereby makes of record in the above-identified application the information listed on the attached form PTO-1449 (modified PTO/SB/08). The order of presentation of the references should not be construed as an indication of the importance of the references.

The undersigned hereby makes the following additional information of record in the above identified application.

The undersigned would like to bring to the Examiner's attention the following application that may contain subject matter related to this application:

Serial No.	Filing Date	Inventor(s)	Docket No.
*18/182,244	03-10-2023	Tillemann-Dick et al.	M1567.70001US01

*A copy of this reference is not provided as the Office has waived the requirement under 37 C.F.R. § 1.98(a)(2)(iii) for submitting a copy of a cited U.S. patent application if it is scanned to the Image File Wrapper system and is available on Private PAIR .

PART III: Remarks

Documents cited anywhere in the Information Disclosure Statement are enclosed unless otherwise indicated. It is respectfully requested that:

1. The Examiner consider completely the cited information, along with any other information, in reaching a determination concerning the patentability of the present claims;

2. The enclosed form PTO-1449 (modified PTO/SB/08) be signed by the Examiner to evidence that the cited information has been fully considered by the United States Patent and Trademark Office during the examination of this application;

3. The citations for the information be printed on any patent which issues from this application.

By submitting this Information Disclosure Statement, the undersigned makes no representation that a search has been performed, of the extent of any search performed, or that more relevant information does not exist.

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, material to patentability as defined in 37 C.F.R. § 1.56(b).

EXHIBIT 1004 – Page 362 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, in fact, prior art as defined by 35 U.S.C. § 102, or an admission by Applicant as prior art.

Notwithstanding any statements by the undersigned, the Examiner is urged to form his or her own conclusion regarding the relevance of the cited information.

An early and favorable action is hereby requested.

The Director is hereby authorized to charge any deficiency or credit any overpayment in the fees occasioned by the filing of this Information Disclosure Statement to our Deposit Account No. 23/2825 under Docket No. M1567.70000US04 from which the undersigned is authorized to draw.

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

Docket No.: M1567.70000US04
Date: July 13, 2023

EXHIBIT 1004 – Page 363 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission	

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban I. Tillemann-Dick
Art Unit	Not Yet Assigned
Examiner Name	Not Yet Assigned
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

- [ ] Fee Transmittal Form
- [ ] Fee Attached
- [ ] Amendment/Reply
- [ ] After Final
- [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [x] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Reply to Missing Parts/ Incomplete Application
- [ ] Reply to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) _____
- [ ] Landscape Table on CD
- [ ] After Allowance Communication to TC
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- [ ] Proprietary Information
- [ ] Status Letter
- [x] Other Enclosure(s) (please Identify below):

Form PTO-14449
Copies of cited references

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Sarah C. C. Schlotter/		
Printed name	Sarah C.C. Schlotter, PhD		
Date	July 13, 2023	Reg. No.	79,027

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: July 13, 2023 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

11455732.1

FORM PTO-1449/A and B (modified PTO/SB/08)				APPLICATION NO.: 17/860,950	ATTY. DOCKET NO.: M1567.70000US04
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				FILING DATE: July 8, 2022	CONFIRMATION NO.: 9208
				FIRST NAMED INVENTOR: Corban Tillemann-Dick	
Sheet	1	of	1	GROUP ART UNIT: Not Yet Assigned	EXAMINER: Not Yet Assigned

U.S. PATENT DOCUMENTS

Examiner's Initials #	Cite No.	U.S. Patent Document Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication or Issue of Cited Document MM-DD-YYYY
		2015-0196221	A1	Garside	07-16-2015
		2018-0045471	A1	Dietrich	02-15-2018
		2023-0008279	A1	Tillemann-Dick et al.	01-12-2023
		2023-0009670	A1	Tillemann-Dick et al.	01-12-2023
		2023-0010758	A1	Tillemann-Dick et al.	01-12-2023
		2023-0010920	A1	Tillemann-Dick et al.	01-12-2023
		2023-0012324	A1	Tillemann-Dick et al.	01-12-2023

FOREIGN PATENT DOCUMENTS

Examiner's Initials #	Cite No.	Foreign Patent Document Office/ Country	Number	Kind Code	Name of Patentee or Applicant of Cited Document	Date of Publication of Cited Document MM-DD-YYYY	Translation (Y/N)
		JP	2012-182176	A	Fujikura Ltd	09-20-2012	Y

OTHER ART – NON PATENT LITERATURE DOCUMENTS

Examiner's Initials #	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation (Y/N)
		International Search Report and Written Opinion mailed November 23, 202, in connection with International Application No. PCT/US2022/036531 (M1567.70000WO00).	
		Invitation to Pay Additional Fees mailed September 16, 2022, in connection with Application No. PCT/US2022/036531 (M1567.70000WO00)	
		POBELL, Matter and Methods at Low Temperatures. Springer Berlin. 15 Feb. 2007:468 pages.	

[NOTE – No copies of U.S. patents, published U.S. patent applications, or pending, unpublished patent applications stored in the USPTO's Image File Wrapper (IFW) system, are included. See 37 CFR § 1.98 and 1287OG163. Copies of all other patent(s), publication(s), unpublished, pending U.S. patent applications, or other information listed are provided as required by 37 CFR § 1.98 unless 1) such copies were provided in an IDS in an earlier application that complies with 37 CFR § 1.98, and 2) the earlier application is relied upon for an earlier filing date under 35 U.S.C. § 120.]

EXAMINER:	DATE CONSIDERED:

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

11050118.1

RECEIVED
Wolf, Greenfield & Sacks, P.C.
SEP 20 2022

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To: SARAH C.C. SCHLOTTER
WOLF, GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

PCT

INVITATION TO PAY ADDITIONAL FEES
AND, WHERE APPLICABLE, PROTEST FEE

(PCT Article 17(3)(a) and Rules 40.1 and 40.2(e))

Date of mailing *(day/month/year)*	SEP 16 2022
Applicant's or agent's file reference M1567.70000WO00	**PAYMENT DUE** within **ONE MONTH** from the above date of mailing
International application No. PCT/US2022/036531	International filing date *(day/month/year)* 08 July 2022
Applicant MAYBELL QUANTUM INDUSTRIES, INC.	

1. This International Searching Authority

   (i) considers that there are 5 *(number of)* inventions claimed in the international application covered by the claims indicated below/on an extra sheet:

   (ii) therefore considers that **the international application does not comply with the requirement of unity of invention** (Rules 13.1, 13.2 and 13.3) for the reasons indicated below/on an extra sheet:

   (iii) ☐ has carried out a partial international search (see Annex) ☒ will establish the international search report on those parts of the international application which relate to the invention first mentioned in claims Nos.:
   1-3

   (iv) will establish the international search report on the other parts of the international application only if, and to the extent to which, additional fees are paid.

2. Consequently, the applicant is hereby **invited to pay**, within the time limit indicated above, additional fees in the amount indicated below:

   $2,180.00 (Fee per additional invention) x 4 (number of additional inventions) = $8,720.00 (See Item 2 of next sheet) (total amount of additional fees/currency)

3. The applicant is informed that, according to Rule 40.2(c), **the payment of any additional fees may be made under protest**, that is, a reasoned statement to the effect that the international application complies with the requirement of unity of invention or that the amount of the required additional fees is excessive, where applicable, subject to the payment of a protest fee.

   Where the applicant pays additional fees under protest, the applicant is hereby invited, within the time limit indicated above, to pay a protest fee (Rule 40.2(e)) in the amount of _____ *(amount/currency)*

   Where the applicant has not, within the time limit indicated above, paid the required protest fee, the protest will be considered not to have been made and the International Searching Authority will so declare.

4. ☒ Claim(s) Nos. 4-24, 30-44, 48-64, 68-84, 90-105 have been found to be unsearchable under Article 17(2)(b) because of defects under Article 17(2)(a) and therefore have not been included with any invention.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Taina Matos PCT Helpdesk: 571-272-4300

Form PCT/ISA/206 (July 2019)

INVITATION TO PAY ADDITIONAL FEES
AND, WHERE APPLICABLE, PROTEST FEE

International application No.
PCT/US2022/036531

Item 2 (continued). For International Applications filed on or after 01 January 2014, Applicant is reminded that the search fee per additional invention indicated in item 2 is the undiscounted fee per additional invention. An Applicant may pay the search fee per additional invention fee reduced by 50% (small entity assertion) or 75% (micro entity certification), as appropriate. See 37 CFR 1.27 and 1.29.

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-3, is drawn to a dilution refrigerator comprising: a first thermalization plate of the plurality of thermalization plates comprising an integrated heat exchanger.

Group II, claims 25-29, is drawn to a dilution refrigerator comprising: a second thermal stage configured to be cooled to a second temperature lower than the first temperature.

Group III, claims 45-47, is drawn to a dilution refrigerator comprising: an outer vacuum chamber comprising at least one substantially planar surface.

Group IV, claims 65-67, is drawn to a distributed refrigeration system comprising a pre-cooling system configured to be thermally coupled to two or more cryogenic devices.

Group V, claims 85-89, is drawn to a dilution refrigerator comprising a coldest thermal stage of the plurality of thermal stages being disposed above warmer thermal stages of the plurality of thermal stages.

The inventions listed as Groups I, II, III, IV, or V do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: a first thermalization plate of the plurality of thermalization plates comprises an integrated heat exchanger, the integrated heat exchanger comprises channels formed in the first thermalization plate, and the channels are configured to allow helium to flow through the first thermalization plate during operation of the dilution refrigerator as claimed therein is not present in the invention of Groups II, III, IV, or V. The special technical feature of the Group II invention: a second thermal stage configured to be cooled to a second temperature lower than the first temperature; a vacuum chamber housing the first thermal stage and the second thermal stage; a first suspension system configured to suspend the first thermal stage from the vacuum chamber; and a second suspension system configured to suspend the second thermal stage from the vacuum chamber independently from the first thermal stage as claimed therein is not present in the invention of Groups I, III, IV, or V. The special technical feature of the Group III invention: an outer vacuum chamber comprising at least one substantially planar surface; and an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber as claimed therein is not present in the invention of Groups I, II, IV, or V. The special technical feature of the Group IV invention: a pre-cooling system configured to be thermally coupled to two or more cryogenic devices and to provide a first cooling stage to the two or more cryogenic devices as claimed therein is not present in the invention of Groups I, II, III, or V. The special technical feature of the Group V invention: a coldest thermal stage of the plurality of thermal stages is disposed above warmer thermal stages of the plurality of thermal stages such that the coldest thermal stage is positioned furthest from a floor supporting the dilution refrigerator as claimed therein is not present in the invention of Groups I, II, III, or IV.

Groups I, II, III, IV, and V lack unity of invention because even though the inventions of these groups require the technical feature of a dilution refrigerator comprising a plurality of thermal stages configured to be cooled to a plurality of temperatures, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2015/0196221 to Oxford Instruments Nanotechnology Tools Limited teaches a dilution refrigerator comprising a plurality of thermal stages configured to be cooled to a plurality of temperatures (the pulse tube refrigerator (PTR 2) is a two-stage PTR, having a first stage illustrated at 101 and a second stage at 102. As is known, during steady state operation, the second stage 102 of the PTR 2 attains a low temperature (such as a few Kelvin). This may be used to cool various types of target apparatus, including parts of a magnet system, experimental sensors or other apparatus for experimental use, or for example to pre-cool the still of a dilution refrigerator. Such a target apparatus 103 is illustrated as being attached directly to the second stage 102 of the PTR, this ensuring a good thermal link, thereby maximizing the cooling power of the second stage of the PTR 2, para. 0112).

Since none of the special technical features of the Group I, II, III, IV or V inventions are found in more than one of the inventions, unity of invention is lacking.

EXHIBIT 1004 – Page 367 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To: SARAH C.C. SCHLOTTER
WOLF, GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)*
Applicant's or agent's file reference M1587.70000WO00	FOR FURTHER ACTION See paragraphs 1 and 4 below
International application No. PCT/US2022/036531	International filing date *(day/month/year)* 08 July 2022
Applicant MAYBELL QUANTUM INDUSTRIES, INC.	

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   How? Directly to the International Bureau preferably through ePCT, or on paper to:
   The International Bureau of WIPO, 34, chemin des Colombettes, 1211 Geneva 20, Switzerland
   (Facsimile No.: +41 22 338 82 70)

   For more detailed instructions, see the *PCT Applicant's Guide*, International Phase, paragraphs 9.004 – 9.011.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to any protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:
   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with any request to forward the texts of both the protest and the decision thereon to the designated Offices.
   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   The applicant may **submit comments on an informal basis on the written opinion of the International Searching Authority** to the International Bureau. These comments will be made available to the public after international publication. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established.

   Shortly after the expiration of **18 months from the priority date, the international application will be published** by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau before the completion of the technical preparations for international publication (Rules 90*bis*.1 and 90*bis*.3).

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for **entry into the national phase** before those designated Offices. In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months. For details about the applicable time limits, Office by Office, see www.wipo.int/pct/en/texts/time_limits.html and the *PCT Applicant's Guide*, National Chapters.

   Within **22 months from the priority date, the applicant may request that a supplementary international search be carried out** by a different International Searching Authority that offers this service (Rule 45*bis*.1). The procedure for requesting supplementary international search is described in the *PCT Applicant's Guide*, International Phase, paragraphs 8.006-8.032.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Taina Matos Telephone No. PCT Helpdesk: 571-272-4300

Form PCT/ISA/220 (revised January 2019)

Search History:

Complete Classification Search

The Patent Analyst performed a complete classification search within the following US, IPC, CPC, ECLA, or F-Term classification areas:

CPC Class/Subclass(es): B33Y 80/00; F25B 9/12; F25D 3/10; F25D 19/006; F28D 2021/0033 (2022.08)

IPC (8) Class/Subclass(es): F25B 9/12; F25D 3/10; B33Y 80/00 (2022.01)

U.S. Class/Subclass(es): 62/610

See Global Search Results.

Global Patent Literature Text Search

The Patent Analyst performed the following global text search, which was not limited by classification but may or may not have been limited by other criteria:

Questel Orbit: https://www.orbit.com

#	Search query	Results
1	((MAYBELL 1D QUANTUM)/PA/OPA)	0
2	((TILLEMANN_DICK 2D CORBAN)/IN/OIN/INH/INV OR (THOMPSON 2D KYLE)/IN/OIN/INH/INV OR (OGANDO_DOS_SANTOS_ALLAN 2D JOHN)/IN/OIN/INH/INV OR (CHOO 2D BRYAN)/IN/OIN/INH/INV OR (BYARS 2D JONATHAN)/IN/OIN/INH/INV OR (HARRIS 2D STEVEN)/IN/OIN/INH/INV OR (ZULTAK 2D JOHANNA)/IN/OIN/INH/INV OR (PLANT 2D TYLER)/IN/OIN/INH/INV)	251
3	((DILUTION 3D REFRIGERAT+) AND (3D_PRINT+ OR ADDITIVE_MANUFACT+ OR THREE_DIMENS+_PRINT+))/TI/AB	0
4	((DILUTION 3D REFRIGERAT+))/TI/AB	122
5	((DILUTION 3D REFRIGERAT+) AND (PLATE+ 5D (CHANNEL+ OR PATH+ OR TUBE+ OR TUBULAR+)))/TI/AB	0
6	((DILUTION 3D REFRIGERAT+) AND (HELIUM+ 5D (CHANNEL+ OR PATH+ OR TUBE+ OR TUBULAR+)))/TI/AB	0
7	((DILUTION 3D REFRIGERAT+) AND STAGE+)/TI/AB	12
8	((DILUTION 3D REFRIGERAT+) AND STAGE+)/TI/AB/CLMS	59
9	((DILUTION 3D REFRIGERAT+) AND STAGE+)/TI/AB/CLMS/OBJ/DESC/ODES/ADB/ICLM/TX/KEYW	832
10	((DILUTION 3D REFRIGERAT+) AND (3D_PRINT+ OR ADDITIVE_MANUFACT+ OR THREE_DIMENS+_PRINT+))/TI/AB/CLMS/OBJ/DESC/ODES/ADB/ICLM/TX/KEYW	24

11	((DILUTION 3D REFRIGERAT+) AND (3D_PRINT+ OR ADDITIVE_MANUFACT+ OR THREE_DIMENS+_PRINT+) AND (PLATE+ 5D (CHANNEL+ OR PATH+ OR TUBE+ OR TUBULAR+)))/TI/AB/CLMS/OBJ/DESC/ODES/ADB/ICLM/TX/KEYW	3
12	((DILUTION 3D REFRIGERAT+) AND (THERMALIZATION_PLATES))/TI/AB/CLMS/OBJ/DESC/ODES/ADB/ICLM/TX/KEYW	3
13	((CRYOSTAT+ OR (DILUTION_REFRIG+)) AND ((STAGE+ OR PLATE+) 5D (GROOVE+ OR CHANNEL+)))/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	742
14	(F25D-003/10)/CPC	2414
15	(F25D-003/10)/IPC	6893
16	(((STAGE+ OR PLATE+) 5D (GROOVE+ OR CHANNEL+ OR PATH+)))/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	5369951
17	16 AND (14 OR 15)	389
18	(F25D-019/006)/CPC	1190
19	16 AND 18	113
20	(F28D-2021/0033)/CPC	302
21	(F25B-009/12)/CPC	100
22	(F25B-009/12)/IPC	146
23	(062610000)/PCL	68
24	(B33Y-080/00)/IPC	14160
25	(B33Y-080/00)/CPC	16801
26	(24 OR 25) AND (21 OR 22 OR 23)	0

Google Patents: https://patents.google.com

#	Search query	Results
1	3d printed heat exchanger plates with grooves	8910
2	dilution refrigerator thermalization plates	196
3	dilution refrigerator	28300

Date search was completed: 31 October 2022

RA/BC

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To: SARAH C.C. SCHLOTTER
WOLF, GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

Applicant's or agent's file reference M1567.70000WO00	Date of mailing (day/month/year) NOV 23 2022 **FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US2022/036531	International filing date (day/month/year) 08 July 2022
Applicant MAYBELL QUANTUM INDUSTRIES, INC.	

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46).

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   How? Directly to the International Bureau preferably through ePCT, or on paper to:
   The International Bureau of WIPO, 34, chemin des Colombettes, 1211 Geneva 20, Switzerland
   (Facsimile No.: +41 22 338 82 70)

   For more detailed instructions, see the *PCT Applicant's Guide*, International Phase, paragraphs 9.004 – 9.011.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to any protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with any request to forward the texts of both the protest and the decision thereon to the designated Offices.

   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   The applicant may **submit comments on an informal basis on the written opinion of the International Searching Authority** to the International Bureau. These comments will be made available to the public after international publication. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established.

   Shortly after the expiration of **18 months from the priority date, the international application will be published** by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau before the completion of the technical preparations for international publication (Rules 90*bis*.1 and 90*bis*.3).

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for **entry into the national phase** before these designated Offices. In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months. For details about the applicable time limits, Office by Office, see www.wipo.int/pct/en/texts/time_limits.html and the *PCT Applicant's Guide*, National Chapters.

   Within **22 months from the priority date, the applicant may request that a supplementary international search be carried out** by a different International Searching Authority that offers this service (Rule 45*bis*.1). The procedure for requesting supplementary international search is described in the *PCT Applicant's Guide*, International Phase, paragraphs 8.006-8.032.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Taina Matos Telephone No. PCT Helpdesk: 571-272-4300

Form PCT/ISA/220 (revised January 2019)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference		FOR FURTHER ACTION
M1567.70000WO00		see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/US2022/036531	08 July 2022	08 July 2021
Applicant		
MAYBELL QUANTUM INDUSTRIES, INC.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 4 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

   b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).

   c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☒ **Certain claims were found unsearchable** (see Box No. II).

3. ☒ **Unity of invention is lacking** (see Box No. III).

4. With regard to the **title**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

   a. the figure of the **drawings** to be published with the abstract is Figure No. 1

   ☒ as suggested by the applicant.

   ☐ as selected by this Authority, because the applicant failed to suggest a figure.

   ☐ as selected by this Authority, because this figure better characterizes the invention.

   b. ☐ none of the figures is to be published with the abstract.

EXHIBIT 1004 – Page 372 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2022/036531

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-24, 30-44, 46-64, 66-84, 90-105
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet(s).

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-3

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

EXHIBIT 1004 – Page 373 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2022/036531

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - INV. - F25B 9/12; F25D 3/10; B33Y 80/00 (2022.01)
ADD.

CPC - INV. - F25B 9/12; F25D 19/006; F25D 3/10; B33Y 80/00 (2022.08)

ADD. - F28D 2021/0033 (2022.08)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2012-182176 A (FUJIKURA LTD) 20 September 2012 (20.09.2012) see machine translation	1, 3
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Y		2
Y	US 2018/0045471 A1 (LINDE AKTIENGESELLSCHAFT) 15 February 2018 (15.02.2018) entire document	2
A	US 2015/0196221 A1 (OXFORD INSTRUMENTS NANOTECHNOLOGY TOOLS LIMITED) 16 July 2015 (16.07.2015) entire document	1-3

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 October 2022	NOV 23 2022
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Taina Matos Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2022/038531

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-3, is drawn to a dilution refrigerator comprising: a first thermalization plate of the plurality of thermalization plates comprising an integrated heat exchanger.

Group II, claims 25-29, is drawn to a dilution refrigerator comprising: a second thermal stage configured to be cooled to a second temperature lower than the first temperature.

Group III, claims 45-47, is drawn to a dilution refrigerator comprising: an outer vacuum chamber comprising at least one substantially planar surface.

Group IV, claims 65-67, is drawn to a distributed refrigeration system comprising a pre-cooling system configured to be thermally coupled to two or more cryogenic devices.

Group V, claims 85-89, is drawn to a dilution refrigerator comprising a coldest thermal stage of the plurality of thermal stages being disposed above warmer thermal stages of the plurality of thermal stages.

The inventions listed as Groups I, II, III, IV, or V do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: a first thermalization plate of the plurality of thermalization plates comprises an integrated heat exchanger, the integrated heat exchanger comprises channels formed in the first thermalization plate, and the channels are configured to allow helium to flow through the first thermalization plate during operation of the dilution refrigerator as claimed therein is not present in the invention of Groups II, III, IV, or V. The special technical feature of the Group II invention: a second thermal stage configured to be cooled to a second temperature lower than the first temperature; a vacuum chamber housing the first thermal stage and the second thermal stage; a first suspension system configured to suspend the first thermal stage from the vacuum chamber; and a second suspension system configured to suspend the second thermal stage from the vacuum chamber independently from the first thermal stage as claimed therein is not present in the invention of Groups I, III, IV, or V. The special technical feature of the Group III invention: an outer vacuum chamber comprising at least one substantially planar surface; and an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber as claimed therein is not present in the invention of Groups I, II, IV, or V. The special technical feature of the Group IV invention: a pre-cooling system configured to be thermally coupled to two or more cryogenic devices and to provide a first cooling stage to the two or more cryogenic devices as claimed therein is not present in the invention of Groups I, II, III, or V. The special technical feature of the Group V invention: a coldest thermal stage of the plurality of thermal stages is disposed above warmer thermal stages of the plurality of thermal stages such that the coldest thermal stage is positioned furthest from a floor supporting the dilution refrigerator as claimed therein is not present in the invention of Groups I, II, III, or IV.

Groups I, II, III, IV, and V lack unity of invention because even though the inventions of these groups require the technical feature of a dilution refrigerator comprising a plurality of thermal stages configured to be cooled to a plurality of temperatures, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2015/0196221 to Oxford Instruments Nanotechnology Tools Limited teaches a dilution refrigerator comprising a plurality of thermal stages configured to be cooled to a plurality of temperatures (the pulse tube refrigerator (PTR 2) is a two-stage PTR, having a first stage illustrated at 101 and a second stage at 102. As is known, during steady state operation, the second stage 102 of the PTR 2 attains a low temperature (such as a few Kelvin). This may be used to cool various types of target apparatus, including parts of a magnet system, experimental sensors or other apparatus for experimental use, or for example to pre-cool the still of a dilution refrigerator. Such a target apparatus 103 is illustrated as being attached directly to the second stage 102 of the PTR, this ensuring a good thermal link, thereby maximizing the cooling power of the second stage of the PTR 2, para. 0112).

Since none of the special technical features of the Group I, II, III, IV or V inventions are found in more than one of the inventions, unity of invention is lacking.

EXHIBIT 1004 – Page 375 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To: SARAH C.C. SCHLOTTER
WOLF, GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)*	NOV 23 2022
Applicant's or agent's file reference M1567.70000WO00	FOR FURTHER ACTION See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US2022/036531	08 July 2022	08 July 2021

International Patent Classification (IPC) or both national classification and IPC

IPC(8) - INV. - F25B 9/12; F25D 3/10; B33Y 80/00 (2022.01)
ADD.

CPC - INV. - F25B 9/12; F25D 19/006; F25D 3/10; B33Y 80/00 (2022.08)

ADD. - F28D 2021/0033 (2022.08)

Applicant MAYBELL QUANTUM INDUSTRIES, INC.

1. This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☒ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☒ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the international application
- ☐ Box No. VIII Certain observations on the international application

2. FURTHER ACTION

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

Name and mailing address of the ISA/	Date of completion of this opinion	Authorized officer
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	31 October 2022	Taina Matos PCT Helpdesk: 571-272-4300 Telephone No. 571-272-4300

Form PCT/ISA/237 (cover sheet) (July 2022)

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US2022/036531

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(b)).

3. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing:

   a. ☐ forming part of the international application as filed.

   b. ☐ furnished subsequent to the international filing date for the purposes of international search (Rule 13*ter*.1(a)),

      ☐ accompanied by a statement to the effect that the sequence listing does not go beyond the disclosure in the international application as filed.

4. ☐ With regard to any nucleotide and/or amino acid sequence disclosed in the international application, this opinion has been established to the extent that a meaningful opinion could be formed without a WIPO Standard ST.26 compliant sequence listing.

5. Additional comments:

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US2022/036531

Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non obvious), or to be industrially applicable have not been examined in respect of:

☐ the entire international application.

☒ claims Nos. 4-24, 30-44, 48-64, 68-84, 90-105

because:

☐ the said international application, or the said claims Nos. _____ relate to the following subject matter which does not require an international search *(specify)*:

☒ the description, claims or drawings *(indicate particular elements below)* or said claims Nos. see claims below are so unclear that no meaningful opinion could be formed *(specify)*:

Claims 4-24, 30-44, 48-64, 68-84, 90-105 are improper multiple dependent claims not drafted in accordance with the second and third sentences of Rule 6.4(a).

☐ the claims, or said claims Nos. _____ are so inadequately supported by the description that no meaningful opinion could be formed *(specify)*:

☒ no international search report has been established for said claims Nos. 4-24, 30-44, 48-64, 68-84, 90-105

☐ a meaningful opinion could not be formed without the sequence listing: the applicant did not, within the prescribed time limit:

☐ furnish a sequence listing complying with WIPO Standard ST.26, and such listing was not available to the International Searching Authority in the form, language and manner acceptable to it.

☐ pay the required late furnishing fee for the furnishing of a sequence listing in response to an invitation under Rule 13*ter*.1(a).

☐ See Supplemental Box for further details.

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US2022/036531

Box No. IV Lack of unity of invention

1. ☒ In response to the invitation (Form PCT/ISA/206) to pay additional fees the applicant has, within the applicable time limit:

   ☐ paid additional fees.

   ☐ paid additional fees under protest and, where applicable, the protest fee.

   ☐ paid additional fees under protest but the applicable protest fee was not paid.

   ☒ not paid additional fees.

2. ☐ This Authority found that the requirement of unity of invention is not complied with and chose not to invite the applicant to pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rule 13.1, 13.2 and 13.3 is

   ☐ complied with.

   ☒ not complied with for the following reasons:

<See Supplemental Box>

4. Consequently, this opinion has been established in respect of the following parts of the international application:

   ☐ all parts.

   ☒ the parts relating to claims Nos. 1-3

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US2022/036531

Box No. V **Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	2	YES
	Claims	1, 3	NO
Inventive step (IS)	Claims	None	YES
	Claims	1-3	NO
Industrial applicability (IA)	Claims	1-3	YES
	Claims	None	NO

2. Citations and explanations:

Claims 1 and 3 lack novelty under PCT Article 33(2) as being anticipated by JP 2012-182176 to Fujikura Ltd (hereinafter, "Fujikura").

Regarding Claim 1, Fujikura discloses a dilution refrigerator (superconductive coil device; abstract) comprising: a plurality of thermalization plates (cooling plates 12; figures 1, 3) configured to be cooled to a plurality of temperatures (cooling plates 12 are cooled by the chiller 28 and are capable of being cooled to a plurality of temperatures; page 3, paragraph [0020]), wherein: a first thermalization plate (top cooling plate 12; figure 3) of the plurality of thermalization plates comprises an integrated heat exchanger (grooves 13 formed in a spiral shape formed on the cooling plate 12; figures 5, 6; page 4, paragraph [0041]), the integrated heat exchanger comprises channels formed in the first thermalization plate (grooves 13 formed in a spiral shape formed on the cooling plate 12; figures 5, 6; page 4, paragraph [0041]), and the channels are configured to allow helium to flow through the first thermalization plate during operation of the dilution refrigerator (grooves 13 are capable of allowing helium to flow through the cooling plate during the operation of the superconductive coil device; figures 5, 6; page 4, paragraph [0041]).

Regarding Claim 3, Fujikura discloses the dilution refrigerator of claim 1, and Fujikura further discloses wherein the first thermalization plate further comprises a detachable portion (top cooling plate 12 can be changed as needed, i.e. detachable portion; figure 3), the detachable portion comprising the integrated heat exchanger (top cooling plate 12 that can be changed as needed comprises the grooves 13 formed in a spiral shape (integrated heat exchanger); figures 5, 6; page 4, paragraph [0041]; figure 3).

Claim 2 lacks an inventive step under PCT Article 33(3) as being obvious over JP 2012-182176 to Fujikura Ltd (hereinafter, "Fujikura") in view of US 2018/0045471 to Linde Aktiengesellschaft (hereinafter, "Linde").

Regarding Claim 2, Fujikura discloses the dilution refrigerator of claim 1. Fujikura fails to explicitly disclose wherein the integrated heat exchanger is formed by additive manufacturing.
Linde teaches wherein the integrated heat exchanger is formed by additive manufacturing (heating surface element 3 for a plate heat exchanger 10 is produced using 3D printing; abstract).
It would have been obvious to one of ordinary skill in the art at the time of the invention to modify Fujikura's integrated heat exchanger to be produced using Linde's additive manufacturing, because as Linde discloses the additive manufacturing may reduce the cost of production (Linde; paragraph [0019]).

Claims 1-3 meet the criteria set out in PCT Article 33(4), and thus have industrial applicability because the subject matter claimed can be made or used in industry.

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US2022/036531

Supplemental Box

In case the space in any of the preceding boxes is not sufficient.
Continuation of:

<Box No. IV Lack of unity of invention>

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-3, is drawn to a dilution refrigerator comprising: a first thermalization plate of the plurality of thermalization plates comprising an integrated heat exchanger.

Group II, claims 26-29, is drawn to a dilution refrigerator comprising: a second thermal stage configured to be cooled to a second temperature lower than the first temperature.

Group III, claims 45-47, is drawn to a dilution refrigerator comprising: an outer vacuum chamber comprising at least one substantially planar surface.

Group IV, claims 65-67, is drawn to a distributed refrigeration system comprising a pre-cooling system configured to be thermally coupled to two or more cryogenic devices.

Group V, claims 85-89, is drawn to a dilution refrigerator comprising a coldest thermal stage of the plurality of thermal stages being disposed above warmer thermal stages of the plurality of thermal stages.

The inventions listed as Groups I, II, III, IV, or V do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: a first thermalization plate of the plurality of thermalization plates comprises an integrated heat exchanger, the integrated heat exchanger comprises channels formed in the first thermalization plate, and the channels are configured to allow helium to flow through the first thermalization plate during operation of the dilution refrigerator as claimed therein is not present in the invention of Groups II, III, IV, or V. The special technical feature of the Group II invention: a second thermal stage configured to be cooled to a second temperature lower than the first temperature; a vacuum chamber housing the first thermal stage and the second thermal stage; a first suspension system configured to suspend the first thermal stage from the vacuum chamber; and a second suspension system configured to suspend the second thermal stage from the vacuum chamber independently from the first thermal stage as claimed therein is not present in the invention of Groups I, III, IV, or V. The special technical feature of the Group III invention: an outer vacuum chamber comprising at least one substantially planar surface; and an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber as claimed therein is not present in the invention of Groups I, II, IV, or V. The special technical feature of the Group IV invention: a pre-cooling system configured to be thermally coupled to two or more cryogenic devices and to provide a first cooling stage to the two or more cryogenic devices as claimed therein is not present in the invention of Groups I, II, III, or V. The special technical feature of the Group V invention: a coldest thermal stage of the plurality of thermal stages is disposed above warmer thermal stages of the plurality of thermal stages such that the coldest thermal stage is positioned furthest from a floor supporting the dilution refrigerator as claimed therein is not present in the invention of Groups I, II, III, or IV.

Groups I, II, III, IV, and V lack unity of invention because even though the inventions of these groups require the technical feature of a dilution refrigerator comprising a plurality of thermal stages configured to be cooled to a plurality of temperatures, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2015/0196221 to Oxford Instruments Nanotechnology Tools Limited teaches a dilution refrigerator comprising a plurality of thermal stages configured to be cooled to a plurality of temperatures (the pulse tube refrigerator (PTR 2) is a two-stage PTR, having a first stage illustrated at 101 and a second stage at 102. As is known, during steady state operation, the second stage 102 of the PTR 2 attains a low temperature (such as a few Kelvin). This may be used to cool various types of target apparatus, including parts of a magnet system, experimental sensors or other apparatus for experimental use, or for example to pre-cool the still of a dilution refrigerator. Such a target apparatus 103 is illustrated as being attached directly to the second stage 102 of the PTR, this ensuring a good thermal link, thereby maximizing the cooling power of the second stage of the PTR 2, para. 0112).

Since none of the special technical features of the Group I, II, III, IV or V inventions are found in more than one of the inventions, unity of invention is lacking.

Electronic Acknowledgement Receipt

EFS ID:	47651104
Application Number:	17860950
International Application Number:	
Confirmation Number:	9208
Title of Invention:	INTEGRATED DILUTION REFRIGERATORS
First Named Inventor/Applicant Name:	Corban Tillemann-Dick
Customer Number:	23628
Filer:	Sarah C.C. Schlotter/Jennifer Weaver
Filer Authorized By:	Sarah C.C. Schlotter
Attorney Docket Number:	M1567.70000US04
Receipt Date:	08-MAR-2023
Filing Date:	08-JUL-2022
Time Stamp:	15:04:25
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Miscellaneous Incoming Letter	M156770000US04-TRN-SCS.pdf	25752 ab26a90ee9315bd9cbebda750942f441cd77977a	no	1

Warnings:

Information:					
2	Letter specifying the conditions for filing under 37 CFR 1.97	M156770000US04-IDSBODY-SCS.pdf	32991 23b855c9bf0b7aa697f88c7a10512bb90ad084c6	no	3
Warnings:					
Information:					
3	Information Disclosure Statement (IDS) Form (SB08)	M156770000US04-IDS1449-SCS.pdf	23775 0a0c35719999e8e44dbf3919fc9fcfac640c8c62	no	1
Warnings:					
Information:					
This is not an USPTO supplied IDS fillable form					
4	Foreign Reference	JP2012182176A_w_Eng_Trans.pdf	2441105 a56e089696dd2c7a9f1204a84295d5f91b82652d	no	78
Warnings:					
Information:					
5	Other reference-Patent/Application/ Search Documents	M156770000WO00_IPAF_dtd_09-16-2022.pdf	6087271 9c70de1b1f22d195e7a7dca18df5c3c8d4f57c81	no	2
Warnings:					
Information:					
6	Other reference-Patent/Application/ Search Documents	M156770000WO00_ISRWO_dtd_11-23-2022pt1.pdf	15769507 e03a324bf3ca0996da614cfa5cd6992284dc4839	no	7
Warnings:					
Information:					
7	Other reference-Patent/Application/ Search Documents	M156770000WO00_ISRWO_dtd_11-23-2022pt2.pdf	14292281 0ae1ab8b452626cdd648456a47dfaa6357171fef	no	7
Warnings:					
Information:					
8	Non Patent Literature	POBELL_Springer_2007_468pgs.pdf	8173236 44e109ca6b1a836245793f9bbe3d2c6b1e89c96e	no	468
Warnings:					
Information:					

Total Files Size (in bytes):	46845918

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission	

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban Tillemann-Dick
Art Unit	Not Yet Assigned
Examiner Name	Not Yet Assigned
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

- [ ] Fee Transmittal Form
- [ ] Fee Attached
- [ ] Amendment/Reply
- [ ] After Final
- [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [x] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Reply to Missing Parts/ Incomplete Application
- [ ] Reply to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) _____
- [ ] Landscape Table on CD
- [ ] After Allowance Communication to TC
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- [ ] Proprietary Information
- [ ] Status Letter
- [x] Other Enclosure(s) (please Identify below):

Form PTO-1449
Copies of cited references

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Sarah C. C. Schlotter/		
Printed name	Sarah C.C. Schlotter, PhD		
Date	March 7, 2023	Reg. No.	79,027

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: March 8, 2023 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

11050113.1

DOCKET NO.: M1567.70000US04

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	Not Yet Assigned
Art Unit:	Not Yet Assigned

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: March 8, 2023 Electronic Signature for Jennifer A. Weaver: /Jennifer A. Weaver/

MAIL STOP AMENDMENT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

STATEMENT FILED PURSUANT TO THE DUTY OF DISCLOSURE UNDER 37 C.F.R. §§ 1.56, 1.97 AND 1.98

Examiner:

Pursuant to the duty of disclosure under 37 C.F.R. §§ 1.56, 1.97 and 1.98, the undersigned requests consideration of this Information Disclosure Statement.

PART I: Compliance with 37 C.F.R. § 1.97

This Information Disclosure Statement has been filed before the mailing of a first Office Action on the merits.

No fee or certification is required.

PART II: Information Cited

The undersigned hereby makes of record in the above-identified application the information listed on the attached form PTO-1449 (modified PTO/SB/08). The order of presentation of the references should not be construed as an indication of the importance of the references.

The undersigned hereby makes the following additional information of record in the above-identified application.

The undersigned would like to bring to the Examiner's attention the following applications that may contain subject matter related to this application:

Serial No.	Filing Date	Inventor(s)	Docket No.
*17/860,909	07-08-2022	Tillemann-Dick et al.	M1567.70000US02
*17/860,923	07-08-2022	Tillemann-Dick et al.	M1567.70000US03
*17/861,026	07-08-2022	Tillemann-Dick et al.	M1567.70000US05
*17/861,044	07-08-2022	Tillemann-Dick et al.	M1567.70000US06

*A copy of this reference is not provided as the Office has waived the requirement under 37 C.F.R. § 1.98(a)(2)(iii) for submitting a copy of a cited U.S. patent application if it is scanned to the Image File Wrapper system and is available on Private PAIR .

The undersigned would like to bring to the Examiner's attention the enclosed search reports or other communications from a corresponding or related International or Foreign National Application:

Serial No.	Date of Mailing	Type(s) of Communication	Docket No.
PCT/US2022/036531	**11-23-2023**	**International Search Report and Written Opinion**	**M1567.70000WO00**
PCT/US2022/036531	**09-16-2022**	**Invitation to Pay Additional Fees**	**M1567.70000WO00**

PART III: Remarks

Documents cited anywhere in the Information Disclosure Statement are enclosed unless otherwise indicated. It is respectfully requested that:

1. The Examiner consider completely the cited information, along with any other information, in reaching a determination concerning the patentability of the present claims;

2. The enclosed form PTO-1449 (modified PTO/SB/08) be signed by the Examiner to evidence that the cited information has been fully considered by the United States Patent and Trademark Office during the examination of this application;

3. The citations for the information be printed on any patent which issues from this application.

By submitting this Information Disclosure Statement, the undersigned makes no representation that a search has been performed, of the extent of any search performed, or that more relevant information does not exist.

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, material to patentability as defined in 37 C.F.R. § 1.56(b).

By submitting this Information Disclosure Statement, the undersigned makes no representation that the information cited in the Statement is, or is considered to be, in fact, prior art as defined by 35 U.S.C. § 102, or an admission by Applicant as prior art.

Notwithstanding any statements by the undersigned, the Examiner is urged to form his or her own conclusion regarding the relevance of the cited information.

An early and favorable action is hereby requested.

The Director is hereby authorized to charge any deficiency or credit any overpayment in the fees occasioned by the filing of this Information Disclosure Statement to our Deposit Account No. 23/2825 under Docket No. M1567.70000US04 from which the undersigned is authorized to draw.

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

Docket No.: M1567.70000US04
Date: March 7, 2023

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
17/860,950	07/08/2022	Corban Tillemann-Dick	M1567.70000US04

CONFIRMATION NO. 9208

23628
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

PUBLICATION NOTICE

OC000000137188745

Title:INTEGRATED DILUTION REFRIGERATORS

Publication No.US-2023-0008279-A1
Publication Date:01/12/2023

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently http://www.uspto.gov/patft/.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Public Records Division. The Public Records Division can be reached by telephone at (571) 272-3150 or (800) 972-6382, by facsimile at (571) 273-3250, by mail addressed to the United States Patent and Trademark Office, Public Records Division, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently https://portal.uspto.gov/pair/PublicPair. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Office of Data Managment, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
17/860,950	07/08/2022	OPAP	910	M1567.70000US04	20	1

CONFIRMATION NO. 9208

CORRECTED FILING RECEIPT

23628
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

CC00000013640460

Date Mailed: 09/27/2022

Receipt is acknowledged of this non-provisional utility patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF FIRST INVENTOR, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection.

Please verify the accuracy of the data presented on this receipt. If an error is noted on this Filing Receipt, please submit a written request for a corrected Filing Receipt, including a properly marked-up ADS showing the changes with strike-through for deletions and underlining for additions. If you received a "Notice to File Missing Parts" or other Notice requiring a response for this application, please submit any request for correction to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections provided that the request is grantable.

Inventor(s)

Corban Tillemann-Dick, Denver, CO;
Kyle Thompson, Boulder, CO;
Bryan Choo, New York, NY;
John Ogando Dos Santos Allan, Boulder, CO;
Jonathan Michael Byars, Golden, CO;

Applicant(s)

Maybell Quantum Industries, Inc., Denver, CO;

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 63/319,248 03/11/2022
and claims benefit of 63/219,795 07/08/2021

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 07/25/2022

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 17/860,950**

Projected Publication Date: 01/12/2023

Non-Publication Request: No

Early Publication Request: No
**** SMALL ENTITY ****
Title

INTEGRATED DILUTION REFRIGERATORS

Preliminary Class

062

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific

EXHIBIT 1004 – Page 391 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop

technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

EXHIBIT 1004 – Page 393 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Electronic Acknowledgement Receipt

EFS ID:	46670145
Application Number:	17860950
International Application Number:	
Confirmation Number:	9208
Title of Invention:	INTEGRATED DILUTION REFRIGERATORS
First Named Inventor/Applicant Name:	Corban Tillemann-Dick
Customer Number:	23628
Filer:	Sarah C.C. Schlotter/Morgan Ryan
Filer Authorized By:	Sarah C.C. Schlotter
Attorney Docket Number:	M1567.70000US04
Receipt Date:	22-SEP-2022
Filing Date:	08-JUL-2022
Time Stamp:	11:28:01
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Miscellaneous Incoming Letter	M156770000US04-TRN-SCS.pdf	25985 701c617960dee9304ed924d5c9149249437c14d7	no	1

Warnings:

Information:					
2	Application Data Sheet	M156770000US04-COPYADS-SCS.pdf	79098 94116f8fc2dba92161aa3eeb49024ed95a5152ac	no	7
Warnings:					
Information:					
This is not an USPTO supplied ADS fillable form					
3	Request for Corrected Filing Receipt	M156770000US04-RCFR-SCS.pdf	26877 cdae7725532e90320a478b197714b4f4cf32b90d	no	2
Warnings:					
Information:					
4	Request for Corrected Filing Receipt	M156770000US04-MUFR-SCS.pdf	138685 bf19480aae81f970f4461cc5a9dfbcf34ff51c1d	no	4
Warnings:					
Information:					
			Total Files Size (in bytes):	270645	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

COPY

Application Data Sheet

Inventor Information

Inventor Number::	1
Given Name::	Corban
Family Name::	Tillemann-Dick
City of Residence::	Denver
State or Province of Residence::	CO
Country of Residence::	US
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City of mailing address::	Denver
State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80220

Inventor Number::	2
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Family Name::	Thompson
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State or Province of Residence::	CO
Country of Residence::	US
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City of mailing address::	Boulder
State or Province of mailing address::	CO

COPY

Country of mailing address::	US
Postal or Zip Code of mailing address::	80305
Inventor Number::	3
Given Name::	Bryan
Family Name::	Choo
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State or Province of Residence::	NY
Country of Residence::	US
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Country of mailing address::	US
Postal or Zip Code of mailing address::	10003
Inventor Number::	4
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City of Residence::	Boulder
State or Province of Residence::	CO
Country of Residence::	US
Street of mailing address::	1565 Linden Ave
City of mailing address::	Boulder

EXHIBIT 1004 – Page 397 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

COPY

State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80304

Inventor Number::	5
Given Name::	Jonathan
Middle Name::	Michael
Family Name::	Byars
City of Residence::	Golden
State or Province of Residence::	CO
Country of Residence::	US
Street of mailing address::	14830 W 53rd Ave.
City of mailing address::	Golden
State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80403

Correspondence Information

Correspondence Customer Number::	23628

Application Information

Application Type::	Nonprovisional
Subject Matter::	Utility

EXHIBIT 1004 – Page 398 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

COPY

CD-ROM or CD-R?::	None
Sequence submission?::	None
Computer Readable Form (CRF)?::	No
Title::	INTEGRATED DILUTION REFRIGERATORS
Attorney Docket Number::	M1567.70000US04
Request for Early Publication?::	No
Request for Non-Publication?::	No
Total Drawing Sheets::	23
Small Entity?::	Yes
Petition included?::	No
Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2::	No

Representative Information

Representative Customer Number::	23628

Domestic Priority Information

Application::	Continuity Type::	Parent Application::	Parent Filing Date::	Prior Appl Status::
This Application	Claims benefit of provisional	63/319248	03/11/22	Pending
This Application	Claims benefit of provisional	63/219795	07/08/21	Pending

COPY

Foreign Priority Information

Applicant Information

Applicant Number::	1
Applicant Type::	Person to whom the inventor is obligated to assign
Organization Name::	Maybell Quantum Industries, Inc.
Street of mailing address::	7100 Broadway Building 3
	Suite D-E
City of mailing address::	Denver
State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80221

Assignee Information Including Non-Applicant Assignee Information

EXHIBIT 1004 – Page 400 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

COPY

Authorization or Opt-Out of Authorization to Permit Access

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

COPY

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Sarah C. C. Schlotter/	Date (YYYY-MM-DD)	2022-07-08
Name	Sarah C.C. Schlotter, PhD	Registration Number	79,027

Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission	

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban Tillemann-Dick
Art Unit	Not Yet Assigned
Examiner Name	Not Yet Assigned
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

- [ ] Fee Transmittal Form
- [ ] Fee Attached
- [ ] Amendment/Reply
- [ ] After Final
- [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [ ] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Reply to Missing Parts/ Incomplete Application
- [ ] Reply to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) _____
- [ ] Landscape Table on CD
- [ ] After Allowance Communication to TC
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- [ ] Proprietary Information
- [ ] Status Letter
- [x] Other Enclosure(s) (please Identify below):

- Request for Corrected Filing Receipt
- Marked-Up Filing Receipt
- Copy of ADS filed 07-08-2022

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Sarah C. C. Schlotter/		
Printed name	Sarah C.C. Schlotter, PhD		
Date	September 22, 2022	Reg. No.	79,027

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: September 22, 2022 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

10693716.1

Docket No.: M1567.70000US04
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	Not Yet Assigned
Art Unit:	Not Yet Assigned

Certificate of Electronic Filing under 37 C.F.R. § 1.8
I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: September 22, 2022 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

REQUEST FOR CORRECTED FILING RECEIPT

Office of Initial Patent Examination's Filing Receipt Corrections
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Applicant hereby requests that a corrected Filing Receipt be issued in the above-identified patent application. The official Filing Receipt received by Applicant, a copy of which is attached hereto, has an error in inventor Ogando Dos Santos Allan's last name:

Inventor(s)

Corban Tillemann-Dick, Denver, CO;

Kyle Thompson, Boulder, CO;

Bryan Choo, New York, NY;

~~John Ogando Dos Santos Allen, Boulder, CO;~~ John Ogando Dos Santos Allan, Boulder, CO;

Jonathan Michael Byars, Golden, CO;

A copy of the Application Data Sheet as filed is attached. Applicant additionally requests that all pertinent U.S. Patent and Trademark Office records relating to the subject application be changed to reflect this correction.

Applicant believes no fee is due with this Request for Corrected Filing Receipt. However, if a fee is due with this Request for Corrected Filing Receipt, please charge our Deposit Account No. 23/2825, under Docket No. M1567.70000US04 from which the undersigned is authorized to draw.

Dated: September 22, 2022

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
Randy J. Pritzker
Registration No.: 35,986
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

EXHIBIT 1004 – Page 405 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

COPY

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
17/860,950	07/08/2022	OPAP	910	M1567.70000US04	20	1

CONFIRMATION NO. 9208
CORRECTED FILING RECEIPT

23628
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

OC000000136063772

Date Mailed: 08/29/2022

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~~John Ogando Dos Santos Allen, Boulder, CO;~~ John Ogando Dos Santos Allan, Boulder, CO;
Jonathan Michael Byars, Golden, CO;

Applicant(s)

Maybell Quantum Industries, Inc., Denver, CO;

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 63/319,248 03/11/2022
and claims benefit of 63/219,795 07/08/2021

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

EXHIBIT 1004 – Page 406 of 510
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COPY

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If Required, Foreign Filing License Granted: 07/25/2022

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 17/860,950**

Projected Publication Date: 01/12/2023

Non-Publication Request: No

Early Publication Request: No
** **SMALL ENTITY** **
Title

INTEGRATED DILUTION REFRIGERATORS

Preliminary Class

062

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

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LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

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This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

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UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
17/860,950	07/08/2022	OPAP	910	M1567.70000US04	20	1

CONFIRMATION NO. 9208

CORRECTED FILING RECEIPT

23628
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206



Date Mailed: 08/29/2022

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Inventor(s)

Corban Tillemann-Dick, Denver, CO;
Kyle Thompson, Boulder, CO;
Bryan Choo, New York, NY;
John Ogando Dos Santos Allen, Boulder, CO;
Jonathan Michael Byars, Golden, CO;

Applicant(s)

Maybell Quantum Industries, Inc., Denver, CO;

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 63/319,248 03/11/2022
and claims benefit of 63/219,795 07/08/2021

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Permission to Access Search Results: Yes

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If Required, Foreign Filing License Granted: 07/25/2022

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 17/860,950**

Projected Publication Date: 01/12/2023

Non-Publication Request: No

Early Publication Request: No
**** SMALL ENTITY ****
Title

INTEGRATED DILUTION REFRIGERATORS

Preliminary Class

062

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

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NOT GRANTED

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technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

EXHIBIT 1004 – Page 413 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Docket No.: M1567.70000US04
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	Corban Tillemann-Dick
Application No.:	17/860,950
Confirmation No.:	9208
Filed:	July 8, 2022
For:	INTEGRATED DILUTION REFRIGERATORS
Examiner:	Not Yet Assigned
Art Unit:	Not Yet Assigned

Certificate of Electronic Filing under 37 C.F.R. § 1.8
I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: August 24, 2022 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

REQUEST FOR CORRECTED FILING RECEIPT

Office of Initial Patent Examination's Filing Receipt Corrections
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Applicant hereby requests that a corrected Filing Receipt be issued in the above-identified patent application. The official Filing Receipt received by Applicant, a copy of which is attached hereto, has an error in:

Inventor(s)

Corban Tillemann-Dick, Denver, CO;

Kyle Thompson, Boulder, CO;

Bryan Choo, New York, NY;

~~John Ogando Dos Santos Allen, Boulderr, CO;~~ John Ogando Dos Santos Allan, Boulder, CO;

Jonathan Michael Byars, Golden, CO;

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Dated: 08/24/2022

Respectfully submitted,

Electronic signature: /Sarah C. C. Schlotter/
Sarah C.C. Schlotter, PhD
Registration No.: 79,027
Randy J. Pritzker
Registration No.: 35,986
WOLF, GREENFIELD & SACKS, P.C.
600 Atlantic Avenue
Boston, Massachusetts 02210-2206
617.646.8000

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CONFIRMATION NO. 9208

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600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

FILING RECEIPT



Date Mailed: 07/27/2022

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Projected Publication Date: 01/12/2023

Non-Publication Request: No

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The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

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The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop

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technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

Electronic Acknowledgement Receipt

EFS ID:	46475125
Application Number:	17860950
International Application Number:	
Confirmation Number:	9208
Title of Invention:	INTEGRATED DILUTION REFRIGERATORS
First Named Inventor/Applicant Name:	Corban Tillemann-Dick
Customer Number:	23628
Filer:	Sarah C.C. Schlotter/Morgan Ryan
Filer Authorized By:	Sarah C.C. Schlotter
Attorney Docket Number:	M1567.70000US04
Receipt Date:	24-AUG-2022
Filing Date:	08-JUL-2022
Time Stamp:	12:22:26
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Miscellaneous Incoming Letter	M156770000US04-TRN-SCS.pdf	25961 f709038c84b928963c708372e433bb4dd698ab1b	no	1

Warnings:

Information:					
2	Application Data Sheet	M156770000US04-COPYADS-SCS.pdf	79098 e49b02f6220208f0afbb3a2ac3cb5e9c9bb00d4b	no	7
Warnings:					
Information:					
This is not an USPTO supplied ADS fillable form					
3	Request for Corrected Filing Receipt	M156770000US04-RCFR-SCS.pdf	26888 2f045e3127af7ba9b53b738c26ad80170c38574f	no	2
Warnings:					
Information:					
4	Request for Corrected Filing Receipt	M156770000US04-MUFR-SCS.pdf	138464 fb50ef34545746daf36dfa7f204fe275607de4b0	no	4
Warnings:					
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		Total Files Size (in bytes):	270411		

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

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Doc Code: TRAN.LET
Document Description: Transmittal Letter

USED IN LIEU OF PTO/SB/21 (07-09)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission	

Application Number	17/860,950-Conf. #9208
Filing Date	July 8, 2022
First Named Inventor	Corban Tillemann-Dick
Art Unit	Not Yet Assigned
Examiner Name	Not Yet Assigned
Attorney Docket Number	M1567.70000US04

ENCLOSURES (*Check all that apply*)

- [ ] Fee Transmittal Form
- [ ] Fee Attached
- [ ] Amendment/Reply
- [ ] After Final
- [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [ ] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Reply to Missing Parts/ Incomplete Application
- [ ] Reply to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) _____
- [ ] Landscape Table on CD
- [ ] After Allowance Communication to TC
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- [ ] Proprietary Information
- [ ] Status Letter
- [x] Other Enclosure(s) (please Identify below):

- Request for Corrected Filing Receipt
- Marked-Up Filing Receipt
- Copy of ADS filed 07-08-2022

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	WOLF, GREENFIELD & SACKS, P.C.		
Signature	/Sarah C. C. Schlotter/		
Printed name	Sarah C.C. Schlotter, PhD		
Date	August 24, 2022	Reg. No.	79,027

Certificate of Electronic Filing under 37 C.F.R. § 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being transmitted via the Office's electronic filing system in accordance with 37 C.F.R. § 1.6(a)(4).

Dated: August 24, 2022 Signature: /Morgan L. Ryan/ (Morgan L. Ryan)

10599344.1

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Application Data Sheet

Inventor Information

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EXHIBIT 1004 – Page 423 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

COPY

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EXHIBIT 1004 – Page 424 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

COPY

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Postal or Zip Code of mailing address::	80304

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State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80403

Correspondence Information

Correspondence Customer Number::	23628

Application Information

Application Type::	Nonprovisional
Subject Matter::	Utility

EXHIBIT 1004 – Page 425 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

COPY

CD-ROM or CD-R?::	None
Sequence submission?::	None
Computer Readable Form (CRF)?::	No
Title::	INTEGRATED DILUTION REFRIGERATORS
Attorney Docket Number::	M1567.70000US04
Request for Early Publication?::	No
Request for Non-Publication?::	No
Total Drawing Sheets::	23
Small Entity?::	Yes
Petition included?::	No
Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2::	No

Representative Information

Representative Customer Number::	23628

Domestic Priority Information

Application::	Continuity Type::	Parent Application::	Parent Filing Date::	Prior Appl Status::
This Application	Claims benefit of provisional	63/319248	03/11/22	Pending
This Application	Claims benefit of provisional	63/219795	07/08/21	Pending

COPY

Foreign Priority Information

Applicant Information

Applicant Number::	1
Applicant Type::	Person to whom the inventor is obligated to assign
Organization Name::	Maybell Quantum Industries, Inc.
Street of mailing address::	7100 Broadway Building 3
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City of mailing address::	Denver
State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80221

Assignee Information Including Non-Applicant Assignee Information

EXHIBIT 1004 – Page 427 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

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Authorization or Opt-Out of Authorization to Permit Access

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

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1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

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The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

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☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

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Signature:

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This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Sarah C. C. Schlotter/	Date (YYYY-MM-DD)	2022-07-08
Name	Sarah C.C. Schlotter, PhD	Registration Number	79,027

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 17/860,950

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	80		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	350		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	400		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	20 minus 20 =	*	x 50 =	0.00	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	1 minus 3 =	*	x 240 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	830		TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE($)	ADDITIONAL FEE($)	OR	RATE($)	ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
17/860,950	07/08/2022	3763	910	M1567.70000US04	20	1

CONFIRMATION NO. 9208

FILING RECEIPT

23628
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
BOSTON, MA 02210-2206

OC000000135397548

Date Mailed: 07/27/2022

Receipt is acknowledged of this non-provisional utility patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF FIRST INVENTOR, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection.

Please verify the accuracy of the data presented on this receipt. If an error is noted on this Filing Receipt, please submit a written request for a corrected Filing Receipt, including a properly marked-up ADS showing the changes with strike-through for deletions and underlining for additions. If you received a "Notice to File Missing Parts" or other Notice requiring a response for this application, please submit any request for correction to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections provided that the request is grantable.

Inventor(s)

Corban Tillemann-Dick, Denver, CO;
Kyle Thompson, Boulder, CO;
Bryan Choo, New York, NY;
John Ogando Dos Santos Allen, Boulderr, CO;
Jonathan Michael Byars, Golden, CO;

Applicant(s)

Maybell Quantum Industries, Inc., Denver, CO;

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 63/319,248 03/11/2022
and claims benefit of 63/219,795 07/08/2021

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 07/25/2022

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 17/860,950**

Projected Publication Date: 01/12/2023

Non-Publication Request: No

Early Publication Request: No
**** SMALL ENTITY ****
Title

INTEGRATED DILUTION REFRIGERATORS

Preliminary Class

062

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

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Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific

EXHIBIT 1004 – Page 432 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

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NOT GRANTED

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The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop

technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

EXHIBIT 1004 – Page 434 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
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Address: COMMISSIONER FOR PATENTS
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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
17/860,950	07/08/2022	Corban Tillemann-Dick	M1567.70000US04

CONFIRMATION NO. 9208

23628
WOLF GREENFIELD & SACKS, P.C.
600 ATLANTIC AVENUE
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INFORMAL NOTICE

OC00000135397547

Date Mailed: 07/27/2022

INFORMATIONAL NOTICE TO APPLICANT

Applicant is notified that the above-identified application contains the deficiencies noted below. No period for reply is set forth in this notice for correction of these deficiencies. However, if a deficiency relates to the inventor's oath or declaration, the applicant must file an oath or declaration in compliance with 37 CFR 1.63, or a substitute statement in compliance with 37 CFR 1.64, executed by or with respect to each actual inventor no later than the expiration of the time period set in the "Notice of Allowability" to avoid abandonment. See 37 CFR 1.53(f).

The item(s) indicated below are also required and should be submitted with any reply to this notice to avoid further processing delays.

- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
  Corban Tillemann-Dick
  Kyle Thompson
  Bryan Choo
  John Ogando Dos Santos Allen
  Jonathan Michael Byars

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/gkara/

PTO/AIA/15 (10-17)
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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	M1567.70000US04
First Named Inventor	Corban Tillemann-Dick
Title	INTEGRATED DILUTION REFRIGERATORS
Priority Mail Express® Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

1. [X] **Fee Transmittal Form** (PTO/SB/17 or equivalent)
2. [X] **Applicant asserts small entity status.** See 37 CFR 1.27
3. [ ] **Applicant certifies micro entity status.** See 37 CFR 1.29. Applicant must attach form PTO/SB/15A or B or equivalent.
4. [X] **Specification** [*Total Pages* 37]
   Both the claims and abstract must start on a new page.
   (See MPEP § 608.01(a) for information on the preferred arrangement)
5. [X] **Drawing(s)** (35 U.S.C. 113) [*Total Sheets* 23]
6. **Inventor's Oath or Declaration** [*Total Pages*]
   (including substitute statements under 37 CFR 1.64 and assignments serving as an oath or declaration under 37 CFR 1.63(e))
   a. [ ] Newly executed (original or copy)
   b. [ ] A copy from a prior application (37 CFR 1.63(d))
7. [X] **Application Data Sheet** ** See note below.*
   See 37 CFR 1.76 (PTO/AIA/14 or equivalent)
8. **CD-ROM or CD-R** in duplicate, large table, or Computer Program (*Appendix*)
   [ ] Landscape Table on CD
9. **Nucleotide and/or Amino Acid Sequence Submission** (*if applicable, items a. – c. are required*)
   a. [ ] Computer Readable Form (CRF)
   b. [ ] Specification Sequence Listing on:
      i. [ ] CD-ROM or CD-R (2 copies); or
      ii. [ ] Paper
   c. [ ] Statements verifying identity of above copies

ADDRESS TO: **Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450**

ACCOMPANYING APPLICATION PAPERS

10. [ ] **Assignment Papers** (cover sheet & document(s))
    Name of Assignee
11. [ ] **37 CFR 3.73(c) Statement** (*when there is an assignee*) [ ] **Power of Attorney**
12. [ ] **English Translation Document** (*if applicable*)
13. [ ] **Information Disclosure Statement** (PTO/SB/08 or PTO-1449)
    [ ] Copies of citations attached
14. [ ] **Preliminary Amendment**
15. [ ] **Return Receipt Postcard** (*MPEP § 503*) (*Should be specifically itemized*)
16. [ ] **Certified Copy of Priority Document(s)** (*if foreign priority is claimed*)
17. [ ] **Nonpublication Request** Under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or equivalent.
18. [ ] **Other:**

***Note:** (1) Benefit claims under 37 CFR 1.78 and foreign priority claims under 1.55 **must** be included in an Application Data Sheet (ADS).
(2) For applications filed under 35 U.S.C. 111, the application must contain an ADS specifying the applicant if the applicant is an assignee, person to whom the inventor is under an obligation to assign, or person who otherwise shows sufficient proprietary interest in the matter. See 37 CFR 1.46(b).

19. CORRESPONDENCE ADDRESS

[X] The address associated with Customer Number: 23628 **OR** [ ] Correspondence address below

Name					
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Signature	/Sarah C. C. Schlotter/	Date	July 8, 2022
Name (Print/Type)	Sarah C.C. Schlotter, PhD	Registration No. (Attorney/Agent)	79,027

10479668.1

INTEGRATED DILUTION REFRIGERATORS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 63/319,248 filed on March 11, 2022, and titled "INTEGRATED DILUTION REFRIGERATORS," and of U.S. Provisional Patent Application No. 63/219,795 filed on July 8, 2021, and titled "INTEGRATED DILUTION REFRIGERATORS," the contents of each of which are incorporated by reference herein in their entirety.

BACKGROUND

Dilution refrigerators are cryogenic devices that rely on the heat of mixing of the ^{3}He and ^{4}He isotopes to provide cooling down to temperatures between approximately 2 mK and 1 K. Classic dilution refrigerators, or "wet" dilution refrigerators, precool the ^{3}He/^{4}He mixture using liquid nitrogen and ^{4}He baths before further cooling of the ^{3}He/^{4}He mixture below 4 K. Modern dilution refrigerators, or "dry" dilution refrigerators, precool the ^{3}He/^{4}He mixture using devices such as a cryocooler rather than cryogenic liquid baths.

SUMMARY

Some embodiments are directed to a dilution refrigerator comprising: an outer vacuum chamber comprising at least one substantially planar surface; and an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises a sample stage housed within the outer vacuum chamber, wherein the opening is configured to provide access to the sample stage through the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the sample stage are slidable and/or removable to provide access to the sample stage.

In some embodiments, the at least one substantially planar surface comprises a first surface disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator.

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In some embodiments, the at least one substantially planar surface comprises: first surfaces disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator; and second surfaces disposed within a plane parallel to the plane of the floor, wherein the first surfaces and the second surfaces are arranged as a rectangular prism.

In some embodiments, the opening comprises a hermetic opening.

In some embodiments, the opening comprises a hinged door.

In some embodiments, the dilution refrigerator further comprises one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the hinged door are slidable and/or removable to provide access to the interior of the outer vacuum chamber.

In some embodiments, the opening further comprises a load lock.

In some embodiments, the outer vacuum chamber comprises: a first section; and a second section suspended from the first section.

In some embodiments, the first section is coupled to the second section by integrated clamps and/or cams.

In some embodiments, the first and/or second section of the outer vacuum chamber are configured to be at least partially removed from the dilution refrigerator to provide access to an interior of the outer vacuum chamber.

In some embodiments, the dilution refrigerator further comprises an external system configured to lift and/or lower the first and/or second section of the outer vacuum chamber.

In some embodiments, the external system comprises pneumatic and/or hydraulic devices configured to lift and/or lower the first and/or second sections.

In some embodiments, the external system comprises a screw mechanism configured to lift and/or lower the first and/or second sections.

In some embodiments, the outer vacuum chamber is configured to fit within a server rack-type container.

In some embodiments, the server rack-type container is configured to integrate with commercial server rack infrastructure.

In some embodiments, the server rack-type container is a 19-inch server rack.

In some embodiments, the server rack-type container comprises an external housing comprising an integrated horizontal surface.

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In some embodiments, the integrated horizontal surface is configured to be stowed when not in use.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing. In the drawings:

FIG. 1 is a schematic diagram of a closed-cycle dilution refrigerator, in accordance with some embodiments described herein.

FIG. 2 is a schematic diagram of helium cleaning devices in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 3 is a schematic diagram of a cooldown turbo charger device in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 4 is a schematic diagram of a still including a device to separate ^{3}He and ^{4}He using second sound effects, in accordance with some embodiments described herein.

FIG. 5A shows illustrative components of a removable dilution insert for the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 5B is a view of an illustrative thermalization plate insert of the removable dilution insert of FIG. 5A, in accordance with some embodiments described herein.

FIG. 5C is a cross-sectional view of an illustrative integrated heat exchanger showing channels for helium flow, in accordance with some embodiments described herein.

FIG. 5D is an image of a high surface area material for use in an integrated heat exchanger, in accordance with some embodiments described herein.

FIG. 5E is an illustrative implementation of a continuous heat exchanger and discrete heat exchanger of the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIGs. 6A-6F are schematic diagrams of illustrative ^{4}He film separation devices, in accordance with some embodiments described herein.

FIG. 7A is an image of sintered metal particles for use in a heat exchanger.

FIG. 7B is an image of nanowires for use in a heat exchanger, in accordance with some embodiments described herein.

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FIG. 7C is an image of a nanocluster for use in a heat exchanger, in accordance with some embodiments described herein.

FIG. 7D includes images of different nanopellets for use in a heat exchanger in accordance with some embodiments described herein.

FIG. 8A is a schematic diagram of an illustrative vibration isolation system for use in the dilution refrigerator of FIG. 1, in accordance with some embodiments described herein.

FIG. 8B shows an illustrative spring for use in the vibration isolation system of FIG. 8A, in accordance with some embodiments described herein.

FIG. 9 is a side view of an illustrative external support rack and integrated lift configured to raise and lower portions of the vacuum chamber, in accordance with some embodiments described herein.

FIG. 10A is a side view of an illustrative implementation of the dilution refrigerator of FIG. 1 including elements configured to provide tool-free assembly of the vacuum chamber and access to the experimental volume, in accordance with some embodiments described herein.

FIGs. 10B and 10C are views of integrated latches in open and closed positions, respectively, configured to provide tool-free assembly of the vacuum chamber, in accordance with some embodiments described herein.

FIG. 11 is an exterior view of a housing configured to support a dilution refrigerator, in accordance with some embodiments described herein.

FIG. 12A is a schematic diagram of an inverted dilution refrigerator, in accordance with some embodiments described herein.

FIGs. 12B and 12C are schematic diagrams of illustrative components of an inverted dilution refrigerator, in accordance with some embodiments described herein.

FIG. 13 is a schematic diagram of a distributed cooling system, in accordance with some embodiments described herein.

FIG. 14 depicts, schematically, an illustrative computing device on which aspects of the technology described herein may be implemented.

DETAILED DESCRIPTION

Dilution refrigerators are cryogenic devices that can provide cooling down to temperatures between approximately 2 mK and 1 K and are used in a variety of

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applications requiring these extremely low temperatures. For example, dilution refrigerators can be used to support quantum computing (e.g., superconducting quantum computing technologies and qubits) and low-temperature condensed matter physics research, among other applications.

As described above, dilution refrigerators rely on the heat of mixing of ^{3}He and ^{4}He isotopes to provide cooling. When cooled below approximately 870 mK, a ^{3}He/^{4}He mixture undergoes spontaneous phase separation to form a ^{3}He-rich phase (the "concentrated" phase) and a ^{3}He-poor phase (the "dilute" phase). These two phases are maintained in equilibrium in a mixing chamber, the coldest part of the dilution refrigerator, and are separated by a phase boundary. In the mixing chamber, the ^{3}He is diluted as it moves from the concentrated phase through the phase boundary into the dilute phase, and the heat necessary for this endothermic dilution process provides the cooling power of the dilution refrigerator.

However, conventional dilution refrigerators can suffer from a multitude of drawbacks and failure points. For example, wet dilution refrigerators require significant amounts of liquid cryogens, which are costly to maintain and supply. As another example, dry dilution refrigerators can be subject to unwanted mechanical vibrations introduced by the cryocooler system and/or may draw large amounts of energy to power the cryocooler.

Conventional dilution refrigerators also typically occupy a large footprint, which may be prohibitive for applications requiring multiple dilution refrigerators. For example, a single conventional dry dilution refrigerator typically requires approximately 300 square feet and ceiling heights between 12 and 14 feet. This space is occupied not only by the dilution refrigerator itself but is also required to support any auxiliary systems such as pumps, compressors, water cooling systems and/or cryocooler systems.

The inventors have recognized and appreciated that, for quantum computing and other quantum technologies to be easily scalable, the quantum technology industry needs reliable, easy-to-use, easy-to-maintain, and compact dilution refrigerators. Accordingly, the inventors have developed dilution refrigerators and distributed cooling systems that can be integrated with commercially available server rack infrastructure (e.g., 19-inch server racks). Additionally, the inventors have developed a number of features, described herein, to ease maintenance of the dilution refrigerators, speed cooling of the dilution refrigerators without the use of mechanical pumps, and to reduce the transmission of mechanical vibrations to the experimental volume of the dilution refrigerator.

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I. Improved Closed-Cycle Dilution Refrigerator

FIG. 1 is a schematic diagram of a dry, closed-cycle dilution refrigerator 100, in accordance with some embodiments described herein. In some embodiments, the dilution refrigerator 100 includes an outer vacuum chamber 106 at room temperature (e.g., approximately 300K) and a number of thermal stages 108a-108f (e.g., thermalization plates) held at decreasing temperature intervals (e.g., approximately 50 K, 9-10 K, 3 K, etc.). For example, the first thermal stage 108a may be at approximately 50 K, the second thermal stage 108b may be at approximately 9-10 K, the third thermal stage 108c may be at approximately 3-4 K, the fourth thermal stage 108d may be at approximately 800 mK, the fifth thermal stage 108e may be at approximately 100 mK, and the sixth thermal stage 108f may be at approximately 10 mK.

In some embodiments, the dilution refrigerator 100 may include a pump system 102 that pressurizes a ^{3}He/^{4}He gas mixture (e.g., to a pressure at or near 1 bar). The ^{3}He/^{4}He gas mixture may enter the outer vacuum chamber 106 through one or more inlets and thereafter may travel through the inner thermal stages 108a-108f through the condensing line 102a. After performing its cooling function, the ^{3}He/^{4}He mixture may return to the pump system through the return 102b.

In some embodiments, the ^{3}He/^{4}He mixture may be purified prior to traveling along the condensing line 102a through the thermal stages 108a-108f. Contaminants in the helium flowing through the dilution refrigerator can clog certain components (e.g., the Joule-Thomson expander or capillaries in the heat exchangers) and lead to performance degradation or system failure. Conventionally, to reduce the risk of contaminants making their way into the system, helium is first passed through an external 'cleaning trap' filled with activated charcoal before entering the dilution unit of the dilution refrigerator. These external traps must be surrounded by liquid nitrogen and refilled at frequent intervals, which requires user maintenance and interaction.

The inventors have recognized and appreciated that passive helium filters, without the need for refilling of liquid nitrogen, can improve the user experience and reduce maintenance frequency of a dilution refrigeration system. Accordingly, in some embodiments, the dilution refrigerator 100 includes one or more helium cleaning devices 110. In some embodiments, where the dilution refrigerator 100 includes two or more helium cleaning devices 110, the dilution refrigerator 100 may further include a switching

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system 109 configured to direct the flow of the helium to a single helium cleaning device 110.

FIG. 2 shows a schematic diagram of helium cleaning devices 110, in accordance with some embodiments described herein. The helium cleaning devices 110 may be coupled to the pump system 102 by a switching system 109 that is disposed outside of the outer vacuum chamber 106. The switching system 109 may include one or more helium-compatible valves. The switching system 109 may be configured to switch helium flow between each of the helium cleaning devices 110. In this manner, one helium cleaning device 110 may be used for actively filtering helium while the dilution refrigerator is in operation while the other helium cleaning device may be cleaned (e.g., by heating and pumping out of impurities), enabling indefinite periods of operation of the dilution refrigerator 100.

In some embodiments, the helium cleaning devices 110 include a counter flow heat exchanger 110a, a trap 110b, and a weak thermal contact 110c (e.g., a gas gap heat exchanger, a low thermal conductivity attachment, etc.). The counter flow heat exchanger 110a and the weak thermal contact 110c may reduce the thermal load of the helium cleaning devices 110 on the dilution refrigerator 100 and may eliminate the use of cryogenic valves in the helium cleaning devices 110. The trap 110b may include, for example, a high surface area material (e.g., charcoal, activated charcoal, and/or a metal powder) configured to capture non-helium impurities in the dilution refrigerator 100.

Returning to FIG. 1, in some embodiments, the dilution refrigerator 100 may include a cooldown turbo charger device 111. Dry dilution refrigerators conventionally use an auxiliary compressor to enable the flow of warm helium, which initially has a high impedance and resists such movement. The extra pressure from the auxiliary compressor also pressurizes the helium, causing the helium to reach a pressure that starts isenthalpic expansion and cooling at a higher temperature. These auxiliary mechanical compressor pumps are costly, prone to reliability issues, frequently leak, and can cause performance degradation over time. The inventors have recognized and appreciated that, alternatively, the helium may be pulsed through the dilution refrigerator during cooldown without the use of an auxiliary mechanical pump, enabling a faster and more efficient cooldown process.

FIG. 3 shows a schematic diagram of a cooldown turbo charger device 111, in accordance with some embodiments described herein. The cooldown turbo charger device

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111 may include a volume of a high surface area material 111a, a heater 111b, a first valve 111c, and a second valve 111d. The first and second valves 111c, 111d may be, for example, cold valves located inside the vacuum chamber 106. As another example, the first and second valves 111c, 111d may be room temperature valves located outside of the vacuum chamber 106. In some embodiments, the heater 111b and the first and second valves 111c, 111d may be communicatively coupled to a controller 330. The controller 330 may be, for example, a computer as described in connection with FIG. 14 herein.

In some embodiments, the cooldown turbo charger device 111 may be thermally coupled to a thermal stage (e.g., to a thermalization plate). In the example of FIG. 3, the high surface area material 111a is thermally coupled to the second thermal stage 108b, though it should be appreciated that the high surface area material 111a could be thermally coupled to another thermal stage in some embodiments (e.g., first thermal stage 108a).

Alternatively, in some embodiments, the cooldown turbo charger device 111 may be thermally coupled to multiple thermal stages (e.g., across two or more thermal stages 108a-108f). In such embodiments, the sequential heating and cooling of the high surface area material 111a may be mediated by heat switches. For example, the cooldown turbo charger device 111 may be switchably thermally coupled between a warmer thermal stage and a colder thermal stage such that the cooldown turbo charger device 111 may be thermally coupled to either the warmer thermal stage or the colder thermal stage. When the cooldown turbo charger device 111 is thermally coupled to the warmer thermal stage, the high surface area material 111a may release any adsorbed helium. When the cooldown turbo charger device 111 is thermally coupled to the colder thermal stage, helium may begin adsorbing to the high surface area material 111a. In this manner, a sequential flushing of helium through the condensing line 102a may be implemented.

In some embodiments, the high surface area material 111a may comprise a material with a porous and/or textured surface such that helium adsorbs to the high surface area material 111a during the cooldown process. For example, the high surface area material 111a may comprise activated charcoal, a metal powder (e.g., a copper or silver powder), and/or a material composite formed of nanostructures (e.g., nanowires, nanoparticles, etc.).

In some embodiments, the cooldown turbo charger device 111 may be operated using a sequential opening and closing of the valves 111c, 111d in concert with operation of the heater 111b. For example, to cause helium to adsorb the high surface area material 111a, the first valve 111c may be closed to prevent helium from flowing to the lower stages

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of the dilution refrigerator 100 and the second valve 111d may be opened to allow helium to reach the high surface area material 111a. The first valve 111c may be closed and the second valve 111d may be opened by the controller 330 in response to a measured pressure or temperature or in response to a timing signal generated by controller 330.

In some embodiments, after sufficient helium has adsorbed onto the high surface area material 111a, the second valve 111d may be closed and the first valve 111c may be opened. The first and second valves 111c, 111d may be opened and/or closed in response to measured temperatures or pressures and/or in response to a timing signal generated by controller 330.

In some embodiments, when the second valve 111d is closed and the first valve 111c is opened, the heater 111b may also be caused, at a same or similar time, to heat the high surface area material 111a in response to a signal generated by controller 330. For example, the heater 111b may be a resistive heater that is caused to heat the high surface area material 111a by a flow of current through the heater 111b. In response to the heat from the heater 111b, the helium adsorbed to the high surface area material 111a may act as a reserve that is then released from the high surface area material 111a. This release of the adsorbed helium may increase the pressure in the remainder of the condensing line 102a, and the increased pressure may enable the start of isenthalpic expansion to speed cooling of the dilution refrigerator 100.

In some embodiments, once the helium has been released from the high surface area material 111a, the first valve 111c may be closed, the second valve 111d may be opened, and the heater 111b may be turned off by the controller 330, allowing new helium to adsorb to the high surface area material 111a. The controller 330 may be configured to periodically (e.g., at regular time intervals, at irregular time intervals, at time intervals determined by the temperature of the experimental volume, at time intervals determined by the pressure of the experimental volume) open and/or close the valves 111c, 111d and to operate the heater 111b to flush the helium intake path. In some embodiments, the controller 330 may be configured to "pulse" the helium from the high surface area material 111a through the condensing line 102a, causing the dilution refrigerator to be cooled.

Returning to FIG. 1, during operation of the dilution refrigerator, the $^3He/^4He$ mixture may be progressively cooled as it travels along the condensing line 102a from the first thermal stage 108a to the mixing chamber 122. At the first thermal stage, the helium may be initially cooled to approximately 50 K. After exiting the cooldown turbo charger

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device, the $^3He/^4He$ mixture may next be cooled by a cryocooler 104. A portion of the cryocooler 104 may be disposed partially outside of the outer vacuum chamber 106, in some embodiments. The cryocooler 104 may be vibrationally isolated from outer vacuum chamber 106 by a vibration isolation stage 105, which may comprise padding and/or any other suitable vibration isolation techniques.

In some embodiments, the cryocooler 104 may be coupled to a cryocooler support 103. The cryocooler support 103 may be, for example, a compressor and/or compression system, in some embodiments. The cryocooler support 103 may include cooling members 103a, in some embodiments, configured to provide air-cooling to the dilution refrigerator 100. The cooling members 103a may be, as a non-limiting example, cooling fins, fans, and/or heat pipes configured to remove waste heat generated by the cryocooler support 103 and/or the cryocooler 104.

The cooling members 103a are in contrast to conventional closed-cycle dilution refrigerators, which typically rely on water-cooling to remove waste heat generated by the integrated cryocooler. Water-cooling of the cryocooler, however, requires installing a large and/or expensive water-cooling system in conjunction with the dilution refrigerator. Additionally, such water-cooling systems are not typically integrated with commercial computing facilities, which typically rely on air-cooling as it is less expensive and does not present hazards (e.g., leaking coolant, flooding, etc.) to the electronic equipment. The inventors have accordingly recognized that using air-cooling to remove heat from the cryocooler of the dilution refrigerator may reduce the costs of manufacturing dilution refrigerators and enable their use in commercial computing facilities.

In some embodiments, the dilution refrigerator 100 may be disposed above a plenum (not pictured) disposed under a floor supporting the dilution refrigerator. The plenum may supply the cooling members 103a with air flow to provide air-cooling. In some embodiments, the cooling members 103a may include inlets and/or louvers configured to draw in air from the plenum. Alternatively or additionally, in some embodiments, the dilution refrigerator 100 may be disposed in a facility including ductwork and/or heat pipes (not pictured) arranged to remove heat from the cooling members 103a, the cryocooler support 103, and/or the cryocooler 104 and to minimize vibrations experienced by the dilution refrigerator 100.

In some embodiments, the $^3He/^4He$ mixture may be cooled by the cryocooler 104 in two steps. The condensing line 102a may be wound around two portions of the

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cryocooler 104 to effect heat exchange between the ^{3}He/^{4}He mixture in the condensing line 102a and the cryocooler 104. In a first step, the ^{3}He/^{4}He mixture may be cooled to approximately 10 K by the cryocooler 104. In a second step, the ^{3}He/^{4}He mixture may be cooled to approximately 3-4 K by the cryocooler 104.

In some embodiments, after being cooled by the cryocooler 104, the ^{3}He/^{4}He mixture may pass through the third thermal stage 108c. The third thermal stage 108c may be thermally coupled but mechanically decoupled from cryocooler 104, in some embodiments, in order to provide vibration isolation to the later thermal stages 108d-108f. As a non-limiting example, in some embodiments, third thermal stage 108c may be mechanically decoupled from the cryocooler by a copper braid, heat strap, or other hanging component configured to maintain thermal coupling between the third thermal stage 108c and the cryocooler 104.

In some embodiments, after passing through the third thermal stage 108c, the ^{3}He/^{4}He mixture may enter a primary impedance stage 112. The primary impedance stage 112 may be a Joule-Thomson expander configured to reduce the temperature and/or pressure of the ^{3}He/^{4}He mixture. For example, in some embodiments, the ^{3}He/^{4}He mixture may be at approximately 3-5 K before entering the primary impedance stage 112 and may be at approximately 1 K after exiting the primary impedance stage 112.

In some embodiments, the primary impedance stage 112 may be a Joule-Thomson expander formed from a fiber optic cable. Conventionally, Joule-Thomson expanders may be formed as metal tubes that are manufactured by pulling. However, such metal Joule-Thomson expanders may suffer from irregularities and/or may have a larger diameter that reduces the cooling power of the device. A hollow-core fiber optic cable may reliably and reproducibly provide the narrow opening needed for a Joule-Thomson expander.

In some embodiments, the dilution refrigerator 100 may include a bypass device 113a configured to increase the speed of cooldown of the dilution refrigerator 100. For example, during the initial cooldown of a dilution refrigerator, the helium flow rate may be low due to the large impedance of Joule-Thomson expanders in the dilution refrigerator and the warm, low density, and viscous circulating helium. This reduced helium flow rate reduces the rate of cooling of the lower portions of the refrigerator. To combat this effect, conventionally, a needle valve may be incorporated at a location on the condensing line above the Joule-Thomson expander to reduce the impedance of the initially-warm helium gas. However, the needle valve includes mechanical components that may fail over time.

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The inventors have recognized and appreciated that the helium flow rate may be improved without reliance on a mechanical component such as a needle valve.

In some embodiments, the bypass device 113a may be disposed along the condensing line 102a in parallel with the primary impedance stage 112 and on a bypass line 113b that bypasses the primary impedance stage 112 (e.g., allowing the ^{3}He/^{4}He mixture to flow around the primary impedance stage 112). The bypass device 113a may include a sheet of vacuum-compatible material configured to allow helium to diffuse through the material at temperatures above a threshold temperature value. For example, the bypass device 113a may allow the ^{3}He/^{4}He mixture to diffuse through the bypass device 113a at temperatures in a range from approximately 40 K to 300 K, in a range from 50 K to 300 K, in a range from 80 K to 300 K, in a range from 100 K to 300 K, in a range from 150 K, or in any range within those ranges. In some embodiments, the bypass device 113a may include a sheet of a vacuum-compatible polymer material. For example, the bypass device 113a may be formed of a sheet of Kapton, PEEK, and/or mylar, as some non-limiting examples. The bypass device 113a therefore allows for the high impedance of the primary impedance stage 112 to be circumvented when the ^{3}He/^{4}He mixture is warm, thereby increasing the helium flow rate and rate of cooling of the dilution refrigerator 100. When the dilution refrigerator 100 has cooled sufficiently (e.g., to below the threshold temperature value), the ^{3}He/^{4}He mixture will no longer diffuse through the bypass device 113a and instead will flow through the primary impedance stage 112.

In some embodiments, after exiting the primary impedance stage 112 or the bypass device 113a, the ^{3}He/^{4}He mixture then travels past the fourth thermal stage 108d and into the still 114. The still 114 may contain a different mixture of liquid ^{3}He/^{4}He that cools the incoming ^{3}He/^{4}He mixture as it passes through the condensing line 102a running through the still 114. In some embodiments, the ^{3}He/^{4}He mixture in the condensing line may be cooled to approximately 400-900 mK by the still 114.

In some embodiments, the still 114 may include a membrane configured to use second sound to improve ^{3}He evaporation within the still. Second sound is a superfluid phenomenon present in superfluid helium and may be produced, for example, when a porous membrane is oscillated or a heated wire is cycled within a bath of superfluid helium. The two-fluid model specifies that the superfluid helium in the mixture moves through the membrane while non-superfluid components of the helium bath cannot pass through the porous membrane as easily. In superfluid helium, this creates an enthalpy or

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temperature wave. Analogously in helium mixtures, the non-superfluid ^{3}He may be preferentially pushed by the oscillating membrane while the superfluid ^{4}He remains relatively stationary. The inventors have recognized and appreciated that this second sound phenomenon can be implemented within the still 114 to increase the ^{3}He evaporation rate at a lower temperature and to reduce a concentration of ^{4}He in the vapor above the liquid helium mixture in the still.

FIG. 4 is a schematic diagram of a still 400 including a device to separate ^{3}He and ^{4}He using second sound effects, in accordance with some embodiments described herein. The still 400 may be implemented as still 114 of dilution refrigerator 100, in some embodiments. The still 400 may include a stationary surface 402 and a porous, movable membrane 404. The porous membrane 404 may be oscillated along the Z direction to create standing concentration waves of ^{3}He within the still so that there are regions 406 of lower ^{3}He concentration and regions 408 of high ^{3}He concentration. The standing wave may be tuned such that regions 408 of high ^{3}He concentration are disposed adjacent an outlet of the still, thereby allowing for improved ^{3}He purification.

Returning to FIG. 1, in some embodiments, after exiting the still 114, the ^{3}He/^{4}He mixture may flow through the condensing line 102a to a secondary impedance stage 116. The secondary impedance stage 116 may be configured to ensure that only liquid ^{3}He/^{4}He proceeds further downstream in the dilution refrigerator 100 and that gas cavitation in the still 114 does not occur (e.g., by maintaining a threshold pressure in the still 114). The secondary impedance stage 116 may therefore reduce downstream cooling loads due to a latent heat of gaseous ^{3}He/^{4}He.

In some embodiments, after exiting the secondary impedance stage 116, the ^{3}He/^{4}He mixture may then flow into a first heat exchanger 118. The first heat exchanger 118 may be a continuous heat exchanger. For example, the first heat exchanger 118 may be a counterflow (e.g., a tube-tube heat exchanger), a cross-counterflow, and/or coflow heat exchanger. At the exit of the first heat exchanger 118, the ^{3}He/^{4}He mixture in the condensing line 102a may be cooled to a temperature of approximately 20 mK.

In conventional closed-cycle dilution refrigerators, prior to entering the still, the ^{3}He/^{4}He mixture in the condensing line typically must pass through a first impedance stage. This first impedance stage typically acts as an independent refrigeration stage, known as a Joule-Thomson refrigerator, where the ^{3}He/^{4}He mixture is cooled by isenthalpic expansion. In order to control the cooling power of the ^{3}He/^{4}He mixture

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expansion, the pressure of the $^3He/^4He$ mixture in the condensing line is typically raised by an external compressor.

The inventors have recognized and appreciated that reducing the temperature of the $^3He/^4He$ mixture prior to entering the first impedance stage can achieve the same cooling effect (e.g., the $^3He/^4He$ mixture can reach the same base temperature after passing through the first impedance stage) while using a lower pressure differential. Such a configuration can improve the efficiency of the dilution refrigerator and reduce or eliminate the need to pressurize the $^3He/^4He$ mixture before the first impedance stage. Further, the inventors have recognized that the heat removed from the $^3He/^4He$ mixture prior to the first impedance stage can be returned to the still, thereby eliminating or reducing the need for a supplemental heater within the still to raise the vapor pressure, and enabling evaporation, of the different $^3He/^4He$ mixture present in the still.

Accordingly, in some embodiments, the dilution refrigerator 100 may include a heat exchange line 117 configured to transfer heat from the incoming condensing line 102a to a return helium mixture being transported from the first heat exchanger 118 to the still 114. The heat exchange line 117 may cool the condensing line 102a at a location above the primary impedance stage 112. The heat exchange line 117 then cools the $^3He/^4He$ mixture in the condensing line 102a prior to entering the primary impedance stage 112. Thereafter, the warmed mixture in the heat exchange line 117 is transported to the still 114.

Cooling the incoming $^3He/^4He$ mixture before it enters the primary impedance stage 112 causes the primary impedance stage 112 to output a $^3He/^4He$ mixture with a higher proportion of ^3He in the liquid state rather than in the vapor state. Thus, the primary impedance stage 112 can be made more efficient by including the additional heat exchange line 117. Additionally, this improved efficiency eliminates or mitigates the need for supplemental pressure (e.g., an external compressor) and may lower the flow impedance of the circulating helium mixture. This is particularly useful in reducing the complexity and size of smaller dilution refrigerators that include smaller (i.e., less powerful) pulse tubes or other cryocoolers.

In some embodiments, after exiting the first heat exchanger 118, the $^3He/^4He$ mixture passes through the fifth thermal stage 108e and enters continuous heat exchanger 119. The continuous heat exchanger 119 may be a counterflow (e.g., a tube-tube heat exchanger), a cross-counterflow, and/or coflow heat exchanger. The continuous heat

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exchanger 119 is disposed below the fifth thermal stage 108e. The fifth thermal stage 108e may be an intermediate cold plate (ICP) configured to be cooled to a temperature of approximately 100-200 mK. While continuous heat exchangers are typically more efficient than discrete heat exchangers, they become less efficient below a temperature of approximately 80 mK. However, adding continuous heat exchanger 119 below the fifth thermal stage 108e may enable the fifth thermal stage 108e to operate with more cooling power during the process of cooling down the dilution refrigerator.

In some embodiments, after exiting the continuous heat exchanger 119, the ^{3}He/^{4}He mixture enters discrete heat exchangers 120. The discrete heat exchangers 120 may be formed of sintered nanoparticles, in some embodiments. Alternatively or additionally, in some embodiments the discrete heat exchangers 120 may be formed of sintered nanowires, as described herein in connection with FIGs. 7A-7D herein. The discrete heat exchangers 120 may be configured to further cool the ^{3}He/^{4}He mixture to a temperature below approximately 10-20mK.

The inventors have additionally recognized and appreciated that the user experience may be improved by allowing users to easily swap parts in and out of the dilution refrigerator 100 (e.g., for maintenance, to change the characteristics of the dilution refrigerator 100, and/or to upgrade the dilution refrigerator 100 as technological innovations are developed). The inventors have accordingly developed a swappable dilution insert that is easily removed and replaced. FIG. 5A shows illustrative components of a removable dilution insert 540 for the dilution refrigerator 100 of FIG. 1, in accordance with some embodiments described herein.

In some embodiments, the removable dilution insert 540 includes detachable plates 540a, 540b, 540c removably coupled to thermal stages 108d, 108e, and 108f, respectively. As shown in the example of FIG. 5A, the detachable plates 540a, 540b, and 540c may be removably coupled using mechanical fasteners (e.g., bolts and/or screws). In some embodiments, the removable dilution insert 540 further includes detachable connections 540d above the still (e.g., flanges) and to the condensing line 102a to further simplify replacement of the removable dilution insert 540.

FIG. 5B shows a close-up view of a detachable plate 540b of the removable dilution insert of FIG. 5A, in accordance with some embodiments described herein. The detachable plate 540b includes an input A and an outlet B to allow helium to flow through the detachable plate 540b, in some embodiments.

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In some embodiments, the detachable plates 540a, 540b, and/or 540c may include integrated heat exchangers. In some embodiments, the integrated heat exchangers may be channels 542 formed in the detachable plates 540a and/or 540b, as illustrated by the example of FIG. 5C, which shows a cross section through the detachable plate 540b of FIG. 5B. The channels 542 may be configured to have a high surface area. By allowing helium to flow through the channels 542 in the detachable plates 540a and/or 540b, the helium's rate of cooling may be increased. In some embodiments, the channels 542 may be formed by machining, welding, and/or by additive fabrication techniques (e.g., three-dimensional printing techniques).

In some embodiments, the integrated heat exchangers may be a high surface area material structure formed in the detachable plate 540c. For example, the integrated heat exchangers may be a lattice structure, as shown in the example of FIG. 5D. The lattice structure may be, as a non-limiting example, a square lattice structure having a periodicity in a range from approximately 400 μm to approximately 1000 μm. For example, the lattice structure may have a periodicity of approximately 600 μm.

In some embodiments, the lattice structure may be fabricated using additive fabrication techniques (e.g., three-dimensional printing techniques). The lattice structure may be fabricated to have a rough surface texture to increase the surface area of the material in contact with the helium mixture passing through the integrated heat exchanger, thereby improving heat exchange. In some embodiments, the lattice structure may be formed of a metal. As non-limiting examples, the lattice structure may be formed of copper, silver, and/or aluminum.

In some embodiments, the dilution insert 540 may include one or more heat exchangers, as described in connection with dilution refrigerator 100 of FIG. 1. FIG. 5E shows an illustrative implementation of a continuous heat exchanger 119 and discrete heat exchanger 120, in accordance with some embodiments described herein. As shown in FIG. 5E, the helium flows from the detachable plate 540b coupled to fifth thermal stage 108e into the continuous heat exchanger 119 followed by the discrete heat exchanger 120 and the detachable plate 540c.

Refrigeration cycles in cryogenic coolers typically use a method to control the flow of heat throughout the system. This control may be achieved with a superconductor, a gas gap, or other mechanisms to make or break a thermal connection between components within the system (i.e., heat switches). One common type of heat switch, a gas gap,

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typically comprises two high surface area objects with a small gap between them that is filled with a gas. As the system falls below a certain temperature, the conductive gas is adsorbed onto surface area in the heat switch, creating a vacuum and reducing heat transfer between the surfaces. Another common type of heat switch is a superconducting switch where a material passes through a superconducting transition and reduces thermal conductivity.

In some embodiments, the dilution refrigerator 100 may further include combined gas gap and/or superconducting heat switches between thermal stages of the dilution refrigerator 100. The example of FIG. 5E shows such a combined gas gap and superconducting heat switch 550 thermally coupled between thermal stages 108e and 108f. The combined gas gap and superconducting heat switches 550 include both a superconducting material (e.g., aluminum, titanium) that becomes superconducting at a temperature higher than a target temperature of the thermal stage to which it is thermally coupled and a gas gap heat switch to improve thermal isolation between the thermal stages.

Returning to FIG. 1, after the ^{3}He/^{4}He mixture exits the discrete heat exchanger 120, it passes through the sixth thermal stage 108f and enters the mixing chamber 122. In the mixing chamber 122, ^{3}He atoms may be pumped from a concentrated phase into a dilute phase (i.e., mixed with ^{4}He). This mixing causes the ^{3}He to be cooled as it passes through the phase transition between the concentrated phase to the dilute phase, and this endothermic phase transition provides the final cooling power of the dilution refrigerator 100.

In some embodiments, an experimental volume 124 (e.g., a sample stage or plate) may be thermally coupled to the mixing chamber 122 and configured to support a sample and/or quantum device. Because the experimental volume 124 is thermally coupled to the mixing chamber 122, the sample and/or quantum device may be held at or near the mixing chamber temperature.

In some embodiments, the experimental volume 124 may be accessed by the user when the dilution refrigerator 100 is not in operation through an opening in the vacuum chamber 106 and door 125. The door 125 may be, in some embodiments, a removable panel (e.g., secured with mechanical fasteners) or may be a hinged door that a user may open using a clamped handle (e.g., as shown in the example of FIG. 10A herein).

As illustrated in the example of FIG. 1, certain components of the dilution refrigerator 100 may be thermally coupled to a thermal stage and disposed on one side

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(e.g., above or below) the thermal stage. For example, the still 114 is shown as being disposed on a lower surface of the fourth thermal stage 108d. It should be appreciated that in some embodiments, such components may be disposed on either side of the associated thermal stage, as aspects of the technology described herein are not limited in this respect. For example, in some embodiments the still 114 may be disposed on an upper surface of the fourth thermal stage 108d. As another example, the helium cleaning devices 110 may be disposed on a lower surface of the first thermal stage 108a, in some embodiments.

In some embodiments, after entering the dilute phase, the ^{3}He/^{4}He mixture may be pumped out of the mixing chamber 122 and back through the dilution refrigerator 100, exiting the outer vacuum chamber 106 through return 102b. At low temperatures and pressures, ^{4}He forms a thick and mobile film that can move long distances across surfaces, including moving in a direction counter to the force of gravity. This helium creep can result in ^{4}He entering portions of a dilution refrigeration system where it is unwanted (e.g., spanning the gap between thermally isolated areas). FIGs. 6A-6F are schematic diagrams of exemplary ^{4}He separation devices that may be implemented at outlets in, for example, the mixing chamber 122 and/or the still 114, in accordance with some embodiments described herein.

FIG. 6A illustrates a cooling stage 600 (e.g., a still, the mixing chamber, etc.) including a bath 602 of a dilute phase helium mixture (e.g., a ^{3}He /^{4}He mixture), in some embodiments. ^{4}He can creep up an outlet pipe (e.g., a still pumping outlet pipe, a mixing chamber outlet pipe) and exit the cooling stage 600 unless a barrier 606 prevents the helium creep. In the example of FIG. 6A, barrier 606 comprises a sharp edge at a right-angled surface configured to prevent helium from exiting the cooling stage 600 through the low pressure pumping outlet.

Other embodiments of a barrier configured to prevent ^{4}He creep are shown in the examples of FIGs. 6B, 6C, 6D, and 6E. In the example of FIG. 6B, a ring 608 with a knife edge 609 is configured to prevent ^{4}He from exiting through the ^{3}He outlet. In some embodiments, the ring 608 may include a heating device (e.g., a resistive heater or any other suitable heater) configured to cause the creeping ^{4}He to leave the superfluid phase, thereby mitigating creep.

In the examples of FIGs. 6C, 6D, and 6E, vertical knife edges are used to prevent ^{4}He from exiting through the ^{3}He outlet. In some embodiments, and in the example of FIG. 6C, the knife edge 610 is on the exterior circumference of the outlet pipe. Alternatively,

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as shown in the example of FIG. 6D, the knife edge 611 may be beveled on the interior circumference of the outlet pipe. Further, as shown in the example of FIG. 6E, the knife edge 612 may be beveled on both the exterior and interior circumferences of the outlet pipe.

In some embodiments, and as shown in the example of FIG. 6F, the ^{3}He outlet may include a p-trap 621 configured to collect ^{4}He 622 at a lower surface of the p-trap 621. The ^{3}He outlet may include a normal leak or a superleak 624 configured to allow normal or superfluid ^{4}He to exit the p-trap 621, and a pump 626 (e.g., a fountain pump) may transport the ^{4}He away from the p-trap 621. In some embodiments, a further barrier 627 may be present on an interior surface of the outlet pipe. For example, the barrier 627 may be configured as a ring. In some embodiments, the barrier 627 may include a heating device to further prevent ^{4}He from exiting the outlet.

The inventors have recognized and appreciated that nanomaterials can provide advantages compared to conventional sintered metal powders (e.g., silver and/or copper powder) used in typical discrete heat exchangers. Accordingly, the inventors have developed nanomaterial heat exchangers that provide efficient heat exchange because of the nanomaterials' large surface area, high mechanical contact strength, and good neck growth between nanowires.

Typical discrete heat exchangers are commonly made out of sintered metal power (e.g., silver and/or copper powder). An example of such sintered particulates is shown in FIG. 7A. To have efficient heat exchange at the sub-Kelvin temperatures, however, a number of factors must be true with regards to the heat exchanger materials. The heat exchange material should have a large surface area, provide high mechanical and/or thermal contact between the liquid helium and the heat exchange material, allow for good neck growth, and provide space inside the heat exchange material for the liquid helium to move through the heat exchanger.

FIG. 7B shows an image of a nanomaterial comprising nanowires for use in a heat exchanger. FIG. 7C shows an image of a nanomaterial comprising nanoclusters for use in a heat exchanger. FIG. 7D shows images of nanomaterials comprising different examples of nanopellet shapes for use in a heat exchanger, in accordance with some embodiments described herein. These nanomaterials may be implemented in dilution refrigerator 100 in discrete heat exchanger 120 and/or in a block heat exchanger (e.g., present in the mixing chamber 122). It should be appreciated that FIGs. 7B-7D show examples of nanomaterial

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shapes, but that embodiments of nanomaterial for use in a discrete heat exchanger are not so limited. For example, the nanomaterial may alternatively be a nanofoam, nanotube, and/or any other suitable nanoshape.

In some embodiments, such a nanomaterial-based heat exchanger may be formed by bonding the nanomaterial through sintering. For example, the nanomaterial may be formed as a chemical precipitate and/or by electronic deposition or electroplating techniques. A substrate with a rough surface (e.g., comprising nucleation sites) may be provided for the nanomaterial to be grown on or adhered to. In some embodiments, the heat exchanger may be produced under heat and/or compression. The nanomaterial may be held in compression during the sintering process to form the nanowire heat exchanger. In some embodiments, the substrate may be patterned with macroscopic structures (e.g., a lattice or series of posts). In some embodiments, the substrate may be a tube, and the nanomaterial may be adhered to the interior or exterior surface of the tube. In some embodiments, the substrate may be formed of a material with a lower thermal conductivity than the nanomaterial adhered to the substrate.

In some embodiments, the nanomaterial may be formed out of one of a selection of vacuum-compatible materials including but not limited to copper, silver, vacuum-compatible polymers, carbon, and/or carbon fiber. For example, the nanomaterial may be nanowires comprising at least one of copper nanowires, silver nanowires, gold nanowires, platinum nanowires, polymer nanowires, carbon nanowires, and/or carbon fiber nanowires.

II. Improved Vibration Isolation

Many experiments conducted at sub-Kelvin temperatures are sensitive to vibrational noise both from the surrounding environment and the dilution refrigerator's cooling system pumps and components. Additionally, at sub-Kelvin temperatures, mechanical vibrations can generate a heat load, reducing the cooling power of the dilution refrigerator or producing tribo-electric noise on electrical inputs and/or outputs of the dilution refrigerator. The inventors have recognized and appreciated that improved vibration isolation can improve the cooling power and other performance characteristics (e.g., magnetic flux disruption) of a dilution refrigerator. Accordingly, the inventors have developed vibration isolation components configured to mechanically decouple the lower thermal stages 108d-108f from the upper thermal stages 108a-108c.

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FIG. 8A shows another schematic diagram of dilution refrigerator 100 including mechanical elements configured to provide vibration isolation, in accordance with some embodiments described herein. The vibration isolation elements include a first suspension system 832, at least one second suspension system 840, and a third suspension system 834.

In some embodiments, the first suspension system 832 may be configured to suspend the first thermal stage 108a, the second thermal stage 108b, and/or the third thermal stage 108c from the top surface of the outer vacuum chamber 106. The first suspension system 832 may include one or more rods configured to rigidly couple the first, second, and/or third thermal stages 108a-108c to the top surface of the outer vacuum chamber 106. The rods may be formed of a material having a high spring constant. For example, the rods may be formed of carbon fiber and/or stainless steel.

In some embodiments, the second suspension system 840 may be configured to independently suspend the fourth thermal stage 108d, the fifth thermal stage 108e, and/or the sixth thermal stage 108f from the top surface of the outer vacuum chamber 106. This independent suspension of the lower thermal stages 108d-108f vibrationally isolates the lower thermal stages 108d-108f from the upper thermal stages 108a-108c, thereby improving the vibration isolation of the lower thermal stages 108d-108f.

In some embodiments, the second suspension system 840 may include one or more springs 842, rods 843, and/or connectors 844. While the example of FIG. 8A shows only one second suspension system 840, it should be appreciated that multiple second suspension systems 840 may be used to suspend the lower thermal stages 108d-108f, in some embodiments. For example, there may be two, three, or four such second suspension systems 840, in some embodiments.

In some embodiments, the springs 842 may be configured to provide a constant spring tension under different loads (e.g., for different dampened masses hanging from the springs 842). An example of a spring 842 is shown in FIG. 8B. The springs 842 may be leaf suspension springs, in some embodiments, and may include an upper flexure 842a separated from a lower flexure 842b by rigid portions 842c. The springs 842 may flex through the flexing of upper and lower flexures 842a, 842b, providing vibrational isolation to the lower thermal stages 108d-108f along the Z axis (e.g., perpendicular to a plane of the floor supporting the dilution refrigerator 100). In some embodiments, a spring constant of the spring 842 may be determined by pre-tensioning the upper and/or lower flexures 842a, 842b. Alternatively or additionally, the spring constant of the spring 842 may be

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determined by changing a length of the upper and/or lower flexures 842a, 842b (e.g., having a lower spring constant for longer lengths of flexures 842a, 842b).

In some embodiments, the springs 842 may be coupled to the third thermal stage 108d by rods 843. The rods 843 may be soft rods having a low spring constant. For example, the rods 843 may be formed out of a polymer (e.g., DELRIN), in some embodiments. The rods 843, due to their softness, may provide vibrational isolation to the lower thermal stages 108d-108f in the X-Y plane (e.g., in a plane parallel to a plane of the floor supporting the dilution refrigerator 100 and perpendicular to the Z axis).

In some embodiments, the connectors 844 may be arranged in a triangular configuration to provide stability to the suspension of the fourth thermal stage 108d. The connectors 844 may be made of materials configured to have a high spring constant. For example, the connectors 844 may be formed of stainless steel and/or carbon fiber.

In some embodiments, the third suspension system 834 may be configured to suspend the fifth thermal stage 108e and the sixth thermal stage 108f from the fourth thermal stage 108d. In this manner, the three lower thermal stages 108d-108f may all be suspended from the top surface of the vacuum chamber 106 using the second suspension system 840. The third suspension system 834 may include one or more rods configured to rigidly couple the fifth and/or sixth thermal stages 108e, 108f to the fourth thermal stage 108d. The rods may be formed of a material having a high spring constant. For example, the rods may be formed of carbon fiber and/or stainless steel, in some embodiments.

It should be appreciated that while the example of FIG. 8A shows the first and third suspension systems 832, 834 as being formed out of rods, in some embodiments, the first and/or the third suspension system 832, 834 may be formed out of flexible springs, as aspects of the present disclosure are not limited in this respect. Additionally, it should be appreciated that while the example of FIG. 8A shows the second suspension system 840 as being formed out of springs, in some embodiments, the second suspension system 840 may be formed out of rods, as aspects of the present disclosure are not limited in this respect.

III. Integrated Dilution Refrigerator

Conventional dilution refrigerator technology often requires large amounts of space and expensive supporting infrastructure such as custom-built floating foundations, high ceilings, and/or access pits. These infrastructure requirements may reduce the

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scalability of quantum technologies that operate at low temperatures. As a non-limiting example, the adoption of certain quantum computing technologies may be limited by the required use of large dilution refrigerators. The inventors have recognized and appreciated that reducing the size and infrastructure requirements of dilution refrigerators may enable the scalability of quantum technologies. The inventors have further recognized that integrating dilution refrigerators with commercial computing infrastructure (e.g., commercial server infrastructure) can further enable the scalability of dilution refrigerators and associated quantum technologies dependent on dilution refrigerators. Such integrated dilution refrigerators may be more easily integrated into telecommunications networks, can use existing telecommunications heat removal architectures, and integrate with fiberoptic networks and systems.

FIG. 9 is a side view of an illustrative external support rack 950, in accordance with some embodiments described herein. In some embodiments, the external support rack 950 may support the dilution refrigerator 100 by suspending the dilution refrigerator 100 off of the floor below the dilution refrigerator 100. As shown in the example of FIG. 9, the external support rack 950 may include arms 952 that are coupled to portions of the top surface of the vacuum chamber 106 by vibration isolation components 954 to suspend the dilution refrigerator 100 off of the floor. In some embodiments, the vibration isolation components 954 may be air pistons, electromagnetic dampeners, and/or springs.

In some embodiments, the external support rack 950 may include castors (not shown) configured to assist in transportation of the dilution refrigerator 100. The castors may be retractable such that the wheels of the castors are not in contact with the floor supporting the external support rack 950 when the dilution refrigerator 100 is not being transported and/or is in operation.

In some embodiments, the external support rack 950 further includes floor supports 958. Floor supports 958 may be configured to extend from the external support rack 950 when the dilution refrigerator 100 is not being transported. Floor supports 958 may extend from the external support rack 950, for example, by the use of screws. The floor supports 958 may be used to lift and/or level the external support rack 950 away from the floor and/or to lift the castors of the external support rack 950 off of the floor. In some embodiments, the floor supports 958 may be used to correct the positioning of the external support rack 950 in the case of an uneven floor surface.

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In some embodiments, the external support rack 950 may support additional components external to the outer vacuum chamber 106 of dilution refrigerator 100. For example, the external support rack 950 may house compressors, pumps, and/or cooling equipment configured to support the operation of the dilution refrigerator 100. Alternatively, these external components may be housed in an adjacent (e.g., a different) server rack-type container and/or support rack 950 than the dilution refrigerator 100, in some embodiments.

In some embodiments, the external support rack 950 may include elements configured to provide tool-free assembly and/or disassembly of the vacuum chamber 106 and access to the experimental volume, in accordance with some embodiments described herein. As shown in the example of FIG. 9, the vacuum chamber 106 includes three sections, a first section 106a, a second section 106b suspended from the first section 106a, and a third section 106c suspended from the second section 106b. It should be appreciated that the technology described herein is not limited to three sections, and that a vacuum chamber may have one, two, four, five, or six sections in some embodiments.

In some embodiments, the vacuum chamber 106 may have one or more substantially planar surfaces. In some embodiments, at least one of the one or more substantially planar surfaces may be disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator. As shown in the example of FIG. 9, the sections 106a-106c may each have at least four substantially planar surfaces such that, when assembled, the vacuum chamber 106 is arranged to form a rectangular prism. In some embodiments, the vacuum chamber 106 may include two substantially planar surfaces disposed within a plane parallel to the plane of the floor and arranged to close the rectangular prism formed by the surfaces of the sections 106a-106c. In some embodiments, and as described below, the vacuum chamber 106 may have an opening accessible by a door 1070 in at least one of the substantially planar surfaces.

In some embodiments, the three sections 106a-106c of the vacuum chamber 106 may be partially or fully removable in order to provide access to internal portions of the dilution refrigerator 100. For example, the three sections 106a-106c of the vacuum chamber 106 may comprise removable panels (e.g., side panels, panels attached to a frame, etc.), in some embodiments. The three sections 106a-106c may be configured to allow a user of the dilution refrigerator 100 to be able to remove the vacuum chamber 106 from the dilution refrigerator 100 without needed a large clearance above or below the dilution

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refrigerator 100 (e.g., without needing high ceilings or a pit underneath the dilution refrigerator 100).

In some embodiments, the external support rack 950 may include an integrated lift 956a configured to support the three sections 106a-106c of the vacuum chamber during assembly, disassembly, and/or maintenance of the dilution refrigerator 100. The integrated lift 956a may be configured to raise and/or lower the sections 106a-106c of the vacuum chamber. For example, the integrated lift 956a may be configured to raise and/or lower arms 956b configured to support portions (e.g., the flanges) of the three sections 106a-106c. In some embodiments, the integrated lift 956a may be operated manually (e.g., using screws and/or cables). In some embodiments, the integrated lift 956a may be operated using an electronically-operated machine (e.g., pneumatic or hydraulic devices).

In some embodiments, the external support rack 950 may include one or more carts 957. The carts 957 may be configured to receive one or more of the sections 106a-106c when lowered manually or by using the integrated lift 956a. For example, the integrated lift 956a may be used to lower the third section 106c onto a cart 957. Thereafter, the third section 106c may be transported using the cart 957 along direction C to provide a user of the dilution refrigerator 100 space under the interior components of the dilution refrigerator 100.

In some embodiments, the integrated lift 956a may be removably coupled to the external support rack 950. For example, the integrated lift 956a may be slidably removable from the external support rack 950 (e.g., sliding horizontally outward along the direction C). Removal of the integrated lift 956a may be desired to provide the user with extra space (e.g., during maintenance of the dilution refrigerator 100).

In some embodiments, the three sections 106a-106c of the vacuum chamber 106 may be suspended from one another by integrated clamps and/or cams. Such integrated clamps and/or cams may be configured to enable a user to unclamp or clamp two sections of the three sections 106a-106c together without the use of any additional tools. FIGS. 10A-10C illustrate an example of an integrated cam 1060, with FIG. 10B showing the integrated cam 1060 in an open position and FIG. 10C showing the integrated cam 1060 in a closed position.

In some embodiments, the integrated cam 1060 includes a handle 1062 that enables a user to clamp or unclamp two sections of the three sections 106a-106c together or apart. The handle 1062 is coupled to two latches 1064 that are configured to connect to bars

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1066. The handle 1062 and latches 1064 are hingedly coupled to a section of the vacuum chamber 106 by cams 1068, which provide the requisite range of motion to perform clamping and unclamping motions.

In some embodiments, a compressive layer may be included at the connection points between the three sections 106a-106c of the vacuum chamber 106 to ensure a proper vacuum-safe seal. For example, a rubber O-ring, copper or indium gasket, or other vacuum-safe compressive layer may be placed between sections 106a-106c.

Returning to FIG. 10A, in some embodiments, the vacuum chamber 106 may include an external opening to provide access to an internal volume within the dilution refrigerator 100. For example, the opening may provide access to a sample stage or experimental volume of the dilution refrigerator 100, or any other interior portion of the dilution refrigerator 100. In some embodiments, the opening may be sealed by a hermetic seal. In some embodiments, the opening may be sealed by a door 1070, as shown in the example of FIG. 10A. The door 1070 may be sealed, for example, using a hinge and/or a clamp that may be manually engaged and disengaged. In some embodiments, the door 1070 may be coupled to the opening by a load lock.

In some embodiments, the door 1070 may provide access through all of the inner radiation shields (not shown, and which may be thermally coupled to one or more of the thermal stages 108a-108f) of the dilution refrigerator 100 to allow a user to access the experimental volume. For example, a portion of the inner radiation shields (not shown) may be coupled to the door 1070 such that when a user opens the door 1070, the inner radiation shields slide or otherwise move to provide the user access with the interior portion of the dilution refrigerator. In some embodiments, a portion the inner radiation shields may be removable through the door 1070 and/or slidable through the door 1070.

In some embodiments, the external support rack 950 may be configured to be integrated with a server rack-type container. For example, the external support rack 950 may be configured to integrate the dilution refrigerator 100 with commercial server rack infrastructure (e.g., server racks). In some embodiments, the external support rack 950 may be configured to integrate the dilution refrigerator 100 with 19-inch server racks.

In some embodiments, the external support rack 950 and dilution refrigerator 100 may be housed within an outer housing. An example of an outer housing 1100 is illustrated in FIG. 11. In some embodiments, the outer housing 1100 may include an integrated horizontal surface 1110. For example, the integrated horizontal surface 1110 may be used

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as a desk or support surface when the user interacts with the dilution refrigerator. The integrated horizontal surface 1110 may be configured to be stowed by folding (as shown in the example of FIG. 11) or sliding away when not in use. In some embodiments, the outer housing 1100 may further include one or more storage locations (e.g., drawers, shelves) for the storage of related parts and/or tools for maintenance of the dilution refrigerator 100.

In some embodiments, the outer housing 1100 may further include a door 1125 providing access through an opening 1120 to the experimental volume of the dilution refrigerator 100. For example, the door 1125 may open to provide access to the experimental volume through the vacuum chamber 106 and the radiation shields inside of the vacuum chamber 106. In some embodiments, the vacuum chamber exterior and/or the radiation shields may be coupled to the door 1125 such that when a user opens the door 1125, the user opens the vacuum chamber exterior 106 and/or the radiation shields. In some embodiments, the radiation shields may alternatively be slidably and/or hingedly movable such that the user may move the radiation shields such that they no longer block access to the experimental volume as needed.

In some embodiments, the housing 1100 may further be configured to perform sound dampening. For example, the housing 1100 may include sound dampening materials to perform passive sound dampening. Alternatively or additionally, the housing 1100 may include audio equipment (e.g., speakers) configured to provide active sound dampening through the emission of destructive interference of the sounds generated by functional components of the system.

IV. Inverted Dilution Refrigerator

Conventionally, dilution refrigerators are oriented such that warmer thermal stages are positioned towards the top of the system with the thermal stages getting increasingly colder as the $^3He/^4He$ mixture progresses to the bottom of the dilution refrigerator. The inventors have recognized and appreciated that an inverted geometry, with the coldest stage disposed at the top of the system (e.g., furthest from the floor) may simplify the operation and use of a dilution refrigerator by making the experimental volume more accessible to a user and offer improved thermodynamic qualities compared to a conventional dilution refrigerator. Accordingly, the inventors have developed an inverted, dry dilution refrigerator.

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FIG. 12A is a schematic diagram of an inverted dilution refrigerator 1200, in accordance with some embodiments described herein. The inverted dilution refrigerator 1200 may include a pump system 1202 configured to circulate the ^{3}He/^{4}He mixture through the dilution refrigerator 1200. The inverted dilution refrigerator 1200 also may include a cryocooler 1204. The cryocooler may be coupled to a cryocooler support (not pictured) as described in connection with cryocooler support 103 herein.

In some embodiments, the inverted dilution refrigerator 1200 may include an outer vacuum chamber 1206 and a series of thermal stages 1208a-1208f disposed inside of the outer vacuum chamber 1206. The series of thermal stages 1208a-1208f may be held at same or similar temperatures as the thermal stages 108a-108f described in connection with FIG. 1 herein.

In some embodiments, the inverted dilution refrigerator 1200 may include an opening in the outer vacuum chamber 1206 and/or through the inner radiation shields to provide ease of access to the coldest stage of the inverted dilution refrigerator 1200. In some embodiments, the opening may comprise hermetic seals and/or an opening mechanism 1225 that may withstand the vacuum within the outer vacuum chamber when the inverted dilution refrigerator 1200 is in operation. For example, the opening mechanism 1225 may include a hinged door and/or a removable panel.

In some embodiments, the inverted dilution refrigerator 1200 may include a number of components arranged along the length of the dilution refrigerator (e.g., from within the vacuum chamber 1206 to within the sixth thermal stage 1208f). The components may be arranged with the coldest thermal stage, the mixing chamber 1222, disposed above warmer thermal stages (e.g., the still 1214, impedance stages 1212 and 1216, heat exchangers 1218, 1219, 1220, etc.).

In some embodiments, the inverted dilution refrigerator 1200 includes a de-mixing chamber 1224 coupled to the mixing chamber 1222. In some embodiments, the de-mixing chamber 1224 may be thermally coupled to the mixing chamber 1222 by a heat exchanger 1223 (e.g., a co-flow heat exchanger). The de-mixing chamber 1224 may be fluidly connected to the mixing chamber 1222 such that ^{3}He may be transported from the de-mixing chamber 1224 to the mixing chamber 1222 to provide additional cooling to the mixing chamber 1222. The de-mixing chamber 1224 may additionally have ^{4}He injected into the de-mixing chamber 1224 to provide a co-flow of ^{3}He and ^{4}He in order to mitigate a concentration gradient forming between the still 1214 and the mixing chamber 1222.

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FIGs. 12B and 12C are schematic diagrams of exemplary internal components of an inverted dilution refrigerator, in accordance with some embodiments described herein. It should be appreciated that the exemplary components of FIGs. 12B and 12C could be implemented within inverted dilution refrigerator 1200 of FIG. 12A (e.g., within the third thermal stage 1208c).

As shown in the example of FIG. 12B, in some embodiments the inverted dilution refrigerator may include a ^{4}He line 1226 configured to transport ^{4}He from the still 1214 to the de-mixing chamber 1224. In some embodiments, the ^{4}He line 1226 may include a pump 1228 configured to assist in the transportation of the ^{4}He to the de-mixing chamber 1224. The pump 1228 may be, for example, a fountain pump in some embodiments. Alternatively or additionally, the ^{4}He line 1226 may include additional heat exchangers to cool the ^{4}He as it travels to the de-mixing chamber 1224.

As shown in the example of FIG. 12C, in some embodiments, the inverted dilution refrigerator may include a heat exchange stage 1230 configured to cool the incoming ^{3}He/^{4}He mixture prior to the primary impedance stage 1212. As should be appreciated from the description of FIG. 1, such a configuration may increase the efficiency of the first impedance stage and/or eliminate or reduce the need for pressurization of the incoming ^{3}He/^{4}He mixture.

V. Distributed Cooling

Dilution refrigerators generally include an integrated cryocooler (e.g., such as a pulse tube or a Gifford-McMahon cryocooler) to pre-cool the ^{3}He/^{4}He mixture gas below 5 K. Conventionally, a dilution refrigerator is paired with at least one of these cryocoolers, and dilution refrigerators do not share cooling systems. Such small-scale dilution refrigeration systems typically rely on low-power cryocooling systems that are relatively inefficient (e.g., requiring more power for each Watt of cooling power at 4 K) in comparison to larger, higher-power cryocooling systems. The inventors have recognized and appreciated that a single, high-efficiency cooling system may be thermally coupled to multiple cryogenic systems such as dilution refrigerators to distribute this first stage of cooling across multiple cryogenic systems. Such distributed cooling therefore allows for increased cooling efficiency across multiple cryogenic systems.

FIG. 13 is a schematic diagram of a distributed cooling system 1300, in accordance with some embodiments described herein. The distributed cooling system 1300 may

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include multiple housings 1305. In some embodiments, the housings 1305 may be server rack-type containers (e.g., commercial server rack infrastructure, 19-inch server racks).

As shown in the example of FIG. 13, each housing 1305 may contain a cooling system 1310 or a cryogenic device 1320. It should be appreciated that cryogenic devices 1320 and/or cooling systems 1310 may be grouped within housings 1305, in some embodiments. It should further be appreciated that while FIG. 13 shows three cryogenic devices 1320 coupled to the cooling system 1310, in some embodiments, there may be two, four, ten, or many tens of cryogenic devices 1320 coupled to the cooling system 1310, as aspects of this disclosure are not so limited.

In some embodiments, the cooling system 1310 may be a cryocooling system configured to cool a first stage of the cryogenic devices 1320 to a temperature of at least 5 K and/or to a temperature of approximately 4-5 K. In some embodiments, the cooling system 1310 may be a pulse tube. For example, the cooling system 1310 may be a pulse tube, a helium liquefier system, and/or a Brayton cryocooler.

In some embodiments, the cooling system 1310 may be thermally coupled to multiple cryogenic devices 1320. Cooling may be distributed to cryogenic devices 1320 from cooling system 1310 by cooling line 1312. Additionally, heat may be returned from the cryogenic devices 1320 to cooling system by return 1314. The cooling line 1312 and/or return 1314 may be lines configured to transfer liquid and/or gaseous helium. For example, the cooling line 1312 and/or return 1314 may be pipes that are vacuum insulated to maintain the temperature of the transported helium. In some embodiments, the cooling line 1312 and/or return 1314 may be fill lines, heat pipes (e.g., traditional and/or pulsed heat pipes), and/or a superfluid loop.

In some embodiments, the cryogenic devices 1320 may include any suitable refrigeration system configured to reach temperatures at or below 5 K. In some embodiments, cryogenic devices 1320 may include one or more dilution refrigerators (e.g., dilution refrigerator 100 as described herein, configured to reach temperatures below 1 K). Alternatively or additionally, it should be appreciated that cryogenic devices 1320 may include cryogenic systems other than dilution refrigerators (e.g., microscopy systems such as scanning tunneling microscopy or atomic force microscopy systems, ^{3}He refrigeration systems, superconducting CMOS systems, etc.).

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In the embodiment shown in FIG. 14, the computer 1400 includes a processing unit 1401 having one or more processors and a non-transitory computer-readable storage medium 1402 that may include, for example, volatile and/or non-volatile memory. The memory 1402 may store one or more instructions to program the processing unit 1401 to perform any of the functions described herein. The computer 1400 may also include other types of non-transitory computer-readable medium, such as storage 1405 (e.g., one or more disk drives) in addition to the system memory 1402. The storage 1405 may also store one or more application programs and/or resources used by application programs (e.g., software libraries), which may be loaded into the memory 1402.

The computer 1400 may have one or more input devices and/or output devices, such as devices 1406 and 1407 illustrated in FIG. 14. These devices can be used, among other things, to present a user interface. Examples of output devices that can be used to provide a user interface include printers or display screens for visual presentation of output and speakers or other sound generating devices for audible presentation of output. Examples of input devices that can be used for a user interface include keyboards and pointing devices, such as mice, touch pads, and digitizing tablets. As another example, the input devices 1407 may include a microphone for capturing audio signals, and the output devices 1406 may include a display screen for visually rendering, and/or a speaker for audibly rendering, recognized text.

As shown in FIG. 14, the computer 1400 may also comprise one or more network interfaces (e.g., the network interface 1410) to enable communication via various networks (e.g., the network 1420). Examples of networks include a local area network or a wide area network, such as an enterprise network or the Internet. Such networks may be based on any suitable technology and may operate according to any suitable protocol and may include wireless networks, wired networks or fiber optic networks. Such networks may include analog and/or digital networks.

Various aspects of the embodiments described above may be used alone, in combination, or in a variety of arrangements not specifically discussed in the embodiments described in the foregoing and is therefore not limited in its application to the details and arrangement of components set forth in the foregoing description or illustrated in the drawings. For example, aspects described in one embodiment may be combined in any manner with aspects described in other embodiments.

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All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

The indefinite articles "a" and "an," as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean "at least one."

The phrase "and/or," as used herein in the specification and in the claims, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, a reference to "A and/or B," when used in conjunction with open-ended language such as "comprising" can refer, in one embodiment, to A only (optionally including elements other than B); in another embodiment, to B only (optionally including elements other than A); in yet another embodiment, to both A and B (optionally including other elements); etc.

As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements); etc.

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Use of ordinal terms such as "first," "second," "third," etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another or the temporal order in which acts of a method are performed, but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish the claim elements.

In the claims, as well as in the specification above, all transitional phrases such as "comprising," "including," "carrying," "having," "containing," "involving," "holding," "composed of," and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of" and "consisting essentially of" shall be closed or semi-closed transitional phrases, respectively.

The terms "approximately," "about," and "substantially" may be used to mean within ±20% of a target value in some embodiments, within ±10% of a target value in some embodiments, within ±5% of a target value in some embodiments, within ±2% of a target value in some embodiments. The terms "approximately," "about," and "substantially" may include the target value.

Having thus described several aspects of at least one embodiment, it is to be appreciated that various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure and are intended to be within the spirit and scope of the principles described herein. Accordingly, the foregoing description and drawings are by way of example only.

What is claimed is:

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CLAIMS

1. A dilution refrigerator comprising:

an outer vacuum chamber comprising at least one substantially planar surface; and

an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber.

2. The dilution refrigerator of claim 1, further comprising a sample stage housed within the outer vacuum chamber, wherein the opening is configured to provide access to the sample stage through the outer vacuum chamber.

3. The dilution refrigerator of claim 2, further comprising one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the sample stage are slidable and/or removable to provide access to the sample stage.

4. The dilution refrigerator of claim 1, wherein the at least one substantially planar surface comprises a first surface disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator.

5. The dilution refrigerator of claim 1, wherein the at least one substantially planar surface comprises:

first surfaces disposed within a plane perpendicular to a plane of a floor supporting the dilution refrigerator; and

second surfaces disposed within a plane parallel to the plane of the floor, wherein the first surfaces and the second surfaces are arranged as a rectangular prism.

6. The dilution refrigerator of claim 1, wherein the opening comprises a hermetic opening.

7. The dilution refrigerator of claim 1, wherein the opening comprises a hinged door.

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8. The dilution refrigerator of claim 7, further comprising one or more radiation shields housed within the outer vacuum chamber, and wherein portions of the one or more radiation shields proximate the hinged door are slidable and/or removable to provide access to the interior of the outer vacuum chamber.

9. The dilution refrigerator of claim 7, wherein the opening further comprises a load lock.

10. The dilution refrigerator of claim 1, wherein the outer vacuum chamber comprises:

a first section; and

a second section suspended from the first section.

11. The dilution refrigerator of claim 10, wherein the first section is coupled to the second section by integrated clamps and/or cams.

12. The dilution refrigerator of claim 10, wherein the first and/or second section of the outer vacuum chamber are configured to be at least partially removed from the dilution refrigerator to provide access to an interior of the outer vacuum chamber.

13. The dilution refrigerator of claim 10, further comprising an external system configured to lift and/or lower the first and/or second section of the outer vacuum chamber.

14. The dilution refrigerator of claim 13, wherein the external system comprises pneumatic and/or hydraulic devices configured to lift and/or lower the first and/or second sections.

15. The dilution refrigerator of claim 13, wherein the external system comprises a screw mechanism configured to lift and/or lower the first and/or second sections.

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16. The dilution refrigerator of claim 1, wherein the outer vacuum chamber is configured to fit within a server rack-type container.

17. The dilution refrigerator of claim 16, wherein the server rack-type container is configured to integrate with commercial server rack infrastructure.

18. The dilution refrigerator of claim 16, wherein the server rack-type container is a 19-inch server rack.

19. The dilution refrigerator of claim 17, wherein the server rack-type container comprises an external housing comprising an integrated horizontal surface.

20. The dilution refrigerator of claim 19, wherein the integrated horizontal surface is configured to be stowed when not in use.

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ABSTRACT

A dilution refrigerator is provided. The dilution refrigerator includes an outer vacuum chamber comprising at least one substantially planar surface and an opening in the at least one substantially planar surface configured to provide access to an interior of the outer vacuum chamber.

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Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	INTEGRATED DILUTION REFRIGERATORS
First Named Inventor/Applicant Name:	Corban Tillemann-Dick
Filer:	Sarah C.C. Schlotter/Annie Fearnley
Attorney Docket Number:	M1567.70000US04

Filed as Small Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
UTILITY FILING FEE (ELECTRONIC FILING)	4011	1	80	80
UTILITY SEARCH FEE	2111	1	350	350
UTILITY EXAMINATION FEE	2311	1	400	400
Pages:				
Claims:				
Miscellaneous-Filing:				
LATE FILING FEE FOR OATH OR DECLARATION	2051	1	80	80
Petition:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**910**

Electronic Acknowledgement Receipt	
EFS ID:	46149940
Application Number:	17860950
International Application Number:	
Confirmation Number:	9208
Title of Invention:	INTEGRATED DILUTION REFRIGERATORS
First Named Inventor/Applicant Name:	Corban Tillemann-Dick
Customer Number:	23628
Filer:	Sarah C.C. Schlotter/Annie Fearnley
Filer Authorized By:	Sarah C.C. Schlotter
Attorney Docket Number:	M1567.70000US04
Receipt Date:	08-JUL-2022
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Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$910
RAM confirmation Number	E202278H59022139
Deposit Account	
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The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Application Data Sheet	M156770000US04-ADS-SCS.pdf	63881 a935e78d28ce6f68e2d477ecfeef9833b8f224d3	no	7
Warnings:					
Information:					
This is not an USPTO supplied ADS fillable form					
2	Drawings-other than black and white line drawings	M156770000US04-DRW-SCS.pdf	1615044 b5130a7fd56cfb089081b4678a0c6d2bda5661a8	no	23
Warnings:					
Information:					
3	Fee Worksheet (SB06)	M156770000US04-FEE-SCS.pdf	32051 fde6400b423bd7a538cc80ac33f3a05b9c0cb631	no	1
Warnings:					
Information:					
4	Transmittal of New Application	M156770000US04-TRN-SCS.pdf	32421 038e619e2e2a3f87650a7026db150d482b17dd16	no	1
Warnings:					
Information:					
5		M156770000US04-UTLAPL-SCS.pdf	141932 4a615cf6de786da53db7e3935ebb9abbe34d3c86	yes	37

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Specification	1	33
	Claims	34	36

	Abstract		37	37	
Warnings:					
Information:					
6	Fee Worksheet (SB06)	fee-info.pdf	46230 d0e4873bd8919940923260a80ddd3d1996943c44	no	2
Warnings:					
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		Total Files Size (in bytes):	1931559		

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Application Data Sheet

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State or Province of mailing address::	CO

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Country of mailing address::	US
Postal or Zip Code of mailing address::	80305

Inventor Number::	3
Given Name::	Bryan
Family Name::	Choo
City of Residence::	New York
State or Province of Residence::	NY
Country of Residence::	US
Street of mailing address::	4 Saint Marks Place, 3S
City of mailing address::	New York
State or Province of mailing address::	NY
Country of mailing address::	US
Postal or Zip Code of mailing address::	10003

Inventor Number::	4
Given Name::	John
Family Name::	Ogando Dos Santos Allan
City of Residence::	Boulder
State or Province of Residence::	CO
Country of Residence::	US
Street of mailing address::	1565 Linden Ave
City of mailing address::	Boulder

EXHIBIT 1004 – Page 480 of 510
QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80304

Inventor Number::	5
Given Name::	Jonathan
Middle Name::	Michael
Family Name::	Byars
City of Residence::	Golden
State or Province of Residence::	CO
Country of Residence::	US
Street of mailing address::	14830 W 53rd Ave.
City of mailing address::	Golden
State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80403

Correspondence Information

Correspondence Customer Number::	23628

Application Information

Application Type::	Nonprovisional
Subject Matter::	Utility

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

CD-ROM or CD-R?::	None
Sequence submission?::	None
Computer Readable Form (CRF)?::	No
Title::	INTEGRATED DILUTION REFRIGERATORS
Attorney Docket Number::	M1567.70000US04
Request for Early Publication?::	No
Request for Non-Publication?::	No
Total Drawing Sheets::	23
Small Entity?::	Yes
Petition included?::	No
Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2::	No

Representative Information

Representative Customer Number::	23628

Domestic Priority Information

Application::	Continuity Type::	Parent Application::	Parent Filing Date::	Prior Appl Status::
This Application	Claims benefit of provisional	63/319248	03/11/22	Pending
This Application	Claims benefit of provisional	63/219795	07/08/21	Pending

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Foreign Priority Information

Applicant Information

Applicant Number::	1
Applicant Type::	Person to whom the inventor is obligated to assign
Organization Name::	Maybell Quantum Industries, Inc.
Street of mailing address::	7100 Broadway Building 3
	Suite D-E
City of mailing address::	Denver
State or Province of mailing address::	CO
Country of mailing address::	US
Postal or Zip Code of mailing address::	80221

Assignee Information Including Non-Applicant Assignee Information

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Authorization or Opt-Out of Authorization to Permit Access

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Sarah C. C. Schlotter/	Date (YYYY-MM-DD)	2022-07-08
Name	Sarah C.C. Schlotter, PhD	Registration Number	79,027

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

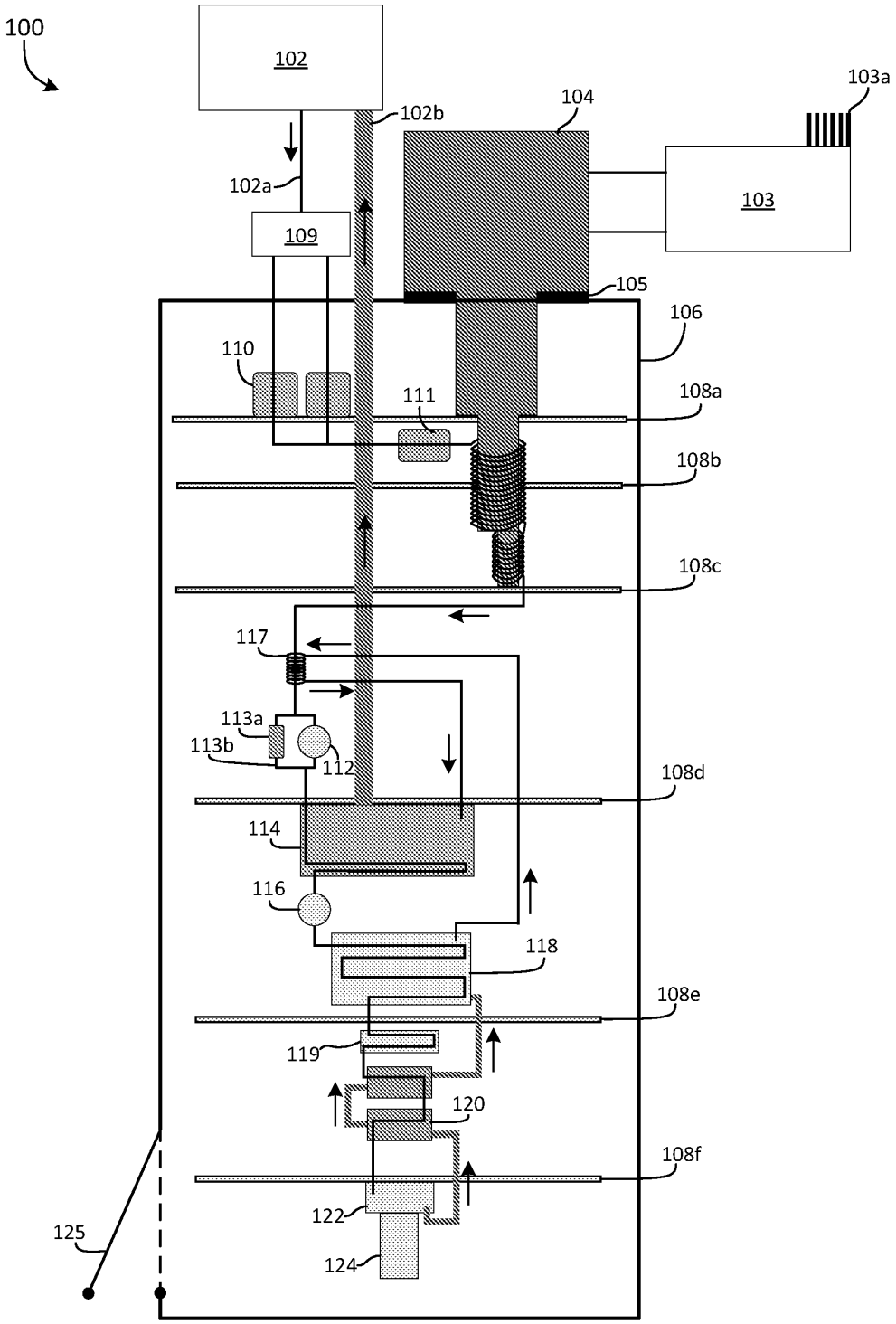

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FIG. 1

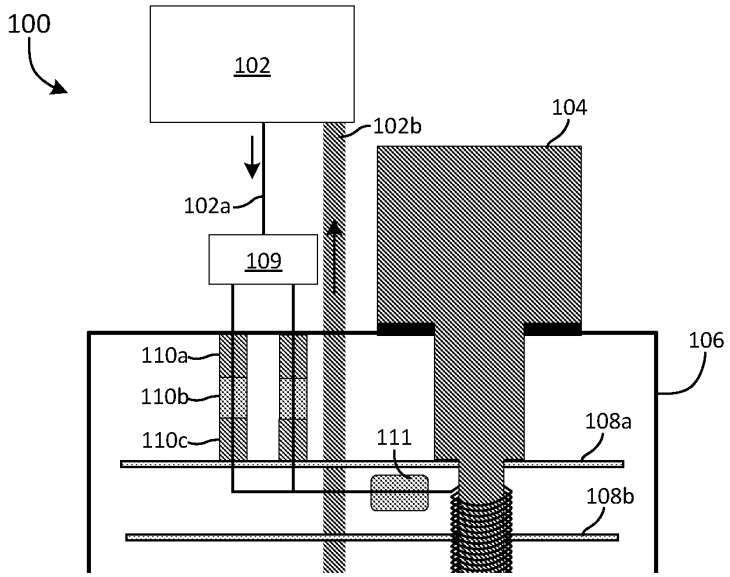


FIG. 2

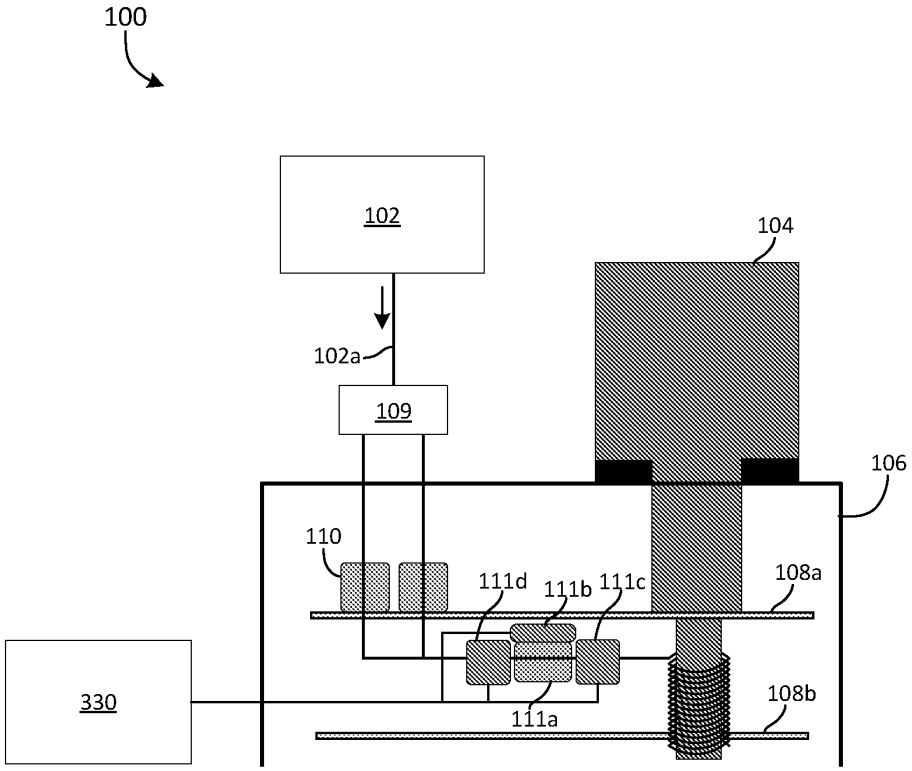


FIG. 3

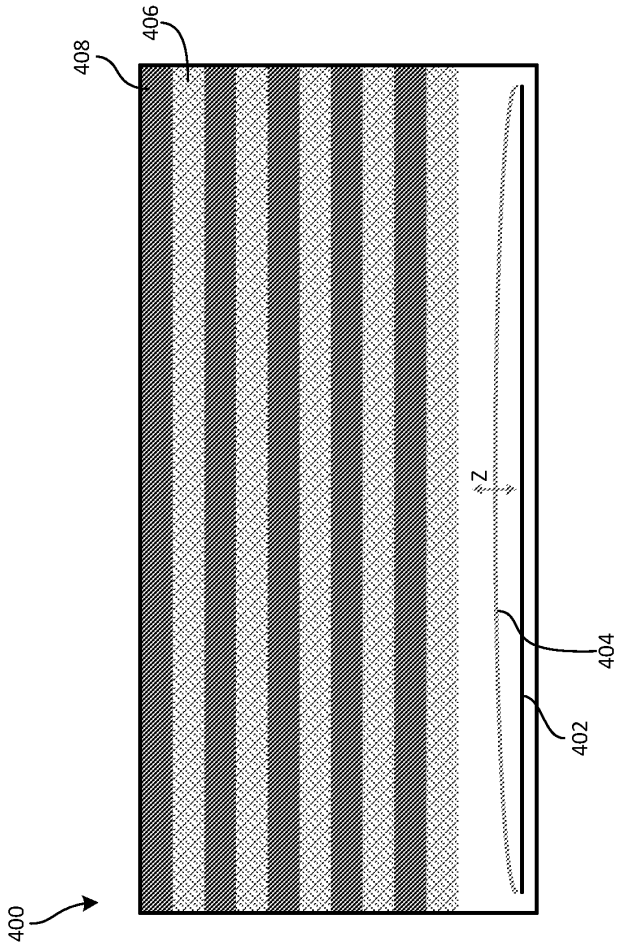


FIG. 4

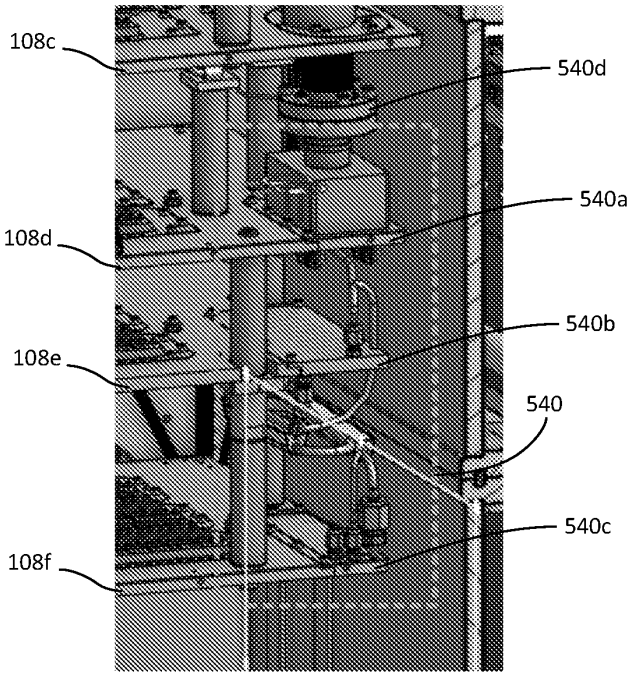


FIG. 5A

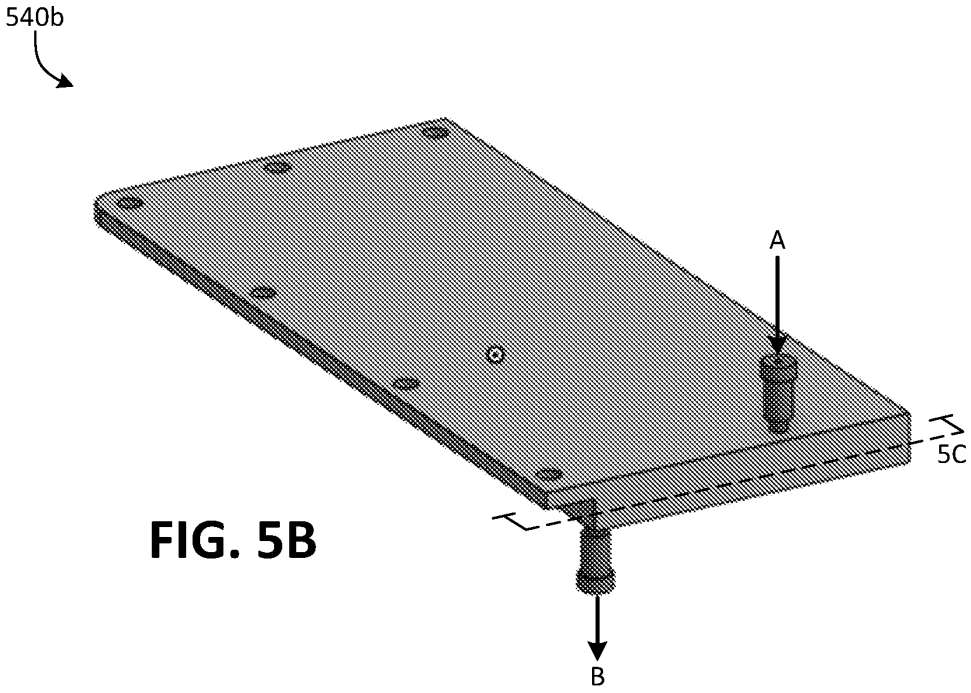


FIG. 5B

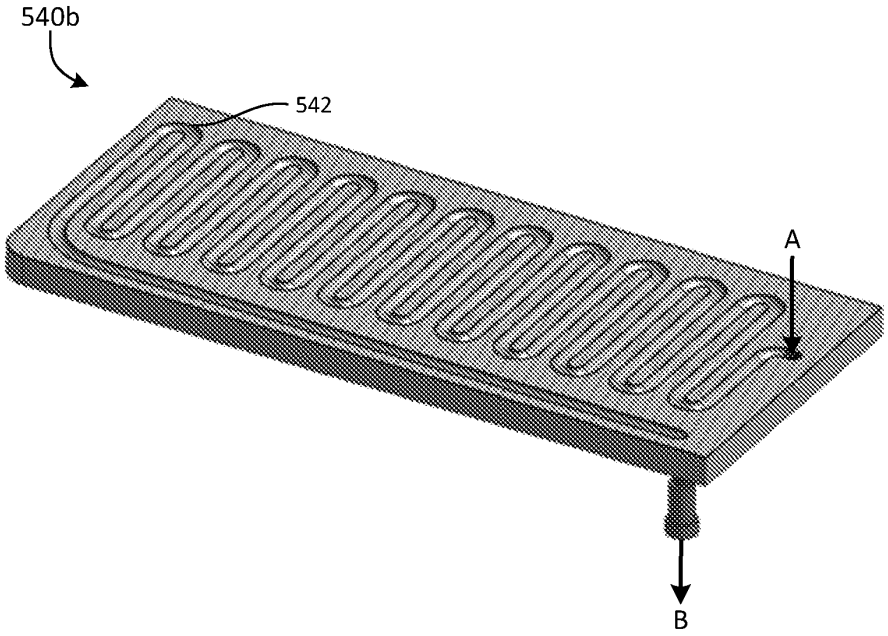


FIG. 5C

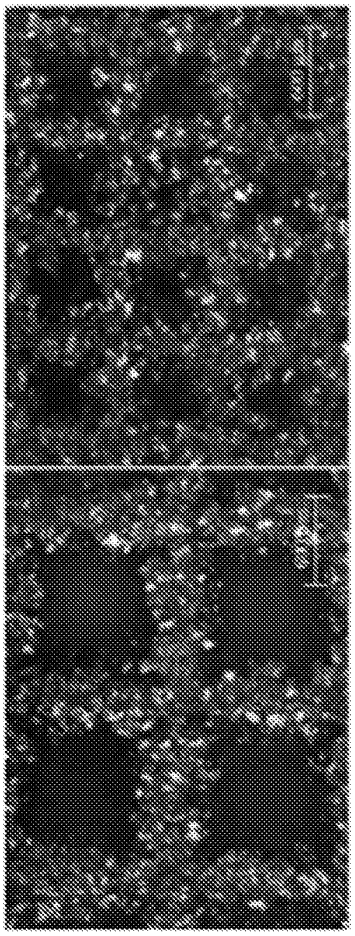


FIG. 5D

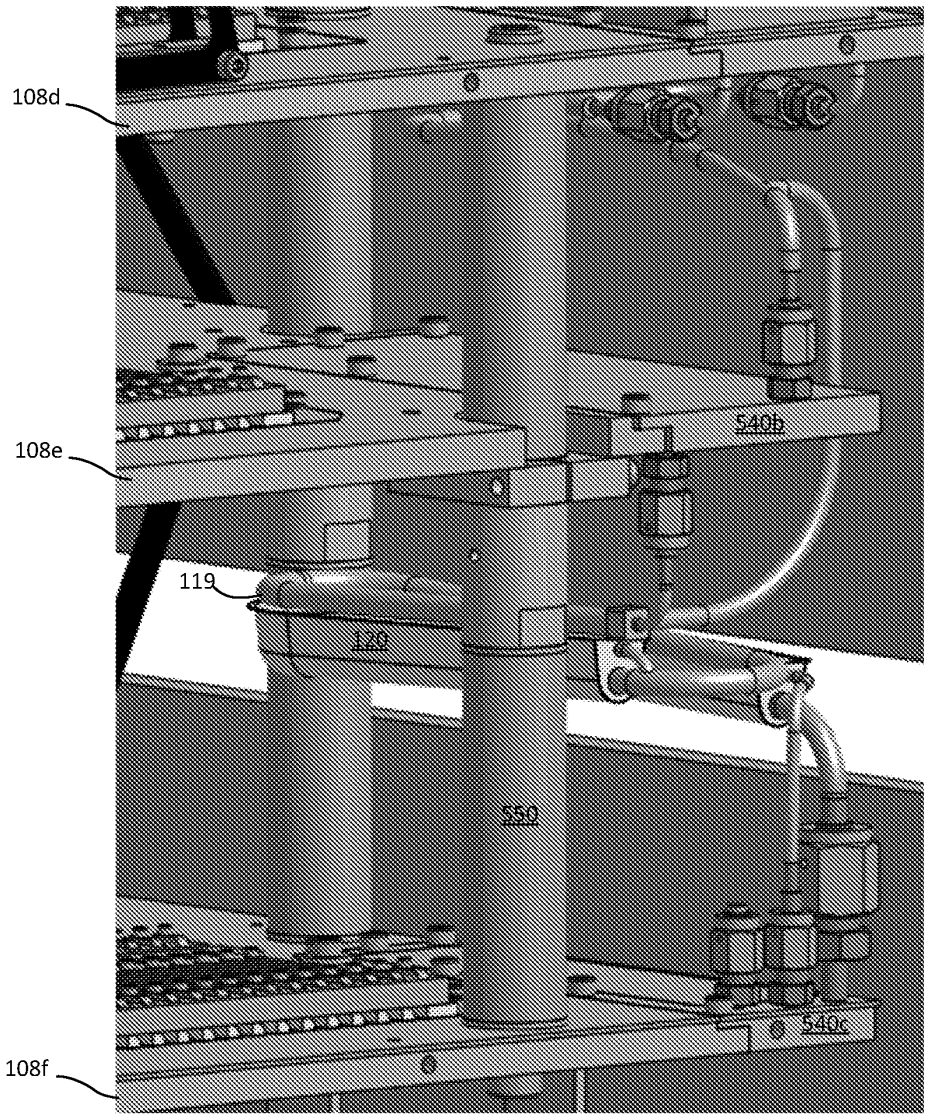


FIG. 5E

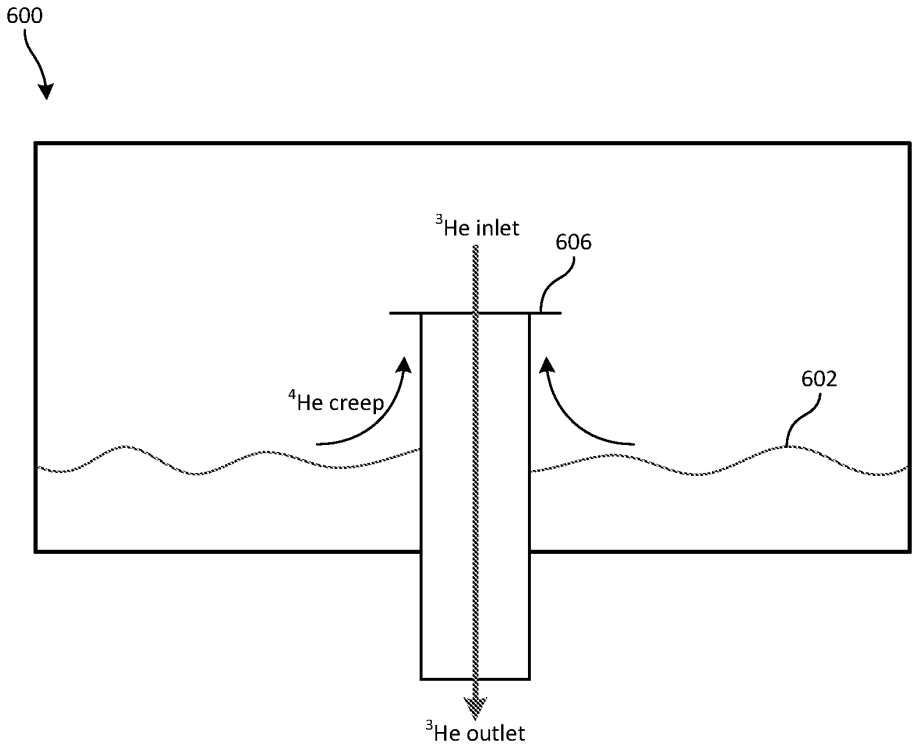


FIG. 6A

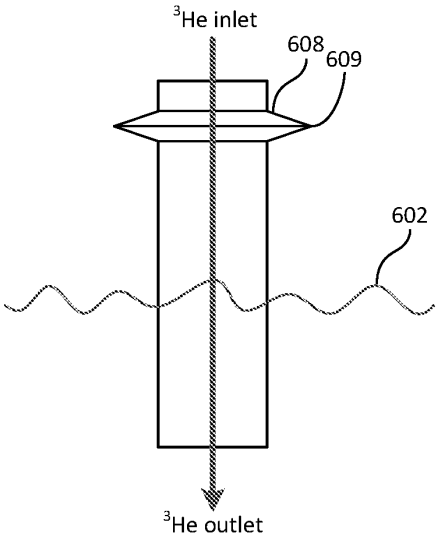


FIG. 6B

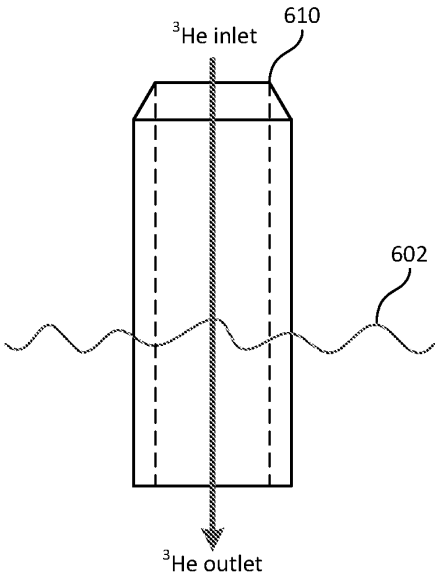


FIG. 6C

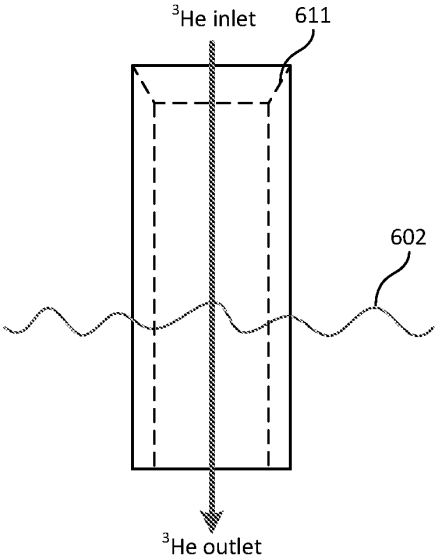


FIG. 6D

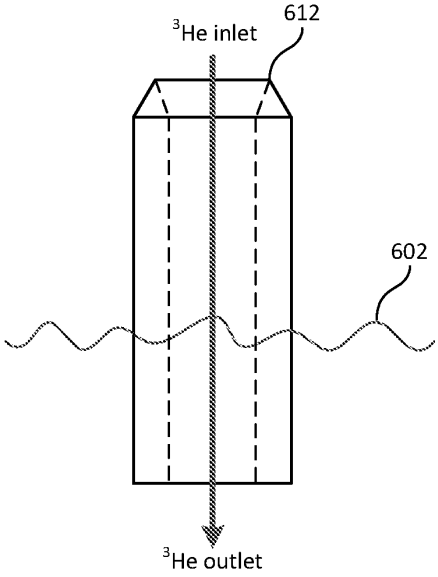


FIG. 6E

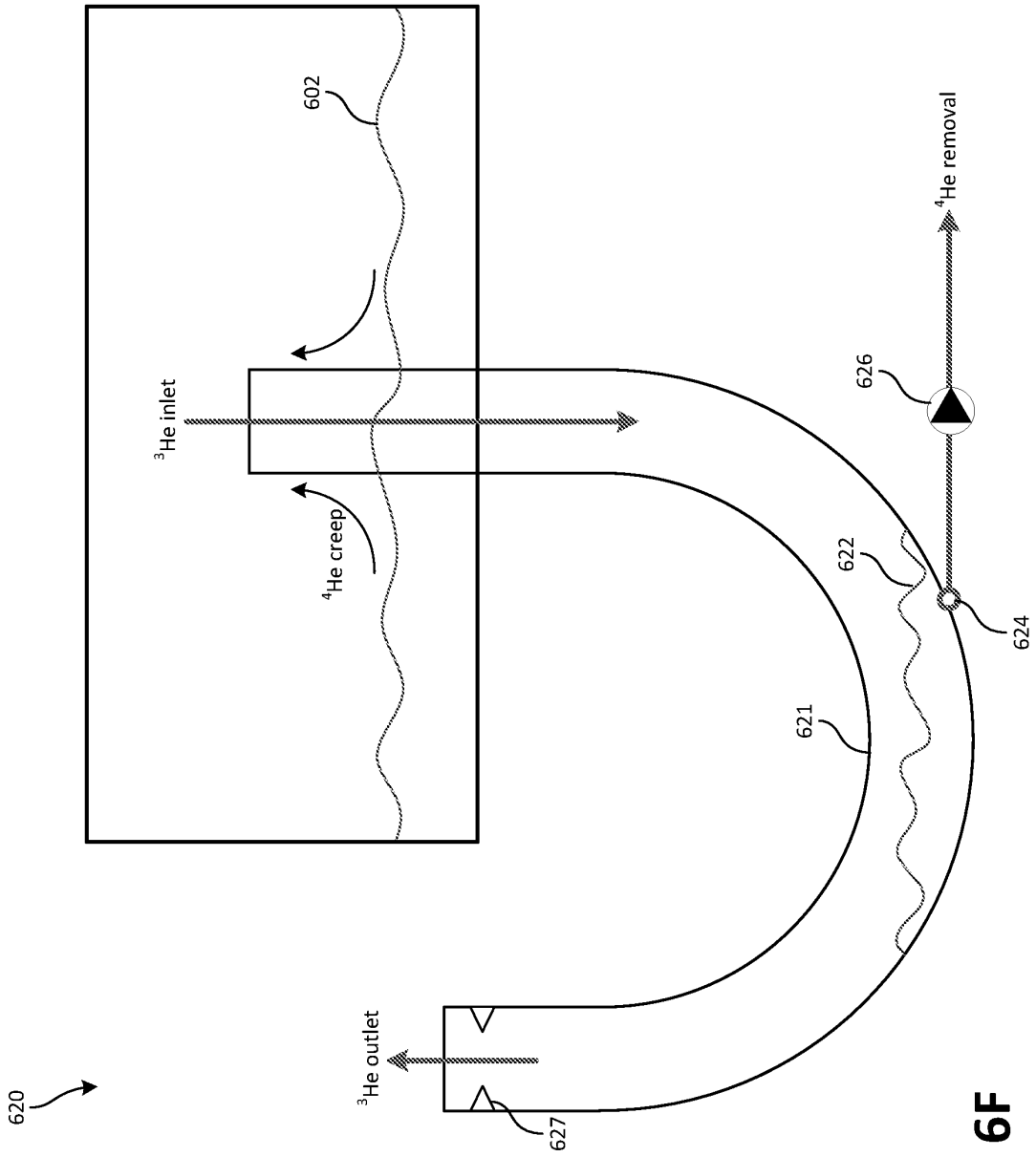

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FIG. 6F

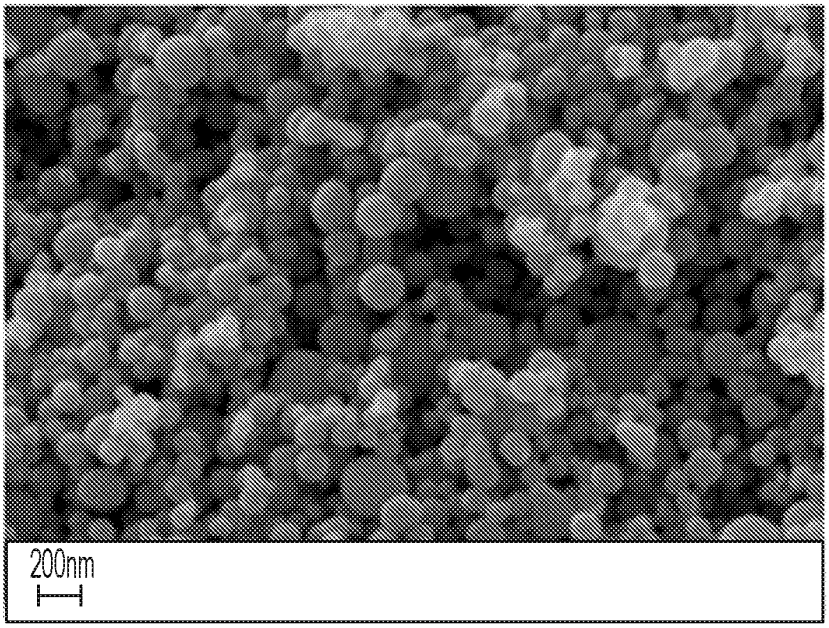


FIG. 7A

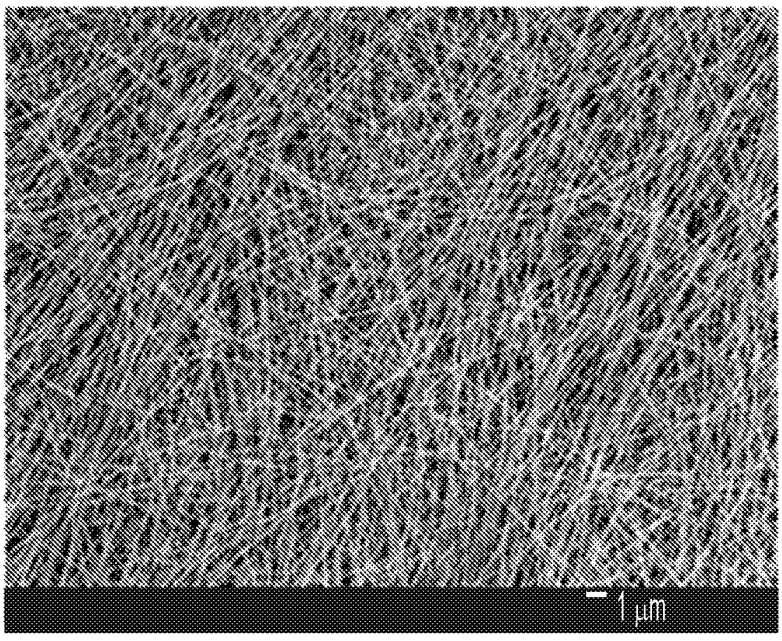


FIG. 7B

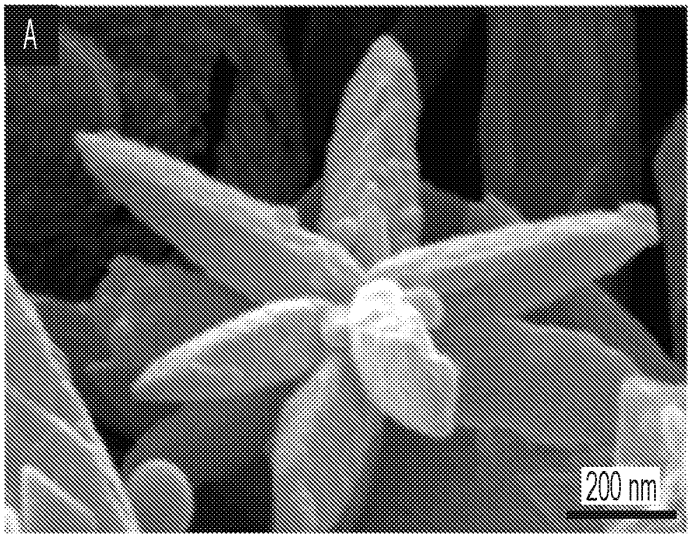


FIG. 7C

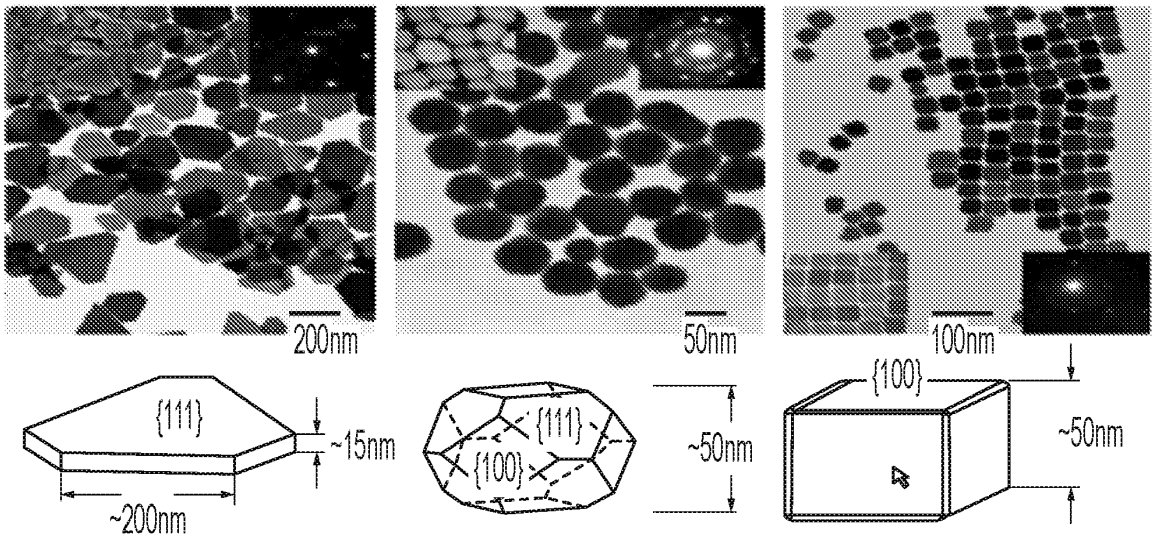


FIG. 7D

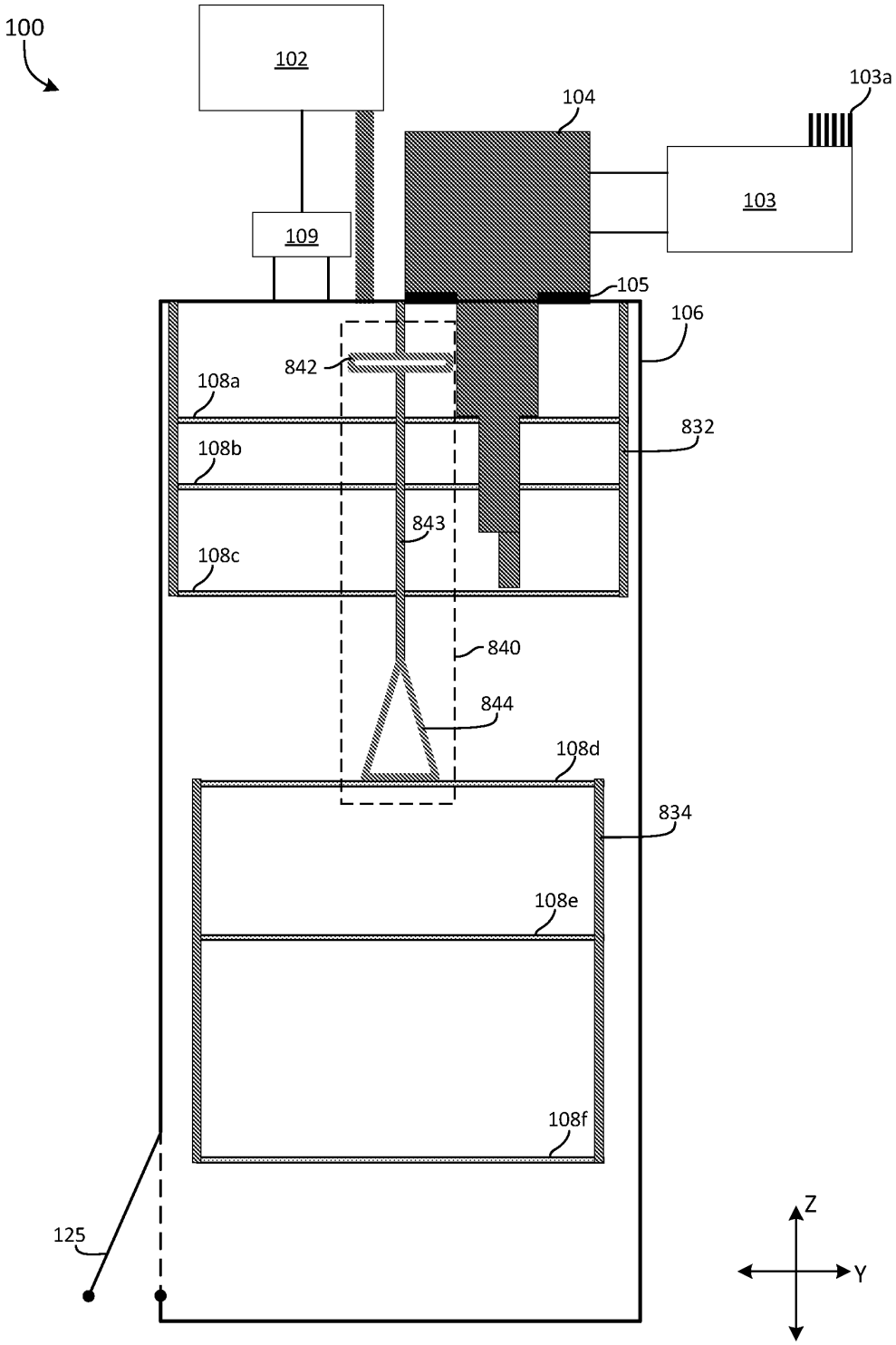

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FIG. 8A

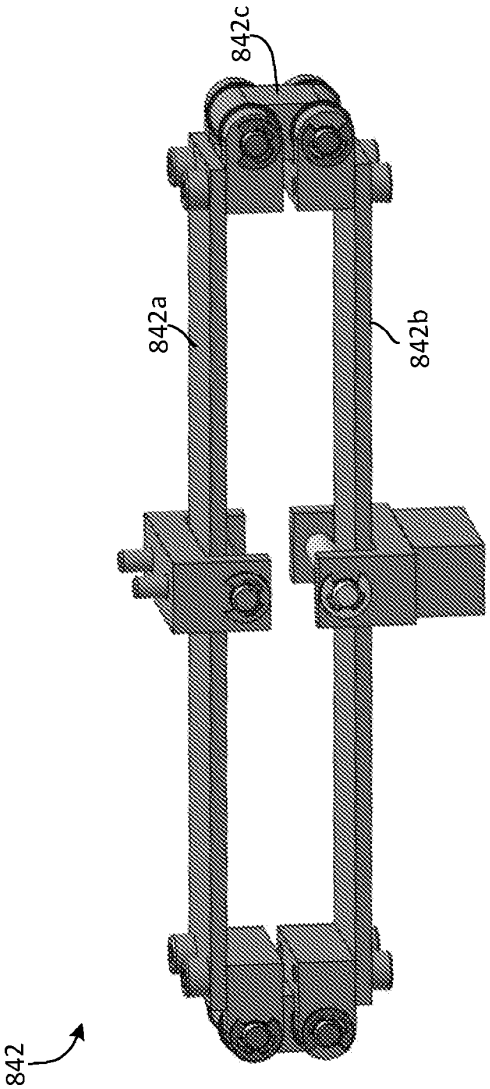


FIG. 8B

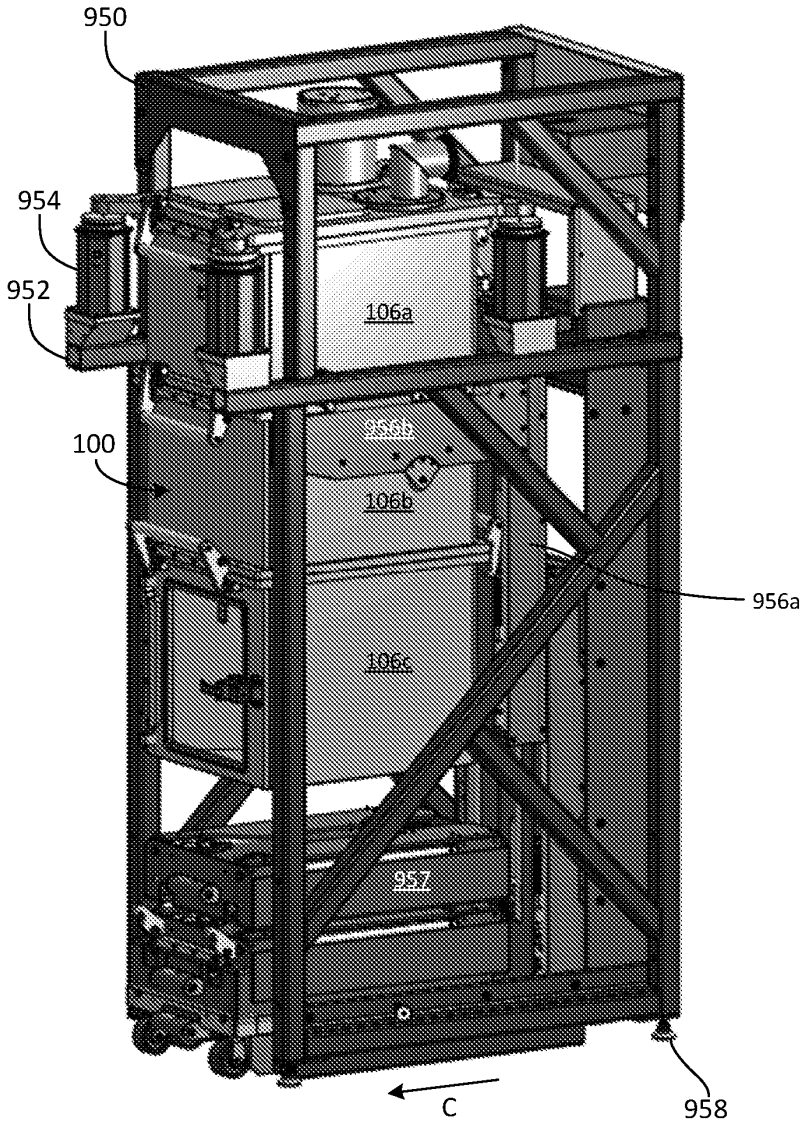


FIG. 9

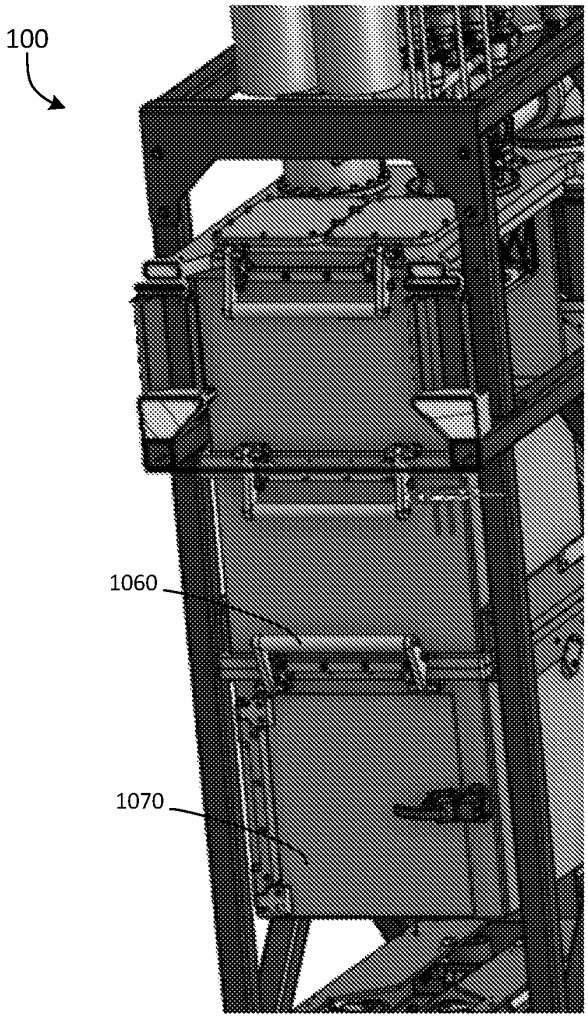


FIG. 10A

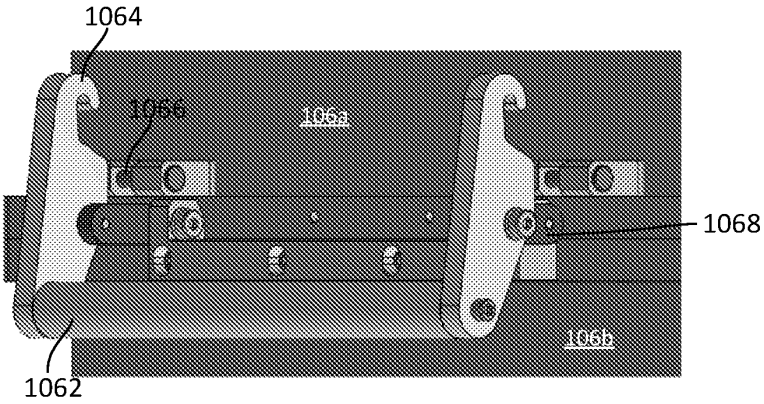


FIG. 10B

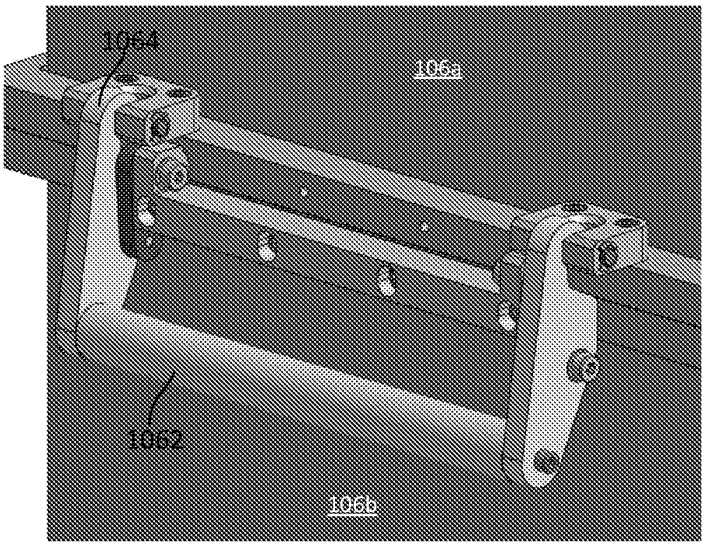


FIG. 10C

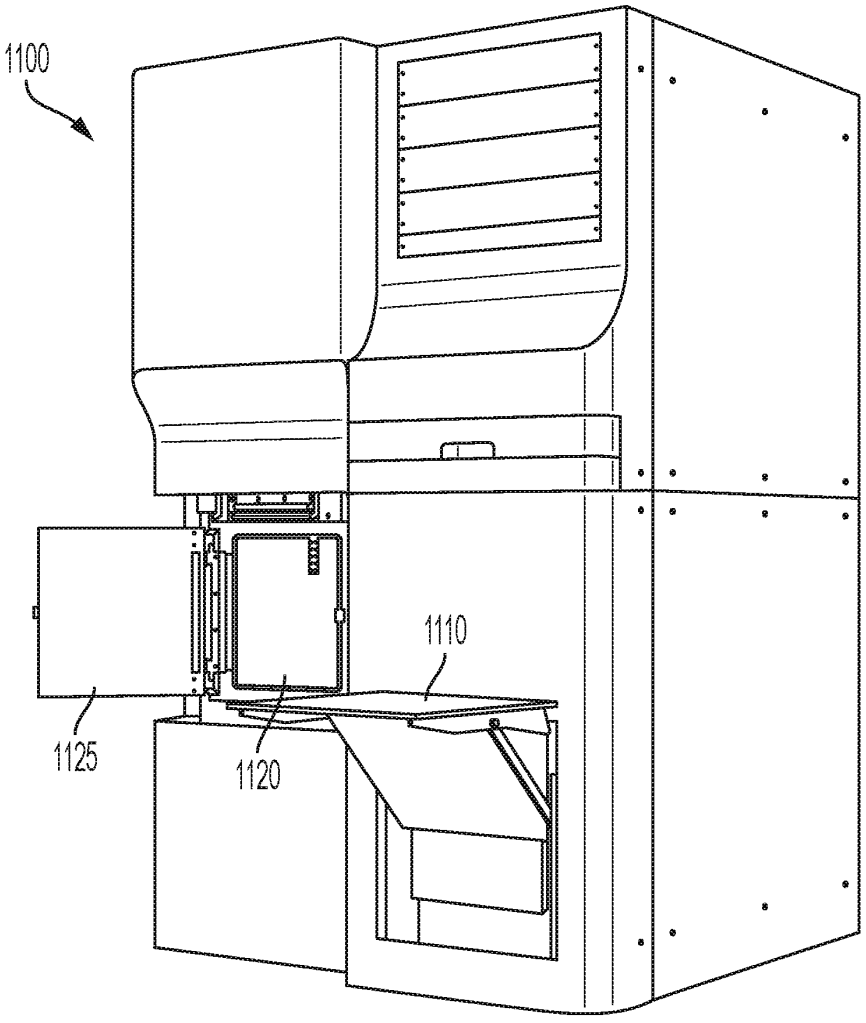


FIG. 11

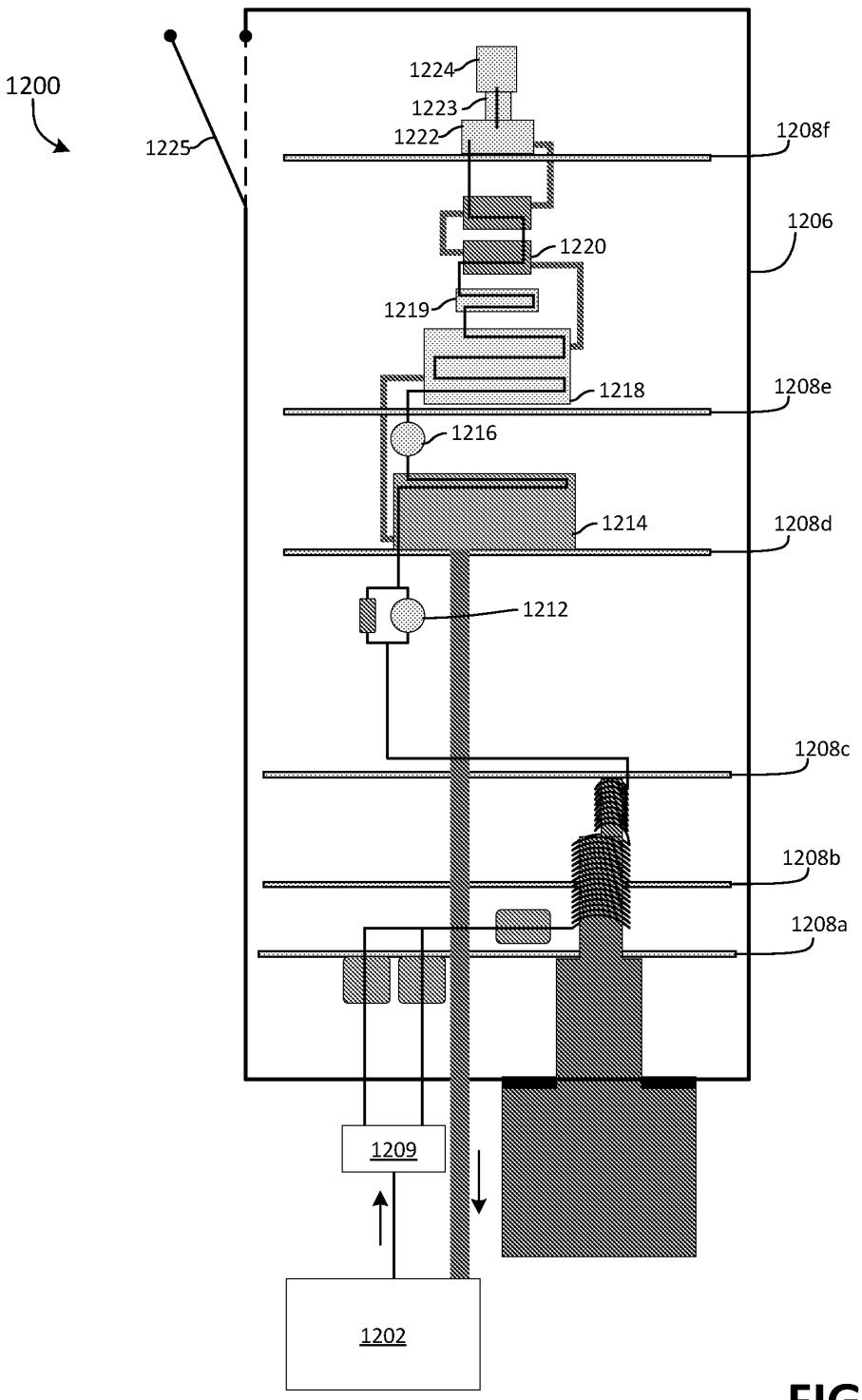

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FIG. 12A

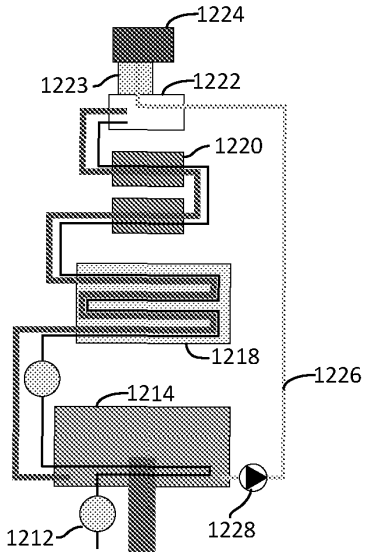


FIG. 12B

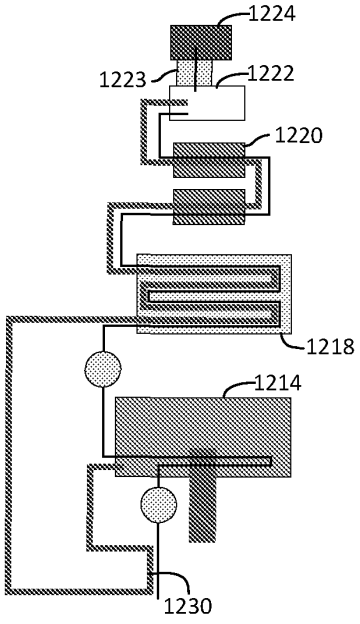


FIG. 12C

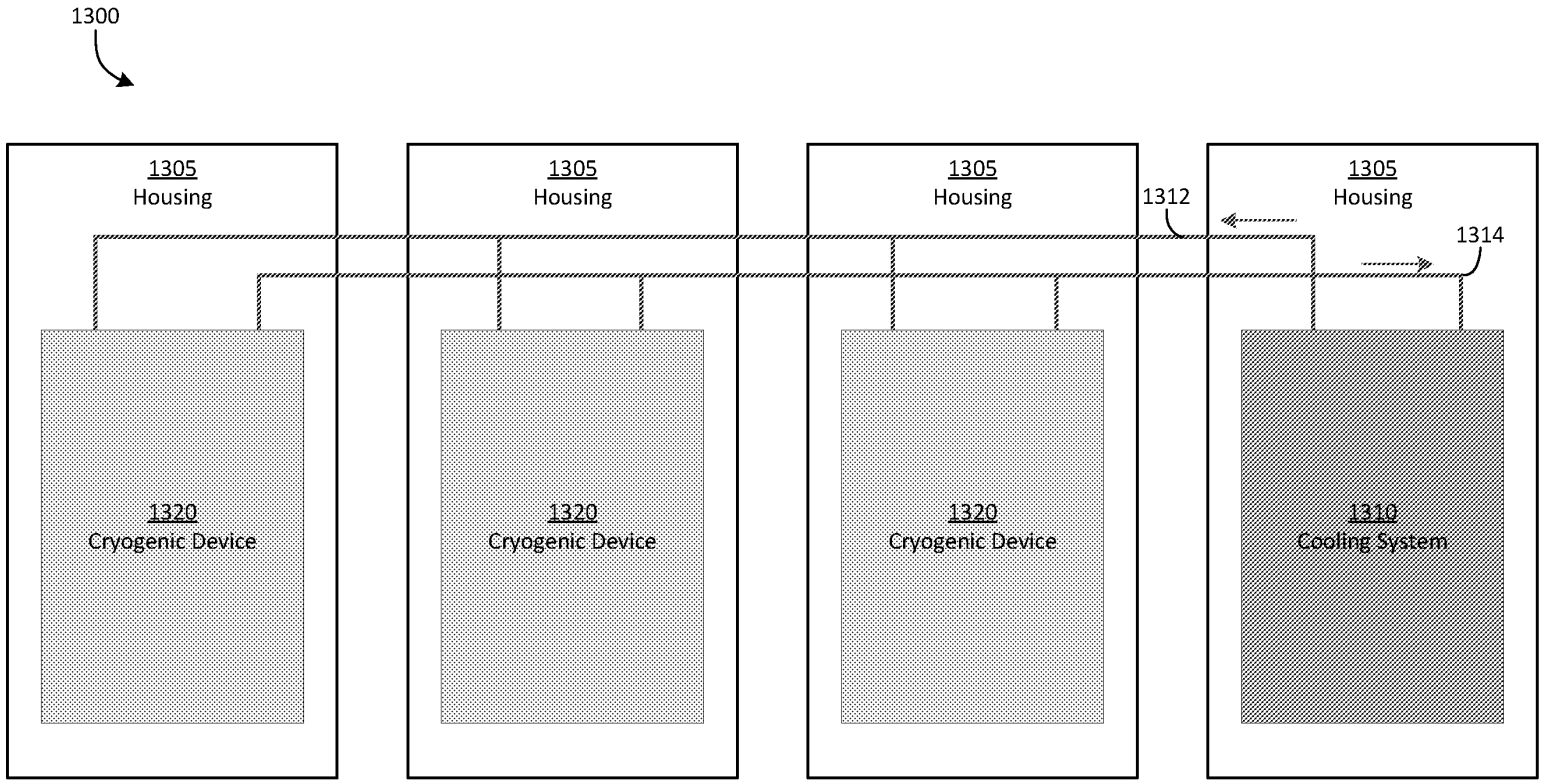


FIG. 13

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QD OXFORD UK LIMITED, et al. v. MAYBELL QUANTUM INDUSTRIES, INC.
IPR2026-00291 - U.S. Patent No. 12,313,320

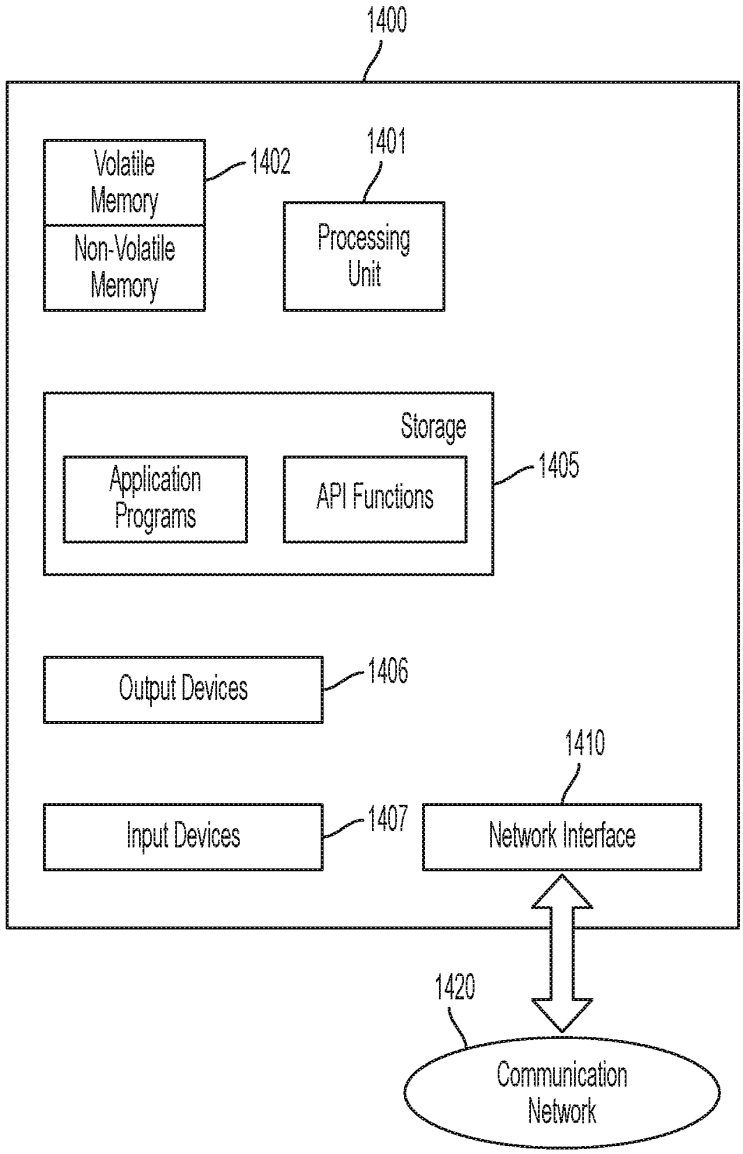

1400
Volatile Memory
1402
Non-Volatile Memory
1401
Processing Unit
Storage
Application Programs
API Functions
1405
Output Devices
1406
1410
Input Devices
1407
Network Interface
1420
Communication Network

FIG. 14

FEE TRANSMITTAL

Complete if known	
Application Number	Not Yet Assigned
Filing Date	
First Named Inventor	Corban Tillemann-Dick
Examiner Name	Not Yet Assigned
Art Unit	Not Yet Assigned
Practitioner Docket No.	M1567.70000US04

[X] Applicant asserts small entity status. See 37 CFR 1.27.

[ ] Applicant certifies micro entity status. See 37 CFR 1.29. Form PTO/SB/15A or B or equivalent must either be enclosed or have been submitted previously.

TOTAL AMOUNT OF PAYMENT ($)910.00

METHOD OF PAYMENT (check all that apply)

[ ] Check [X] Credit Card [ ] Money Order [ ] None [ ] Other (please identify): _____

[X] Deposit Account Deposit Account Number: 23/2825 Deposit Account Name: Wolf, Greenfield & Sacks, P.C.

For the above-identified deposit account, the Director is hereby authorized to (check all that apply):

[ ] Charge fee(s) indicated below

[ ] Charge fee(s) indicated below, **except for the filing fee**

[X] Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17, **except for any excess claims fees or multiple dependent claim fee**

[ ] Charge any additional fee(s) or underpayment of fee(s) under 37 CFR 1.16 and 1.17

[X] Credit any overpayment of fee(s)

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES (U = undiscounted fee; S = small entity fee; M = micro entity fee)

	FILING FEES			SEARCH FEES			EXAMINATION FEES			
Application Type	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**U ($)**	**S ($)**	**M ($)**	**Fees Paid ($)**
Utility	320	160*	80	700	350	175	800	400	200	830.00
Design	220	110	55	160	80	40	640	320	160	
Plant	220	110	55	440	220	110	660	330	165	
Reissue	320	160	80	700	350	175	2,320	1,160	580	
Provisional	300	150	75	0	0	0	0	0	0	

* The $160 small entity status filing fee for a utility application is further reduced to $80 for a small entity status applicant who files the application via EFS-Web.

2. EXCESS CLAIM FEES

Fee Description	**Undiscounted Fee ($)**	**Small Entity Fee ($)**	**Micro Entity Fee ($)**
Each claim over 20 (including Reissues)	100	50	25
Each independent claim over 3 (including Reissues)	480	240	120
Multiple dependent claims	860	430	215

Total Claims	**Extra Claims**	**Fee ($)**	**Fee Paid ($)**
20 - 20 or HP =		x	=

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims	**Extra Claims**	**Fee ($)**	**Fee Paid ($)**
1 - 3 or HP =		x	=

HP = highest number of independent claims paid for, if greater than 3.

Multiple Dependent Claims	
Fee ($)	**Fee Paid ($)**

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $420 ($210 for small entity) ($105 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets	**Extra Sheets**	**Number of each additional 50 or fraction thereof**	**Fee ($)**	**Fee Paid ($)**
45 - 100 =	/50 =	(round **up** to a whole number) x	=	

4. OTHER FEE(S)

	Fees Paid ($)
Non-English specification, $130 fee (no small or micro entity discount)	
Non-electronic filing fee under 37 CFR 1.16(t) for a utility application, $400 fee ($200 small or micro entity)	
Other (e.g., late filing surcharge): 2051 Surcharge - Late filing fee, search fee, ...	80.00

SUBMITTED BY

Signature	/Sarah C. C. Schlotter/	Registration No. (Attorney/Agent)	79,027	Telephone	617.646.8000
Name (Print/Type)	Sarah C.C. Schlotter, PhD			Date	July 8, 2022

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DocCode - SCORE

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Application Number: 17860950 Document Date: 07/08/2022

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Form Revision Date: March 1, 2019