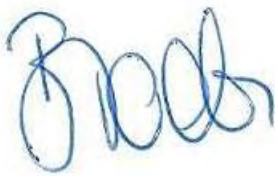
Certification of Translator

The undersigned declares the following:

That I am knowledgeable in both the German and English languages and verify that the English translation of WO2020182671 (published on October 15, 2020) is a true and accurate translation of the application.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. §1001.

Date: March 12, 2026



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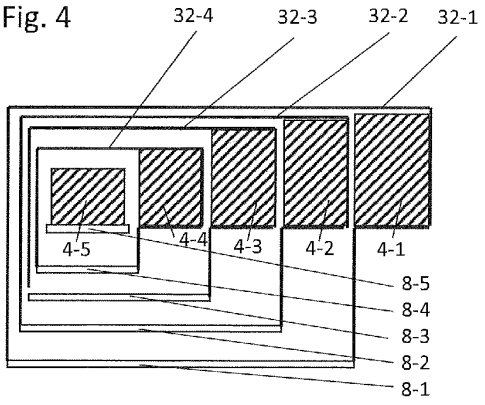
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(81) Bestimmungsstaaten *(soweit nicht anders angegeben, für jede verfügbare nationale Schutzrechtsart)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,

(54) **Title:** CRYOSTAT

(54) **Bezeichnung:** KRYOSTAT

Fig. 4



(57) Abstract: The present document specifies a cryostat for experiments in the region of below 2K, which permits improved accessibility for the experimentation places (4-i) and at the same time a smaller construction volume. By virtue of the fact that the experimentation places (4-i) are arranged next to one another instead of one below the other, after removal of the respective heat shields (32-i) these places are accessible from above and from the side, whereas in the prior art they are accessible only from the side. This simplifies various experiments and more generally the handling of the cryostat during use. The side-by-side arrangement of the experimentation places also substantially reduces the construction height of the cryostat, and it is possible to operate the cryostat in standard-height laboratory spaces, which is not possible with cryostats having a vertically suspended arrangement. Although the side-by-side arrangement of the experimentation places can lead to heat shields having a larger surface area, this drawback (increased cooling power from the various coolers being necessary for operation) can be compensated for by the possibility of use in standard-height laboratory spaces.

(57) Zusammenfassung: Es wird ein Kryostat für Experimente bei Temperaturen im Bereich von kleiner 2 K angegeben, der eine verbesserte Zugänglichkeit der Experimentierplätze (4-i) ermöglicht und gleichzeitig ein geringeres Bauvolumen aufweist. Dadurch, dass die Experimentierplätze (4-i) nicht untereinander, sondern nebeneinander angeordnet sind, sind diese nach Abnahme der jeweiligen Wärmeschilde (32-i) von oben und von der Seite zugänglich während sie beim Stand der Technik nur von der Seite zugänglich sind. Dies vereinfacht verschiedene Experimente und im Allgemeinen die Handhabung des Kryostaten im Einsatz. Durch die Nebeinanderanordnung der Experimentierplätze

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[Fortsetzung auf der nächsten Seite]

Cryostat

Description

Technical field

The present disclosure relates to a cryostat according to claim 1 for experiments at temperatures in the range of less than 2 K.

Cryostats, and in particular demixing cryostats for temperatures in the range of less than 2 K, are currently required and built primarily for the development of quantum computers and quantum communication devices. The arrangement of the individual temperature levels or cold plates, and thus also the arrangement of the experimental stations, is determined by the vertical arrangement of conventional cryostats.

Figs. 7a and 7b show a schematic diagram of a state-of-the-art demixing cryostat with a suspended, vertical design. The demixing cryostat according to Fig. 7 comprises six cooling stages 2-1 to 2-6 with four experimental stations 4-1 to 4-4. The room temperature area is not equipped as an experimental station. The temperature levels of the six cooling stages 2-i are provided by three unspecified cooling devices.

A first cooling device, not shown in detail, e.g., a first stage of a GM cooler, comprises a first cold plate 8-1 with the first experimental station 4-1 arranged below the first cold plate 8-1. The first cooling stage 2-1 provides a temperature level of approximately 50 K for the first experimental station 4-1.

A second cooling device, not shown in detail, e.g., a second stage of the GM cooler, comprises a second cold plate 8-2 arranged below the first experimental station 4-1.

The second cooling plate 8-2 or the second cooling stage 2-2 is at a temperature level of approx. 4 K. The second experimental station 4-2 is arranged below the second cooling plate 8-2 at the temperature level of the second cooling stage 2-2. Below the second experimental station 4-2 is a third cooling plate 8-3 of a third cooling stage 2-3 with a temperature level of approx. 1 K, which is cooled by a third cooling device, e.g. a Joule-Thomson stage, which is not shown in detail.

A fourth cooling device, not shown in detail, e.g., a ^{3}He/^{4}He demixing cooler, provides the temperature levels of the fourth, fifth, and sixth cooling stages 2-4, 2-5, and 2-6. Between the fourth cold plate 8-4 and the fifth cold plate 8-5, the third experimental station 4-3 is provided on the fourth cooling stage 2-4. Below the third experimental station 4-3 and below the fifth cold plate 8-5, a sixth cold plate 8-6 is provided for the lowest cooling stage 2-6. The temperature level of the fourth cold plate 8-4 is in the range between 500 and 700 mK, the temperature level of the fifth cold plate 8-5 is between 100 and 200 mK, and the lowest temperature level of the sixth cold plate 8-6 and the fourth experimental station 4-4 located below it is in the range <100 mK.

The entire arrangement is housed in a vacuum container 10. In the vacuum container 10, all six cooling stages 2-1 to 2-6 are enclosed by a first heat shield 12-1. Inside the first heat shield 12-1, the second to sixth cooling stages 2-2 to 2-6 are enclosed by a second heat shield 12-2. Within the second heat shield 12-2, the fourth to sixth cooling stages 2-4 to 2-6 are enclosed by a third heat shield 12-3. The lowest sixth cooling stage 2-6 is shielded by a fourth heat shield 12-4.

This conventional arrangement has the advantage that the individual temperature levels are nested like onion skins and are easy to manufacture – see Fig. 7b. However, due to the increasing requirements in terms of experimental space at the individual levels, these known cryostats become relatively large and, above all, tall or long. As a result, the heat shields are becoming longer and longer, and they either have to be divided or a lot of space has to be provided underneath the apparatus so that these heat shields can be removed in order to access the experimental stations.

Furthermore, all structures on the individual stages must be suspended, as experimental areas are provided within the heat shields below the cold plate of the corresponding temperature level.

The article by Kurt Uhlig, "Concepts for a low-vibration and cryogen-free tabletop dilution refrigerator" in Cryogenics 87 (2017) 29-34 describes a so-called tabletop demixing cryostat, which enables a smaller construction volume due to the arrangement of the Still and mixing chamber, but has the same disadvantage as the state of the art according to Fig. 7, namely that the individual cold plates or experimental stations are only accessible from the side.

DE 102014015665B4 discloses an optical table that has a single cooling plate integrated into the tabletop.

DE 102016214731 B3, DE 102005041383A1, and DE102011115303A1, NMR apparatus or low-temperature devices are known in which sample head components at different temperature levels are arranged below or above each other when viewed from above. From DE102011115303A1, it can be seen from the drawing that two sample heads are arranged horizontally and vertically offset from each other. No written explanations on this can be found in DE102011115303A1.

It is therefore the task of the present invention to specify a cryostat that allows improved accessibility to the experimental stations and at the same time requires a smaller construction volume.

This task is solved by the features of claim 1.

Because the experimental stations are arranged next to each other rather than below each other, they are accessible from above and from the side after removing the respective heat shields, whereas in the prior art they are only accessible from the side. This simplifies various experiments and, in general, the handling of the cryostat in use.

The side-by-side arrangement of the experimental stations also significantly reduces the overall height of the cryostat, making it possible to operate the cryostat in laboratories with standard ceiling heights, which is not possible with cryostats with a vertical hanging arrangement. Although the side-by-side arrangement of the experimental stations can lead to larger heat shields, this disadvantage (increased cooling capacity of the various coolers required for operation) is accepted in view of the possibility of use in laboratories with standard height.

According to the preferred embodiment of claim 2, when the experimental stations are arranged side by side, care is taken to ensure that they are accessible from above and from one side.

According to the advantageous design of the invention according to claim 3 or 4, several cooling stages are served by a mixture cooler.

The advantageous embodiments of the invention according to claims 5 to 7 relate to suitable cooling devices for the cryostat.

The advantageous embodiment of the invention according to claim 8 represents a simple side-by-side arrangement of the experimental stations, which are still at different temperature levels.

The advantageous embodiment of the invention according to claim 9 provides side-by-side experimental stations that are located at approximately the same height level.

Further details, features, and advantages of the invention are apparent from the following description of preferred embodiments of the invention.

Brief description of the figures

Fig. 1a and 1b schematically show the basic idea of the present invention;

Figs. 2a and 2b show the geometric structure of a first embodiment of the invention;

Fig. 3 shows the geometric structure of a second embodiment of the invention;

Fig. 4 shows the arrangement of the heat shields in the embodiments according to Figs. 2 and 3;

Fig. 5 shows a third embodiment of the invention with the experimental stations arranged side by side in one plane;

Fig. 6 shows a fourth embodiment of the invention in which a GM cooler penetrates the vacuum container from below, and

Figs. 7a and 7b show a cryostat according to the prior art.

Figs. 1a and 1b schematically show the basic principle of the present invention, the side-by-side arrangement of five experimental stations 4-1 to 4-5 on the cold plates 8-1 to 8-5 in one plane. The five experimental stations 4-1 to 4-5 are located on the cooling stages 2-1 to 2-5 with the corresponding temperatures, room temperature 50 K, 4 K, 700 mK, and 100 mK.

Fig. 1a shows the side view of the experimental stations arranged next to each other and thus, in effect, the volume of the experimental stations 4-1 to 4-5 above the respective cold plate 8-1 to 8-5, and Fig. 1b shows a top view of the representation according to Fig. 1.

Fig. 2a and 2b show a first embodiment of the invention, in which the cryostat according to the invention has a rectangular cross-sectional shape and the individual experimental stations 4-1 to 4-5 arranged next to each other in a plane are nested in an L-shape; with the fifth experimental station 4-5 as a cube.

Fig. 3 shows a second embodiment of the invention, in which the basic structure is circular or cylindrical and the individual experimental stations 4-1 to 4-5 surround each other.

Fig. 4 shows a possible arrangement of four heat shields 32-1 to 32-4 for the individual embodiments according to Figs. 2 and 3.

Fig. 5 shows a third embodiment of the invention. The individual components of the cryostat are arranged in a vacuum container 10. The vacuum container 10 comprises a base plate 20 on which a side rim 22 is arranged, resulting in a trough 24. On the left side of the trough 24, a pulse tube cooler 26 extends into the trough 24. The right side of the side rim 22 supports a first partial cooling plate 30-1 at room temperature. A first experimental station 4-1 is arranged on the first partial cooling plate 30-1. The first experimental station 4-1 is enclosed by a first heat shield 32-1 and is at room temperature. The entire vacuum container 10 constitutes the first heat shield 32-1.

A second cooling plate 8-2 is provided, spaced from the base plate 20 by support elements 28, which is in thermal contact with the pulse tube cooler 26 and also has a lateral border 22. In the right-hand edge area of the second cooling plate 8-2, a support element 28 supports a second partial cooling plate 30-2, which is offset upwards and is located in the plane of the first partial cooling plate 30-1. The second cooling plate 8-2 and the second partial cooling plate 30-2 are at a second temperature level of approx. 50 K. A second experimental station 4-2 is located on or above the second partial cooling plate 30-2. Starting from the second cold plate 8-2, a second heat shield 32-2 surrounds the second experimental station 4-2.

Again spaced by support elements 28, a third cold plate 8-3 is arranged on the second cold plate 8-2, which in turn is thermally coupled to the pulse tube cooler 26 and provides a temperature level of approx. 4 K.

A support element 28 on the right side of the third cold plate 8-3 carries a third partial cold plate 30-3, which is offset upwards. The third partial cold plate 30-3 is located in the plane of the second and first partial cold plates 30-1 and 30-2. A third experimental station 4-3 with a temperature level of approx. 4 K is arranged on or above the third partial cooling plate 30-3. Starting from the third cooling plate 8-3, a third heat shield 32-3 encloses the third experimental station 4-3.

Again spaced apart by support elements 28, a fourth cold plate 8-4 is arranged above the third cold plate 8-3, on which the components of a $^3He/^4He$ demixing cooler 34 are arranged. On the right side of the fourth cooling plate 8-4, a support element 28 supports a fourth partial cooling plate 30-4, which is offset upwards, at the same height as the other partial cooling plates 30-1 to 30-3.

Further support elements or support walls 28 are used to arrange a fifth cooling plate 8-5 above the fourth cooling plate 8-4 at the same height as the partial cooling plates 30-i at the lowest temperature level of approx. 30 mK. A fifth experimental station 4-5 is arranged above or on the fifth cooling plate 8-5. Starting from the fifth cooling plate 8-5, a fifth heat shield 32-5 encloses the fifth experimental station 8-5.

The $^3He/^4He$ demixing cooler 34 between the fourth and fifth cold plates 8-4, 8-5 comprises a Still 36 with a concentric heat exchanger 38, a mixing chamber 40, and connections 42. The Still is thermally coupled to the fourth cold plate 8-4 and the fourth partial cold plate 30-4. The mixing chamber 40 is thermally coupled to the fifth cold plate 8-5.

The thermal coupling of the individual cold plates 8-i with the partial cold plates 30-i and the pulse tube cooler 26 or the $^3He/^4He$ demixing cooler 34 is achieved via heat conductors 44. The pulse tube cooler 26 is mounted in the vacuum container 10 via a vibration decoupling 46.

Fig. 6 shows a fourth embodiment of the invention, which differs from the third embodiment according to Fig. 5 in that, instead of a pulse tube cooler penetrating the vacuum container 10 laterally, a GM cooler 48 penetrates the vacuum container 10 from below, approximately in the center of the fifth cooling plate 8-5. The GM cooler 48 also penetrates an opening in the second cold plate 8-2 so that thermal coupling with the third cold plate can take place. The installation of the GM cooler 48 from below results in a slightly narrower but slightly taller design.

As can be seen from the sectional views in Figs. 5 and 6, the side-by-side arrangement of the experimental stations 4-i allows for a significantly lower design. The low height of the cryostat makes it possible to operate the cryostat in laboratories with standard ceiling heights, which is not possible with cryostats with a vertical hanging arrangement. Although the side-by-side arrangement of the experimental stations can lead to larger heat shields, this disadvantage (increased cooling capacity of the various coolers required for operation) is accepted in view of the possibility of use in laboratories with standard height.

Reference list:

2-i	Cooling stages
4-i	Experiment stations
8-i	Cold plates
10	Vacuum containers
12-i	Heat shields
20	Base plate
22	Side borders of 20, 8-2
24	Tub
26	Pulse tube coolers
28	Support elements
30-i	Partial cooling plate
32-i	Heat shield
34	^{3}He/^{4}He demixing cooler
36	Still
38	Concentric heat exchanger
40	Mixing chamber
42	Connections of 34
44	Heat conductors
46	Vibration decoupling
48	GM cooler

Claim 1

1. Cryostat, with
a plurality of cooling stages (2-i) with different temperature levels, which are assigned to cooling devices (26, 34),
a plurality of experimental stations (4-i) at the temperature levels of the cooling stages (2-i),
a plurality of heat shields (32-i) for the cooling stages (2-i) which enclose the experimental stations (4-i), and
a vacuum container (10) in which the plurality of cooling stages (2-i) are arranged,
characterized in that the experimental stations (4-i) are arranged side by side when viewed from above.

2. Cryostat according to claim 1, characterized in that the experimental stations (4-i) are arranged next to each other in such a way that they are accessible from above and from the side.

3. Cryostat according to claim 1 or 2, characterized in that a cooling device (26, 34) is assigned to several cooling stages (2-i).

4. Cryostat according to claim 3, characterized in that the cooling device for the cooling stages (2-4, 2-5) with the two lowest temperature levels is a $^3He/^4He$ demixing cooler (34) comprising a still (36) and a mixing chamber (40).

5. Cryostat according to one of claims 1 to 3, characterized in that the cooling device for the cooling stage (2-4, 2-5) with the lowest temperature level is a Joule-Thomson cooler, a 1-K pot and/or a ^3He stage.

6. Cryostat according to one of claims 1 to 3, characterized in that the cooling device for the cooling stage (2-4, 2-5) with the lowest temperature level is an ADR cooler.

7. Cryostat according to one of the preceding claims, characterized in that the cooling devices for the cooling stages (2-1, 2-2, 2-3) with higher temperature levels are pulse tube coolers, GM coolers, Stirling coolers, and/or Joule-Thomson coolers.

8. Cryostat according to one of the preceding claims, characterized in that at least two of the cooling stages (2-i) comprise a cold plate (8-i) at the temperature level of the respective cooling stage (2-i),
that the individual cold plates (8-i) are formed below each other and protrude laterally, so that the laterally protruding part of the cold plates (8-i) is accessible from above, and
that experimental stations (4-i) are formed above the laterally protruding parts of the cooling plates (8-i).

9. Cryostat according to claim 8, characterized in that

that partially cold plates (30-i) offset upwards are provided on the laterally protruding parts of the cold plates, which are mechanically supported on the protruding parts of the cold plates, that the horizontally offset partial cold plates (30-i) are connected to the protruding parts of the cold plates at the respective temperature level by thermal couplings (44), and
that the experimental stations (4-i) are formed above the cooling plate (8-5) at the lowest temperature level and the partial cooling plates (30-i).

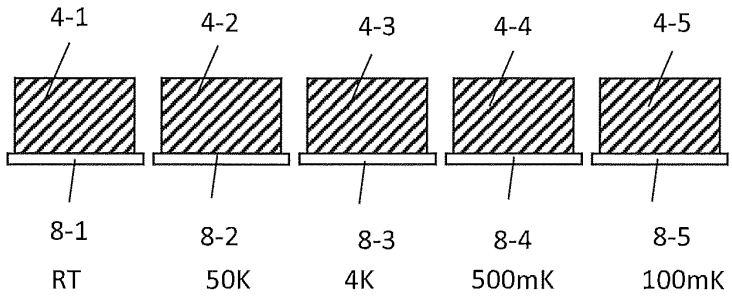

4-1
4-2
4-3
4-4
4-5
8-1
8-2
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8-4
8-5
RT
50K
4K
500mK
100mK

Fig. 1a

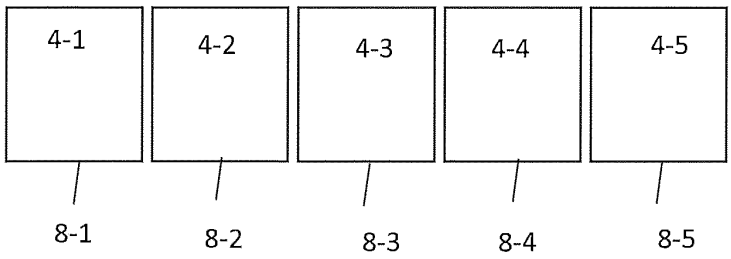

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8-5

Fig. 1b

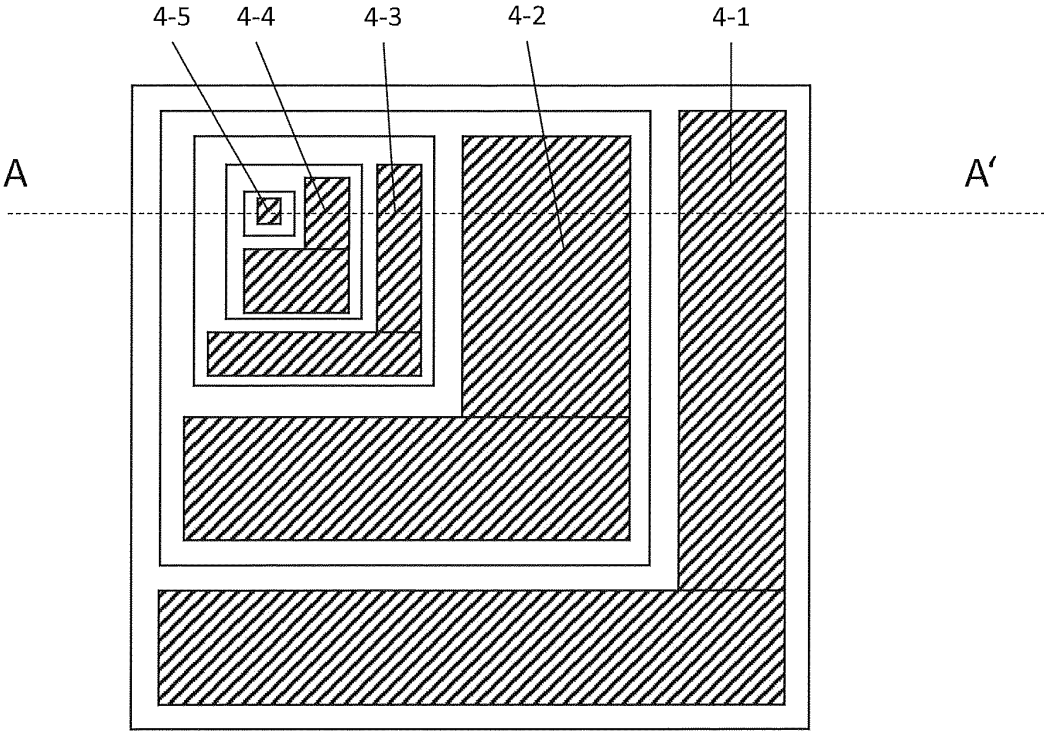


Fig. 2a

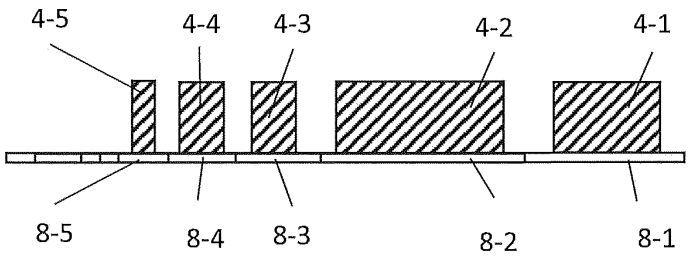


Fig. 2b

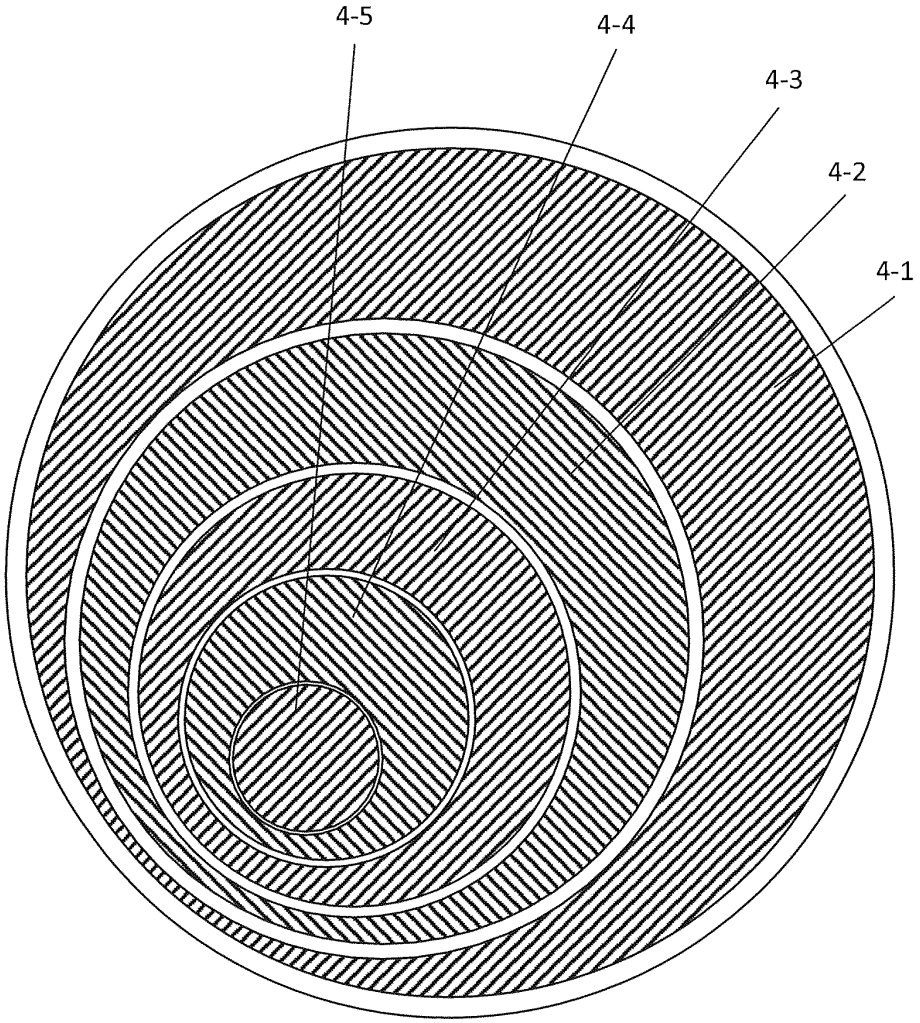


Fig. 3

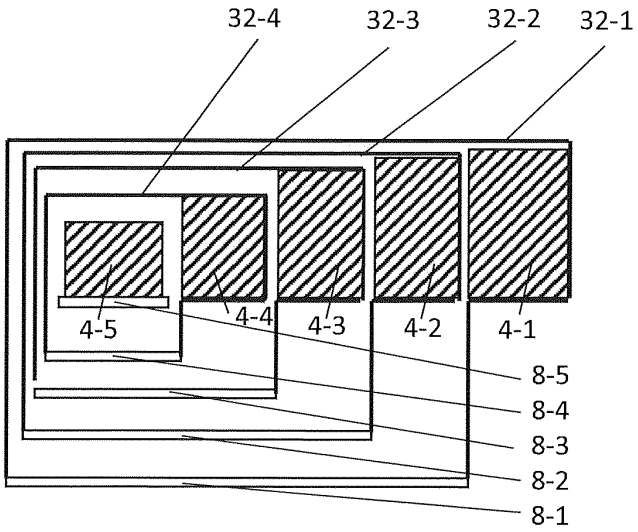


Fig. 4

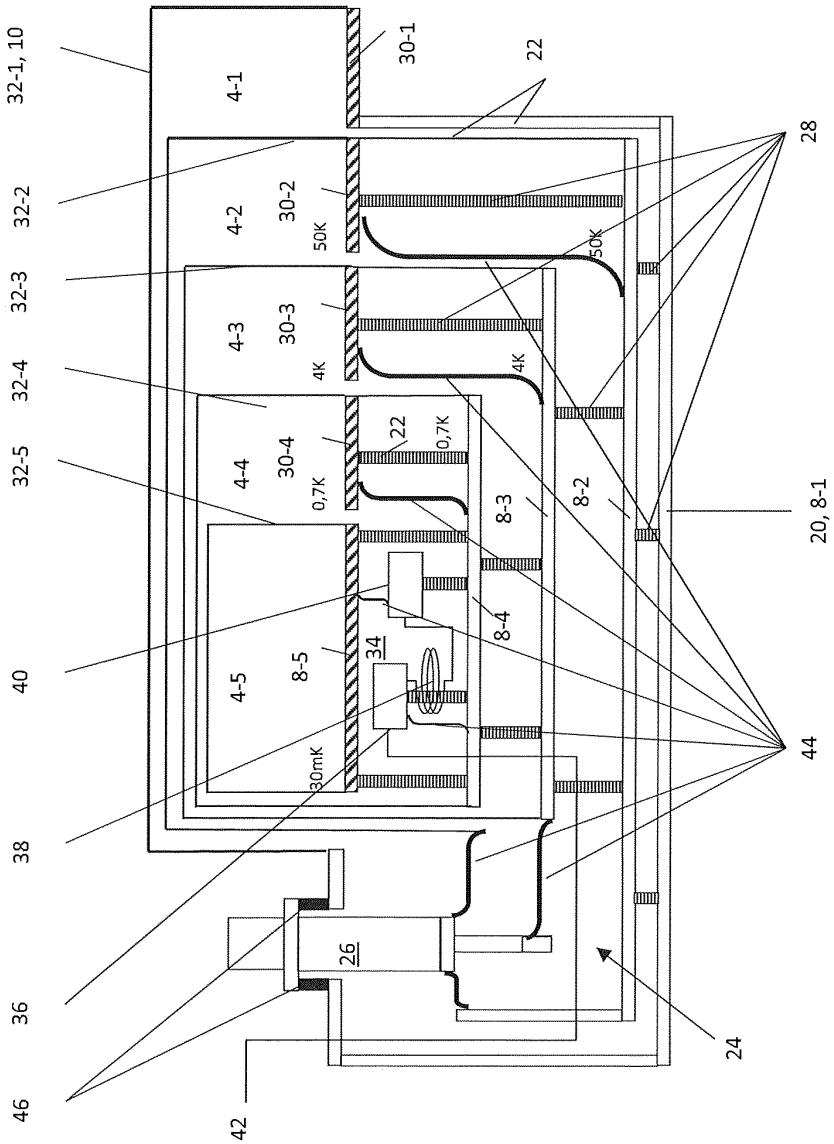

32-1, 10
32-2
32-3
32-4
32-5
40
38
36
46
42
4-1
30-1
22
28
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30-2
50K
50K
4-3
30-3
4K
4K
4-4
30-4
22
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4-5
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8-4
30mK
44
26
24

Fig. 5

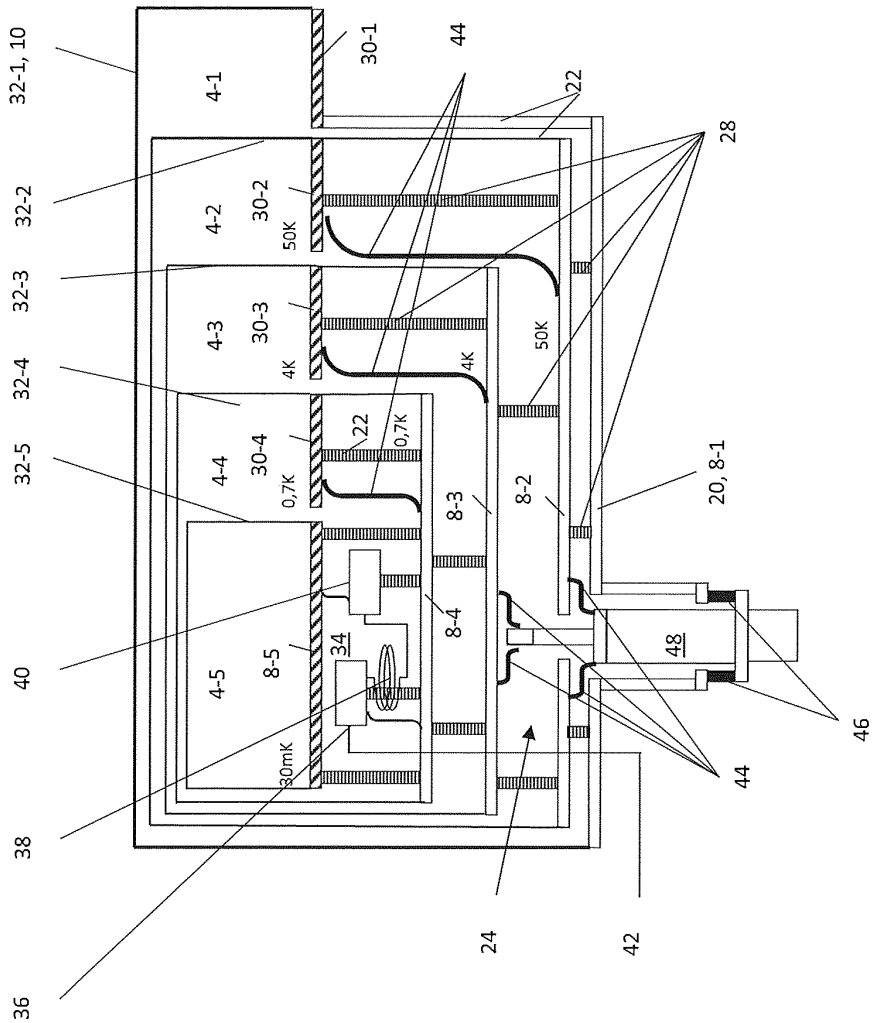

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8-3
8-2
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50K
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48
46
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42

Fig. 6

State of the Art

Stand der Technik

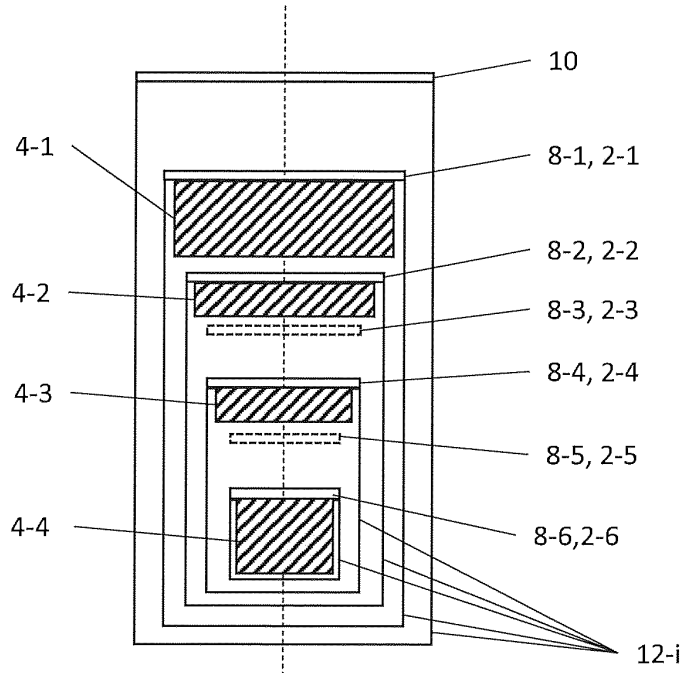


Fig. 7a

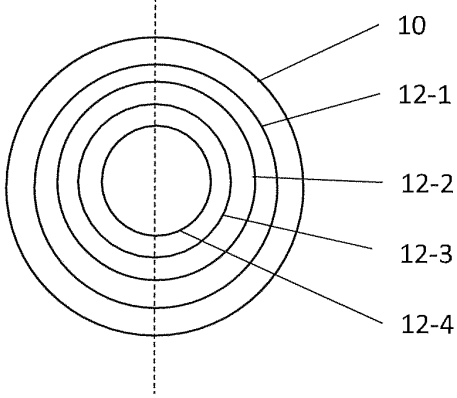


Fig. 7b