CUSTOMER NO.	38327

CONTINUATION/DIVISIONAL APPLICATION TRANSMITTAL

(Rule 53(b) Continuation or Divisional) ☐ DUPLICATE

Address to: **Assistant Commissioner of Patents**
Box Patent Application
Alexandria, VA 22313-1450

Attorney Docket No.:	NAGI-0005
First Named Inventor:	YUASA
Total Pages:	35

This requests a ☒ Continuation or ☐ Divisional application under 37 CFR §1.53(b) of prior application:

Appln. No.:	13/400,340	Group Art Unit:	2897
Filed on:	February 20, 2012	Examiner:	Alonzo Chambliss
Inventors	SHINJI YUASA		
Entitled:	MAGNETIC TUNNEL JUNCTION DEVICE		

☒ 1. The entire disclosure of the pending, prior application is hereby incorporated by reference.

☐ 2. Submitted herewith is a copy of the complete prior application as filed.

☐ 3. This application is filed by fewer then all the inventors named in the prior nonprovisional application, 37 CFR 1.53(b)(1). DELETE the following inventor(s):

☐ 4. Submitted herewith is a copy of the signed Oath/Declaration from the prior application.

☐ 5. Small entity status was established in the prior application, and is still proper and desired.

☐ 6. A _____ month Petition for Extension of Time is filed concurrently in the prior application.

☒ 7. The Commissioner is authorized to credit any overpayment and charge any deficiency in any fees required under 37 CFR § 1.16 and/or 1.17 to Deposit Account No. 12-0555.

☒ 8. Credit Card Form 2038 in the amount of $ 1,550.00 for filing fee and Assignment Recordation fee is submitted herewith.

☐ 9. Insert before the first sentence of the specification:

☐ 10. Cancel in this application original claims _____ of the prior application before calculating filing fee.

☒ 11. The prior application is assigned of record to: Japan Science and Technology Agency and National Institute of Advanced Industrial Science and Technology.

☒ 12. Priority is claimed from U.S. Application 13/400,340 filed on February 20, 2012, which claims priority from U.S. 12/923,643 filed on September 30, 2010, which claims priority from U.S. Application 10/591,947 filed on September 8, 2006, which claims priority from PCT/JP2005/004720 filed on March 10, 2005, which claims priority from Japanese Application Nos. 2004-313350 and 2004-071186 filed October 28, 2004 and March 12, 2004, respectively, the content of which is hereby incorporated by reference into this application.

☐ 13. A Preliminary Amendment is enclosed.

☒ 14. Other: Information Disclosure Statement with Form PTO-1449

THE FILING FEE IS CALCULATED AS FOLLOWS:				BASIC FEE (FILING, EXAMINATION AND SEARCH FEES):	$1,260.00
Total Claims:	11	-20 =	0	× $62 =	0
Independent claims:	4	-3 =	1	× $250 =	250.00
				Multiple Dependent Claim (Add $360.00):	0
			Total Pages	35 -100	0
				Subtotal:	1,510.00
				50% Reduction if Small Entity Status:	0
				Total:	1,510.00

STITES & HARBISON PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314
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Please use Customer No. 38327

Date:	Name:	Signature:	Reg. No.
February 14, 2013	Juan Carlos A. Marquez		34,072

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	NAGI-0005
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Shinji		YUASA	

Residence Information (Select One) ○ US Residency ◉ Non US Residency ○ Active US Military Service

City	Ibaraki	Country of Residence i	JP

Mailing Address of Inventor:

Address 1	c/o Nat. Inst. of Adv. Industrial Sci. & Tech.		
Address 2	Tsukuba Central 2, 1-1, Umezono 1-chome		
City	Tsukuba-shi, Ibaraki	**State/Province**	
Postal Code	305-8568	**Country** i	JP

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	38327		
Email Address	iplaw@stites.com	Add Email	Remove Email

PTO/AIA/14 (08-12)
Approved for use through 01/31/2014. 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 contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	NAGI-0005
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

Application Information:

Title of the Invention	Magnetic Tunnel Junction Device		
Attorney Docket Number	NAGI-0005	**Small Entity Status Claimed** ☐	
Application Type	Nonprovisional		
Subject Matter	Utility		
Suggested Class (if any)		**Sub Class (if any)**	
Suggested Technology Center (if any)			
Total Number of Drawing Sheets (if any)	10	**Suggested Figure for Publication (if any)**	

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	38327		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	Continuation of	US13400340	2012-02-20
Prior Application Status	Patented		Remove

Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)	Patent Number	Issue Date (YYYY-MM-DD)
US13400340	Continuation of	US12923643	2010-09-30	8319263	2012-11-27

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	NAGI-0005
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

Prior Application Status	Patented				Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)	Patent Number	Issue Date (YYYY-MM-DD)
US12923643	Continuation of	US10591947	2006-09-08	7884403	2011-02-08

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
US10591947	a 371 of international	PCT/JP2005/04720	2005-03-10

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.

Foreign Priority Information:

This section allows for the applicant to claim benefit of foreign priority and to identify any prior foreign application for which priority is not claimed. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(a).

Remove

Application Number	Country[1]	Filing Date (YYYY-MM-DD)	Priority Claimed
2004-313350	JP	2004-10-28	(•) Yes ( ) No

Remove

Application Number	Country[1]	Filing Date (YYYY-MM-DD)	Priority Claimed
2004-071186	JP	2004-03-12	(•) Yes ( ) No

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Authorization to Permit Access:

☐ Authorization to Permit Access to the Instant Application by the Participating Offices

If 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 World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the instant patent application is filed access to the instant patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the instant patent application is filed to have access to the instant patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the instant patent application with respect to: 1) the instant patent application-as-filed; 2) any foreign application to which the instant patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the instant patent application; and 3) any U.S. application-as-filed from which benefit is sought in the instant patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date of filing this Authorization.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	NAGI-0005
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

◉ Assignee	○ Legal Representative under 35 U.S.C. 117	○ Joint Inventor
○ Person to whom the inventor is obligated to assign.	○ Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor :

If the Applicant is an Organization check here. ☒

Organization Name	Japan Science and Technology Agency		
Mailing Address Information:			
Address 1	1-8, Hon-cho 4-chome		
Address 2			
City	Kawaguchi-shi, Saitama	**State/Province**	
Country	JP	Postal Code	332-0012
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	NAGI-0005
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

Applicant 2

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

◉ Assignee	○ Legal Representative under 35 U.S.C. 117	○ Joint Inventor
○ Person to whom the inventor is obligated to assign.	○ Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor :

If the Applicant is an Organization check here. ☒

Organization Name	National Institute of Advanced Industrial Science and Technology		
Mailing Address Information:			
Address 1	3-1, Kasumigaseki 1-chome, Chiyoda-ku		
Address 2			
City	Tokyo	**State/Province**	
Country	JP	Postal Code	100-8921
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button.

Non-Applicant Assignee Information:

Providing assignment information in this section does not subsitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Assignee 1

Complete this section only if non-applicant assignee information is desired to be included on the patent application publication in accordance with 37 CFR 1.215(b). Do not include in this section an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest), as the patent application publication will include the name of the applicant(s).

If the Assignee is an Organization check here. ☐

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	NAGI-0005
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information:

Address 1	
Address 2	

City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee Data may be generated within this form by selecting the Add button.

Signature:

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

Signature				Date (YYYY-MM-DD)	2013-02-14
First Name	Juan Carlos A.	Last Name	Marquez	Registration Number	34072

Additional Signature may be generated within this form by selecting the Add button.

This collection of information is required by 37 CFR 1.76. 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 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet 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.**

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)
	)
YUASA	)
	)
Application Number: To Be Determined	)
	)
Filed: Concurrently Herewith	)
	)
For: MAGNETIC TUNNEL JUNCTION DEVICE	)
	)
Attorney Docket No. NAGI-0005	)

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

INFORMATION DISCLOSURE STATEMENT

Sir:

The present application is a Continuation of U.S. Application 13/400,340 filed on February 20, 2012, which is a Continuation of U.S. Application 12/923,643 filed on September 30, 2010, which is a Continuation of U.S. Application 10/591,947 filed on September 8, 2006, which is a National Stage Application of PCT/JP2005/004720 filed on March 10, 2005.

Pursuant to 37 C.F.R. §§ 1.56 and 1.97, this Information Disclosure Statement is being submitted in connection with the above-identified patent application. A listing of documents to be published on the face of any patent granted from this application is submitted herewith on the accompanying Form PTO-1449. Any other documents or information submitted for consideration by the Examiner are listed in this paper. A copy of each non-US or foreign patent or non-patent publication or any portion thereof listed or herein identified is submitted herewith.

CERTIFICATION

1. This Information Disclosure Statement is being submitted:

[x] (a) Concurrently with the above captioned U.S. Continuation application, whereby it is believed that no fee is due; OR

[ ] **(b)** After three months from the filing date of the above-identified U.S. patent application but before the mailing date of the first Office Action on the merits of the above-identified application, whereby it is believed that no fee is due; OR

[ ] **(c)** After three months from the filing date of the above-identified U.S. patent application and after the mailing date of the first Office Action on the merits of the above-identified application, but prior to the issuance of any Final Action or Notice of Allowance sent in such application, whereby Applicant(s) hereby submit the requisite certification hereinbelow, or authorization for the payment of the requisite fee is attached; OR

[ ] **(d)** After the issuance of a Final Action or Notice of Allowance, but before the payment of the Issue Fee, whereby Applicant(s) hereby submit the requisite certification hereinbelow, and the attached authorization for the payment of the requisite fee.

2. In accordance with the requirements of 37 C.F.R. §1.97, and Parts 1(c) or 1(d) above, Applicant(s) hereby certify that:

[ ] Each item of information contained in this Information Disclosure Statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of this Information Disclosure Statement; OR

[ ] No item of information contained in this Information Disclosure Statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in §1.56(c) more than three months prior to the filing of this Information Disclosure Statement.

Please charge any additional fees or credit any overpayments in connection with the submission of this Information Disclosure Statement to Deposit Account No 12-0555.

WD EX1008
Western Digital v IP Bridge
Page 9

The Examiner is requested to acknowledge receipt and consideration of the information provided in this paper in accordance with prescribed procedures.

Respectfully submitted,

Juan Carlos A. Marquez
Registration Number 34,072

STITES & HARBISON PLLC
1199 N. Fairfax Street, Suite 900
Alexandria, Virginia 22314
(703) 739-4900
February 14, 2013

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	To Be Determined
	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 1 of 12	Docket #	NAGI.0005

U.S. PATENT DOCUMENTS

Exam. Initial*	Document No. Number – Kind Code	Publ. Date MM/DD/YYYY	Name Patentee or Applicant	Relevance Passages/Figs.
	US-2007/0128470 [X]	06/07/2007	Nagahama et al.	
	US-2004/0144995 [X]	07/29/2004	Nagahama et al.	
	US-2004/0245553 [X]	12/09/2004	Hosomi et al.	
	US-2006/0056115 [X]	03/16/2006	Djayaprawira et al.	
	US-2002/0159203 A1 [X]	10/31/2002	Saito et al.	
	US-2005/0207071 A1 [X]	09/22/2005	Sato et al.	
	US-2002/0191355 A1 [X]	12/19/2002	Hiramoto et al.	
	US-2002/0149962 A1 [X]	10/17/2002	Horiguchi	
	US-2007/0195592 A1 [X]	08/23/2007	Yuasa	
	US-2009/0324814 A1 [Y, YY]	12/31/2009	Parkin	
	US-2008/0062581 A1 [Y]	03/13/2008	Parkin	
	US-2007/0258170 A1 [Y]	11/08/2007	Yuasa	
	US-7,884,403 B2 [Y]	02/08/2011	Yuasa	
	US-6,544,801 B1 [Y]	04/08/2003	Slaughter et al.	
	US-5,514,484 [Y]	05/07/1996	Nishimoto	
	US-6,379,978 [YY]	04/30/2002	Goebel et al.	
	US-7,276,384 [YY]	10/02/2007	Parkin et al.	
	US-5,759,265 [YY]	06/02/1998	Nashimoto et al.	
	US-6,911,685 [YY]	06/28/2005	Anthony et al.	
	US-6,767,655 [YY]	07/27/2004	Hiramoto et al.	
	US-6,054,226 [YY]	04/25/2000	Takeda et al.	
	US-2008/0055793 [8, Z]	03/06/2008	Djayaprawira et al.	

Examiner Signature		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 the applicant.*

** Corresponds to U.S. Patent 2007/0128470, U.S. Patent 2004/0144995, WO2002/099905, and EP1 391 942, listed above.

*** Corresponds to U.S. Patent 2004/0245553, WO 2003/085750, and EP 1 494 295, listed above.

**** Corresponds to U.S. Patent 2006/0056115, listed above.

Corresponds to U.S. Document No. 2007-0195592 A1 listed above.

[3] Corresponds to US 2004-0144995, (the U.S. Pat. of '995 was previously filed in an IDS on 02-20-2012

[8] Corresponds to JP 2006-080116 and US 2006-0056115, which were filed in an IDS on 02-20-2012

[10] Corresponds to US 2006-0056115 (previously filed in IDS on 02-20-2012) and EP 1633007 listed above

X = Filed in Great Grandparent Application 10/591,947
Y = Filed in grandparent Application 12/923,643
YY = Cited by Examiner in grandparent Application 12/923,643
Z = Filed in Parent Application 13/400,340

Substitute for Form 1449/PTO	Application #	To Be Determined
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 2 of 12	Docket #	NAGI.0005

U.S. PATENT DOCUMENTS				
Exam. Initial*	**Document No.** Number – Kind Code	**Publ. Date** MM/DD/YYYY	**Name** Patentee or Applicant	**Relevance** Passages/Figs.
	US-2002/0080641 A1 [9, Z]	06/27/2002	Asao et al.	
	US-2002/0064595 A1 [6, Z]	05/30/2002	Nomura et al.	
	US-2003/0128483 A1 [Z]	07/10/2003	Kamijo	
	US-2004/0082201 A1 [5, Z]	04/29/2004	Sharma et al.	
	US-2004/0136232 A1 [4, Z]	07/15/2004	Hosomi et al.	
	US-2004/0139914 A1 [Z]	07/22/2004	Yamazaki et al.	
	US-2004/0234818 A1 [Z]	11/25/2004	Tanahashi et al.	
	US-2004/0257719 A1 [Z]	12/23/2004	Ohba et al.	
	US-2005/0110004 A1 [Z]	05/26/2005	Parkin et al.	
	US-2006/0012926 A1 [Z]	01/19/2006	Parkin	
	US-2006/0125034 A1 [Z]	06/15/2006	Ohba et al.	
	US-2006/00261425 A1 [Z]	11/23/2006	Suemitsu et al.	
	US-2008/0124454 A1 [Z]	05/29/2008	Djayaprawira et al.	
	US-2008/0180862 A1 [Z]	07/31/2008	Djayaprawira et al.	
	US-2008/0182342 A1 [Z]	07/31/2008	Parkin	
	US-2008/0212243 A1 [Z]	09/04/2008	Zhao et al.	
	US-2008/0253039 A1 [Z]	10/16/2008	Nagamine et al.	
	US-2009/0128167 A1 [Z]	05/21/2009	Hamada et al.	
	US-5,506,063 A [Z]	04/09/1996	Kamijo et al.	
	US-5,817,366 A [Z]	10/06/1998	Arai et al.	
	US-5,945,694 A [Z]	08/31/1999	Reyes et al.	
	US-6,181,537 B1 [Z]	01/30/2001	Gill	
	US-6,201,672 B1 [Z]	03/13/2001	Pinarbasi	
	US-6,252,750 B1 [Z]	06/26/2001	Gill	
	US-6,275,362 B1 [Z]	08/14/2001	Pinarbasi	

Examiner Signature		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 the applicant.*

[4] Corresponds to JP 2004-12805 listed above
[5] Corresponds to JP 2004-153258 listed above
[6] Corresponds to KR 2002-0042448 listed above
[9] Corresponds to JP 2002-270790 listed above

Z = Filed in Parent Application 13/400,340

Substitute for Form 1449/PTO	Application #	To Be Determined
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 3 of 12	Docket #	NAGI.0005

U.S. PATENT DOCUMENTS				
Exam. Initial*	**Document No.** Number – Kind Code	**Publ. Date** MM/DD/YYYY	**Name** Patentee or Applicant	**Relevance** Passages/Figs.
	US-6,828,260 B2 [Z]	12/07/2004	Sharma et al.	
	US-6,831,312 B2 [Z]	12/14/2004	Slaughter et al.	
	US-6,839,206 B2 [Z]	01/04/2005	Saito et al.	
	US-6,927,952 B2 [Z]	08/09/2005	Shimizu et al.	
	US-6,999,287 B2 [Z]	02/14/2006	Hayashi et al.	
	US-7,149,105 B2 [Z]	12/12/2006	Brown	
	US-7,220,498 B2 [Z]	05/22/2007	Nagahama et al.	
	US-7,252,852 B1 [Z]	08/07/2007	Parkin	
	US-7,262,064 B2 [Z]	08/28/2007	Ohba et al.	
	US-7,270,896 B2 [7, Z]	09/18/2007	Parkin	
	US-2006/0003185 [Z]	01/05/2006	Parkin	
	US-7,408,749 B2 [Z]	08/05/2008	Gill	
	US-7,443,639 B2 [Z]	10/28/2008	Parkin	
	US-7,453,672 B2 [Z]	11/18/2008	Dieny et al.	
	US-7,570,463 B2 [Z]	08/04/2009	Parkin	
	US-7,598,555 B1 [Z]	10/06/2009	Papworth Parkin	

FOREIGN PATENT DOCUMENTS					
Exam. Initial *	**Country-Number-Kind Code** if known	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Relev.** Psg/Figs.	**Trans-lation**
	JP 2003-318465** [,X]	11/7/2003			Abstract
	JP 2002-204004 [X]	7/19/2002			Abstract
	JP 2002-289943 [X]	10/4/2002			
	JP 2003-304010*** [,X]	10/24/2003	Sony Corp		Abstract

Examiner Signature		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 the applicant.*

** Corresponds to U.S. Patent 2007/0128470, U.S. Patent 2004/0144995, WO2002/099905, and EP1 391 942, listed above.

*** Corresponds to U.S. Patent 2004/0245553, WO 2003/085750, and EP 1 494 295, listed above.

[7] Corresponds to US 2006-0003185 listed above

X = Filed in Great Grandparent Application 10/591,947

Z = Filed in Parent Application 13/400,340

Substitute for Form 1449/PTO	Application #	To Be Determined
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 4 of 12	Docket #	NAGI.0005

FOREIGN PATENT DOCUMENTS					
Exam. Initial *	**Country-Number-Kind Code** if known	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Relev.** Psg/Figs.	**Trans-lation**
	WO 2002/099905 X	5/24/2002	National Institute of Advanced Industrial Science and Technology		Abstract
	EP 1 391 942 X	5/24/2002	National Institute of Advanced Industrial Science and Technology; Japan Science and Technology Agency		Yes
	WO 2003/085750 X	10/16/2003	Sony Corp		Abstract
	EP 1 494 295 X	1/5/2005	Sony Corp		Yes
	JP 2006-080116 ****,X	3/23/2006			Abstract
	EP 1 633 007 A2 X	3/8/2006	Anelva Corporation		Yes
	EP 1 633 007 A3 X	3/8/2006	Anelva Corporation		Yes
	EP 1 085 586 A2 X	3/21/2001	Kabushiki Kaisha Toshiba		Yes
	JP 2000-030236 X	1/28/2000	Hitachi Ltd.		Yes
	JP 2001-101645 X	4/13/2001	Akita Prefecture		Yes
	JP 2004-022599 X, Z	1/22/2004	Sony Corp		Yes
	JP 2002-270921 X	9/20/2002	Toshiba Corp		Abstract
	JP 2002-319722 X	10/31/2002	Matsushita Electric Ind Co Ltd		Abstract
	WO 2004/025744 A1 X	3/25/2004	Fujitsu Limited		Abstract
	JP 2003-283001 X	10/3/2003	Toshiba Corp		Yes
	JP 2002-246567 X	8/30/2002	Toshiba Corp		Abstract

Examiner Signature		Date Considered	

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** Corresponds to U.S. Patent 2007/0128470, U.S. Patent 2004/0144995, WO2002/099905, and EP1 391 942, listed above.

*** Corresponds to U.S. Patent 2004/0245553, WO 2003/085750, and EP 1 494 295, listed above.

**** Corresponds to U.S. Patent 2006/0056115, listed above.

10 Corresponds to US 2006-0056115 (previously filed in IDS on 02-20-2012) and EP 1633007 listed above

X = Filed in Great Grandparent Application 10/591,947
Z = Filed in Parent Application 13/400,340

Substitute for Form 1449/PTO	Application #	To Be Determined
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	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
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FOREIGN PATENT DOCUMENTS					
Exam. Initial *	**Country-Number-Kind Code** if known	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Relev.** Psg/Figs.	**Trans-lation**
	WO 2005/088745 A1 X	9/22/2005	Japan Science and Technology Agency; National Institute of Advanced Industrial Science and Technology		Abstract
	JP 11-097766 X	4/9/1999	Res Inst Electric Magnetic Alloys		Abstract & ¶22 & 23
	JP 2008-004956 #,Y	01/10/2008	Japan Science & Technology Agency; National Institute of Advanced Industrial & Technology		Abstract
	JP 2002-270790 A Z	09/20/2002	Toshiba Corp.		Abstract
	JP 2003-304012 A Z	10/24/2003	Matsushita Electric Ind Co. Ltd.		Partial
	JP H05-144729 A Z	06/11/1993	Hitachi Ltd.		Partial
	EP 0 145 403 A2 Z	06/19/1985	Energy Conversion Devices, Inc.		Yes
	EP 1 061 592 A Z	12/20/2000	Odagawa et al.		Yes
	EP 1 793 434 A1 Z	06/06/2007	Japan Science and Technology Agency		Yes
	JP 2002-359413 A Z	12/13/2002	Nat. Inst. Of Adv. Ind. & Technol.; Japan Science & Tech Corp.		Abstract

Examiner Signature		Date Considered	

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Corresponds to U.S. Document No. 2007-0195592 A1 listed above.
9 Corresponds to JP 2002-270790 listed above

X = Filed in Great Grandparent Application 10/591,947
Y = Filed in grandparent Application 12/923,643
Z = Filed in Parent Application 13/400,340

Substitute for Form 1449/PTO	Application #	To Be Determined
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 6 of 12	Docket #	NAGI.0005

FOREIGN PATENT DOCUMENTS					
Exam. Initial *	**Country-Number-Kind Code** if known	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Relev.** Psg/Figs.	**Trans-lation**
	JP 2003-86863 A	03/20/2003	Nat. Inst. Of Adv. Ind. & Technol; Japan Science & Tech Corp.		Abstract
	JP 2004-063592 A	02/26/2004	Sony Corp.		Abstract
	JP 2004-128015 A	04/22/2004	Sony Corp.		
	JP 2004-153258 A	05/27/2004	Hewlett Packard Development Co.		Abstract
	KR 2002-0042448 A	06/05/2002	Anelva Corp.		Abstract
	KR 2003-0097904 [3]	12/31/2003	Nagahama et al.		Partial
	WO 01/056090 A1	08/02/2001	Takahashi		Abstract

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	International Search Report of PCT/JP2005/004720 mailed June 21, 2005 [X]	Yes
	WOLF, S.A. et al., "Spintronics: A Spin-Based Electronics Vision for the Future", Science, Vol. 294, November 16, 2001, pp. 1488-1495. [X]	Yes
	WULFHEKEL, W. et al., "Single-Crystal Magnetotunnel Junctions", Applied Physics Letters, Vol. 78, No. 4, January 22, 2001, pp. 509-511 [X]	Yes
	JULLIERE, M., "Tunneling Between Ferromagnetic Films", Physics Letters, Vol. 54A, No. 3, September 8, 1975, pp.225-226. [X]	Yes

Examiner Signature		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 the applicant.*

[3] Corresponds to US 2004-0144995, (the U.S. Pat. of '995 was previously filed in an IDS on 02-20-2012
[4] Corresponds to JP 2004-12805 listed above
[5] Corresponds to JP 2004-153258 listed above
[6] Corresponds to KR 2002-0042448 listed above

X = Filed in Great Grandparent Application 10/591,947
Z = Filed in Parent Application 13/400,340

Substitute for Form 1449/PTO	Application #	To Be Determined
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 7 of 12	Docket #	NAGI.0005

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	SOULEN, R.J.., Jr. et al., "Measuring the Spin Polarization of a Metal with a Superconducting Point Contact", Science, Vol. 282, October 2, 1998, pp. 85-88. X	Yes
	SAITO, Y. et al., "Correlation between Barrier Width, Barrier Height, and DC Bias Voltage Dependences on the Magnetoresistance Ratio in Ir-Mn Exchange Biased Single and Double Tunnel Junctions", Jpn. J. Appl. Phys., Vol. 39 (2000), pp. L1035-L1-38. X	Yes
	IURA, S. et al., "Enhancement of Thermal Stability in Ferromagnetic Tunnel Junctions Prepared by the Radical Oxidation Method", Journal of the Magnetics Society of Japan, Vol. 26, No. 6 (2002), pp. 839-842, abstract only in English. X	Yes
	BOWEN, M. et al., "Large Magnetoresistance in Fe/MgO/FeCo(001) Epitaxial Tunnel Junctions on GaAs(001)", Applied Physics Letters, Vol. 79, No. 11, September 10, 2001, pp. 1655-1657. X	Yes
	SIMMONS, JOHN G., "Generalized Formula for the Electric Tunnel Effect between Similar Electrodes Separated by a Thin Insulating Film", Journal of Applied Physics, Vol. 34, NO. 6, June 1963, pp. 1793-1803. X	Yes
	VASSENT, J.L. et al., "A Study of Growth and the Relaxation of Elastic Strain in MgO on Fe(001)", J. Appl. Phys. Vol. 80, No. 10, November 15, 1996, pp. 5727-5735. X	Yes
	FAURE-VINCENT, J. et al., "High Tunnel Magnetoresistance in Expitaxial Fe/MgO/Fe Tunnel Junctions", Applied Physics Letters, Vol. 82, No. 25, June 23, 2003, pp. 4507-4509. X	Yes
	MEYERHEIM, H.L. et al., "Geometrical and Compositional Structure at Metal-Oxide Interfaces: MgO on Fe(001)", Physical Review Letters, Vol. 18, No. 7, August 13, 2001, pp. 076102-1 – 076102-4. X	Yes
	BUTLER, W.H. et al., "Spin-dependent Tunneling Conductance of Fe[MgO]Fe Sandwiches", Physical Review B., Vol. 63, 054416, 2001, pp. 054416-1 – 054416-12. X	Yes

Examiner Signature		Date Considered	

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	First Inventor	Yuasa
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	Examiner	
Sheet 8 of 12	Docket #	NAGI.0005

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial *	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	MATHON, J. et al., "Theory of Tunneling Magnetoresistance of an Epitaxial Fe/MgO/Fe(001) Junction", Physical Review B., Vol. 63, 220403(R), 2001, pp. 220403-1 – 220403-4. X	Yes
	ZHANG, X.-G. et al., "Effects of the Iron-Oxide Layer in Fe-FeO-MgO-Fe Tunneling Junctions", Physical Review B, Vol. 68, 092402, 2003, pp. 092402-1 – 092402-4. X	Yes
	ZHANG, X.-G. et al., "Large Magnetoresistance in bcc Co/MgO/Co and FeCo/MgO/FeCo Tunnel Junctions", Physical Review B., Vol. 70, 172407, 2004, pp. 172407-1 – 172407-4. X	Yes
	GIBSON, A. et al., "Stability of Vacancy Defects in MgO: The Role of Charge Neutrality", Physical Review B., Vol. 50, No. 4, July 15, 1994-II, pp. 2582-2592. X	Yes
	YUASA, S. et al., "High Tunnel Magnetoresistance at Room Temperature in Fully Expitaxial Fe/MgO/Fe Tunnel Junctions Due to Coherent Spin-Polarized Tunneling", Japanese Journal of Applied Physics, Vol. 43, No. 4B, 2004, pp. L588-L590. X	Yes
	MITANI, S., *et al.*, "Fe/MgO/FeCo (100) Epitaxial Magnetic Tunnel Junctions Prepared by Using *in situ* Plasma Oxidation", Journal of Applied Physics, Vol. 93, No. 10, Parts 2 and 3, May 15, 2003, pp. 8041-8043. X	Yes
	POPOVA, E., *et al.*, "Epitaxial MgO Layer for Low-Resistance and Coupling-Free Magnetic Tunnel Junctions", Applied Physics Letters, Vol. 81, No. 6, August 5, 2002, pp.1035-1037. X	Yes
	BOUBETA, C. MARTINEZ, et al., "Magnetic Coupling in Epitaxial TM/MgO/Fe(001) (TM=FeCo, Fe/Co, Fe) Macroscopic and MicroscopicTrilayers", Journal of Applied Physics, Vo. 94, No. 6, September 15, 2003, pp. 4006-4012. X	Yes
	Supplementary European Search Report from European Patent Office for Application No. 05720955.3 2222, Patent No. 1737055, PCT/JP2005004720 dated July 2, 2008. X	

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	First Inventor	Yuasa
	Art Unit	
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NON PATENT LITERATURE DOCUMENTS		
Exam. Initial *	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	Office Action from European Patent Office dated November 6, 2009 X	
	F. ERNULT et al., "Preparation of Nanometer-Scale Iron Dots on Insulating Layer", Science and Technology of Advanced Materials, Vol. 4, (2003), pp. 383-389 X	Yes
	DAVID J. SMITH et al., "Structural Characterization of Thin Film Ferromagnetic Tunnel Junctions", Journal of Applied Physics, Vol. 83, No. 10, 15 May 1998, pp. 5154-5158 X	Yes
	X. W. LI et al., "Fabrication and Properties of Heteroepitaxial Magnetite (Fe_3O_4) Tunnel Junctions", Applied Physics Letters, Vol. 73, No. 22, 30 November 1998, pp.3282-3284 X	Yes
	C. L. PLATT, et al., "Spin Polarized Tunneling in Reactively Sputtered Tunnel Junctions", Journal of Applied Physics, Vol. 81, No. 8, 15 April 1997, pp. 5523-5525 X	Yes
	P. TURBAN et al., "Growth and Characterization of Single Crystalline NiMnSb Thin Films and Epitaxial NiMnSb/MgO/NiMnSb(001) Trilayers", 2002 The American Physical Society, Physical Review B., Vol. 65, pp. 134417-1 to 134417-13 X	Yes
	T. MORIYAMA et al., "Preparation and Magnetoresistance in Single-Crystal and Polycrystal Fe/MgO/FeCo Tunnel Junctions", The Physical Society of Japan, 2003 Spring meeting, Abstracts Book 58(1-3), 460, (2003-03-06) X	Yes
	JAGADEESH S. MOODERA et al., "Ferromagnetic-Insulator-Ferromagnetic Tunneling: Spin-Dependent Tunneling and Large Magnetoresistance in Trilayer Junctions (Invited), Journal of Applied Physics, Vol. 79, No. 8, 15 April 1996, pp. 4724-4729 X	Yes
	MASAYOSHI TONOUCHI et al., "Epitaxial Growth of NbN on an Ultrathin MgO/Semiconductor System", Journal of Applied Physics, Vol. 62, No. 3, 1 August 1987, pp. 961-966 X	Yes

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Exam. Initial *	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	"Giant tunnel magnetoresistance in magnetic tunnel junctions with a crystalline $M_gO(001)$ barrier," S. Yuasa and D.D. Djayaprawira, Journal of Applied Physics D: Applied Physics, 1 Phys, D: Appl. Phys. 40 (2007) R337-R354 [Y]	Yes
	Office Action issued from Japanese Patent Office, in corresponding Japanese Patent Application No. 2011-226907, dated January 31, 2012, pp. 1-3. [Z]	Yes
	ARAKI et al., "Fabrication and Electric Properties of Lapped Type of TMR Heads for ~50 Gb/In^2 and Beyond," IEEE Transactions on Magnetics, Vol. 38, No. 1, pp. 72-77, January 2002. [Z]	Yes
	David D. DJAYAPRAWIRA et al., "230% Room-Temperature Magnetoresistance in CoFeB/MgO/CoFeB, Magnetic Tunnel Junctions," IEICE Technical Report, Vol. 104, No. 713, March 4, 2005 [Z]	Yes
	David D. DJAYAPRAWIRA et al., "Novel Sputtering Technology of Magnetic Tunnel Junctions for MRAM Application," Papers 01 the 66th Symposium on Semiconductors and Integrated Circuits Technology, Vol. 66, pp. 58-61, 2004 [Z]	Yes
	H. DOMON et al., "Effect of Ge Addition on Postannealed CoCrGePt Thin Film Media," Journal of Applied Physics, Vol. 91, No. 10, pp, 8632-8634, May 15, 2002. [Z]	Yes
	H. DOMON et al. "Reduction of Magnetic Interaction in CoB/Pd Multilayer Perpendicular Media Using a Phase-Separated Pd-SiO Underlayer," Journal of Applied Physics, Vol. 93, No. 10, pp. 8164-8166, May 15, 2003. [Z]	Yes
	Extended European Search Report, issued from European Patent Office, of European Application No. 08159511.8, dated June 5, 2009. [10, Z]	Yes

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[10] Corresponds to US 2006-0056115 (previously filed in IDS on 02-20-2012) and EP 1633007 listed above

Y = Filed in grandparent Application 12/923,643
Z = Filed in Parent Application 13/400,340

Substitute for Form 1449/PTO	Application #	To Be Determined
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	First Inventor	Yuasa
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Sheet 11 of 12	Docket #	NAGI.0005

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	T. KAKUTA et al., " Novel PVD Tool for Magnetoresistive Random Access Memory (MRAM) Mass Production," Anelva Technical Report, Vol. 10, pp, 27-33, January 25, 2004. Z	Abstract
	A. KOBAYASHI et al., "TMR Devices Fabricated with RIE Etching Using Co+ NH_3," Journal of the Magnetics Society of Japan, Vol. 28, No. 2, February 1, 2004. Z	Abstract
	J.S. MOODERA et al., "Large Magnetoresistance at Room Temperature in Ferromagnetic Thin Film Tunnel Junctions," Physical Review Letters, Vol. 74, No. 16, pp. 3273-3276, April 17, 1995. Z	Yes
	J.S. MOODERA, "Interface Magnetism and Spin Wave Scattering in Ferromagnet-Insulator-Ferromagnet Tunnel Junctions," Physical Review Letters, Vol. 80, No. 13, pp. 2941-2944, March 30, 1998. Z	Yes
	J. MURAI et al., "Direct Observation of Magnon Excitation in a Ferromagnetic Tunnel Junction Using Inelastic-Electron-Tunneling Spectroscopy," Japanese Journal of Applied Physics, Vol. 38, pp. L1106-L1108, October 1, 1999. Z	Yes
	K. NAGASAKA et al., "CPP Operational Mode of GMR Head," Fujitsu Sci. Tech. J., Vol. 37, No. 2, pp. 192-200, December 2001. Z	Yes
	T. OSADA et al., "Dry Etching of Magnetic Thin Film Stacks Using CO/NH_3 and CH_3OH Gases for Tunneling Magneto-Resistance Devices," 2004 Dry Process International Symposium, Vol. 4, pp. 127-131, 2004. Z	Yes
	Stuart S.P. PARKIN et al." Giant Tunnelling Magnetoresistance At Room Temperature with MgO (100) Tunnel Barriers," Nature Materials, Vol, 3, pp. 862-867, December 2004. Z	Yes
	M. TAKAGISHI et al., "The Applicability of CPP-GMR Heads for Magnetic Recording," IEEE Transactions on Magnetics, Vol. 38, No. 5, pp. 2277-2282, September 2002. Z	Yes
	A. TANAKA et al., "Spin-Valve Heads in the Current-Perpendicular-to-Plane Mode for Ultrahigh-Density Recording," IEEE Transactions on Magnetics, Vol. 38, No. 1, January 2002. Z	Yes
	K. TSUNEKAWA et al., "Surface Treatment Techniques in Fabrication of GMR and TMR Films, "Journal of the Magnetics Society of Japan, Vol. 28, No. 11, pp. 1074-1080, November 1, 2004. Z	Yes

Examiner Signature		Date Considered	

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Z = Filed in Parent Application 13/400,340

Substitute for Form 1449/PTO		
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	Confirmation #	
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	First Inventor	Yuasa
	Art Unit	
	Examiner	
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Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	D. WANG et al., "70% TMR at Room Temperature for SDT Sandwich Junctions With CoFeB as Free and Reference Layers," IEEE Transactions on Magnetics, Vol. 40, No. 4, pp. 2270-2271, July 2004. Z	Yes
	S. YOSHIMURA et al., " Magnetic Grain Size Reduction by Using Oxygen Exposure Process Onto Very Thin Islandlike WCr Seedlayer in Longitudinal Recording Media," Journal of Applied Physics, Vol. 91, No. 10, pp. 8629-8631, May 15, 2002. Z	Yes
	S. YOSHIMURA et al. "Grain Size Reduction by Utilizing A Very Thin, High-Melting-Point WCr Seedlayer in Longitudinal Media: Media Noise Reduction in High H_k^{grain} Media, Vol. 25, No. 4-2, pp. 627-630 (2001). Z	Abstract
	YU et al., "Electron Transport Properties in Magnetic Tunnel Junctions with Epitaxial NiFe (111) Ferromagnetic Bottom Electrodes," Applied Physics Letters, Vol. 82, No. 26, pp. 4735-4737, June 30, 2003. Z	Yes
	S. YUASA et al. "Magnetic Tunnel Junctions With Single-Crystal Electrodes: A Crystal Anisotropy of Tunnel Magneto-Resistance," Europhysics Letters, Vol. 52, No. 3, pp. 344-350 November 1, 2000. Z	Yes
	S. YUASA et al., "Giant Room-Temperature Magnetoresistance in Single-Crystal Fe/MgO/Fe Magnetic Tunnel Junctions," Nature Materials Vol. 3, pp. 868-871, October 31, 2004 Z	Yes
	S. YUASA et al., "Spin-Polarized Resonant Tunneling In Magnetic Tunnel Junctions," Science, Vol. 297, pp. 234-237, July 12, 2002. Z	Yes
	S. Zhang et al. "Quenching of Magnetoresistance by Hot Electrons in Magnetic Tunnel Junctions," Physical Review Letters, Vol. 79, No. 19, pp. 3744-3747, November 10, 1997. Z	Yes

Examiner Signature		Date Considered	

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Z = Filed in Parent Application 13/400,340

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Juan Carlos A. Marquez/Sheila Price
Attorney Docket Number:	NAGI-0005

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Utility application filing	1011	1	390	390
Utility Search Fee	1111	1	620	620
Utility Examination Fee	1311	1	250	250
Pages:				
Claims:				
Independent claims in excess of 3	1201	1	250	250
Miscellaneous-Filing:				
Petition:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
	Total in USD ($)			**1510**

Electronic Acknowledgement Receipt

EFS ID:	14953817
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	38327
Filer:	Juan Carlos A. Marquez/Sheila Price
Filer Authorized By:	Juan Carlos A. Marquez
Attorney Docket Number:	NAGI-0005
Receipt Date:	14-FEB-2013
Filing Date:	
Time Stamp:	15:27:17
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$1510
RAM confirmation Number	2204
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1	Specification	NAGI-5-SPEC.pdf	137392 4b9c57364422c7809b1110cc2ca0a3d3921241c1	no	20
Warnings:					
Information:					
2	Claims	NAGI-5-CLAIMS.pdf	63390 df33a9c4caa16e5b7790f08ef120e2d51b3fbf04	no	4
Warnings:					
Information:					
3	Abstract	NAGI-5-ABST.pdf	27479 04314b09b1ad9bbb9c6fe9ee549677cadec147b3	no	1
Warnings:					
Information:					
4	Drawings-only black and white line drawings	NAGI-5-DRAWS.pdf	420686 0eb81a8273a93d126067cc7e04b9709ab2c52118	no	10
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Information:					
5	Transmittal of New Application	NAGI-5-CONT_TRANSMITTAL.pdf	215931 488da08f5033a49bcaea56c107c7b9dd870d53e8	no	1
Warnings:					
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MAGNETIC TUNNEL JUNCTION DEVICE

[0001] CROSS-REFERENCE TO RELATED APPLICATION

[0002] The present application is a Continuation of U.S. Application 13/400,340 filed on February 20, 2012, which is a Continuation of U.S. Application 12/923,643 filed on September 30, 2010, which is a Continuation of U.S. Application 10/591,947 filed on September 8, 2006, which is a National Stage Application of PCT/JP2005/004720 filed on March 10, 2005. Priority is claimed from U.S. Application 13/400,340 filed on February 20, 2012, which claims priority from U.S. Application 12/923,643 filed on September 30, 2010, which claims priority from U.S. Application 10/591,947 filed on September 8, 2006, which claims priority from PCT/JP2005/004720 filed on March 10, 2005, which claims priority from Japanese Application Nos. 2004-313350 and 2004-071186 filed October 28, 2004 and March 12, 2004, respectively, the content of which is hereby incorporated by reference into this application.

[0003] BACKGROUND OF THE INVENTION

[0004] Field of the Invention

[0005] The present invention relates to a magnetic tunnel junction device and a method of manufacturing the same, particularly to a magnetic tunnel junction device with a high magnetoresistance and a method of manufacturing the same.

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[0006] Description of Related Art

[0007] Magnetoresistive random access memories (MRAMs) refer to a large-scale integrated memory circuit that is expected to replace the currently widely used DRAM memories. Research and development of MRAM devices, which are fast and non-volatile memory devices, are being extensively carried out, and sample products of a 4Mbit MRAM have actually been delivered.

[0008] Fig. 8 shows the structure and operation principle of a magnetic tunnel junction device (to be hereafter referred to as a "MTJ device"), which is the most important part of the MRAM. As shown in Fig. 8(A), a MTJ device comprises a tunnelling junction structure in which a tunnel barrier (to be hereafter also referred to as a "barrier layer") made of an oxide is sandwiched between a first and a second electrode made of a ferromagnetic metal. The tunnel barrier layer comprises an amorphous Al-O layer (see Non-Patent Document 1). As shown in Fig. 8(A), in the case of parallel magnetization alignment where the directions of magnetizations of the first and second ferromagnetic electrodes are aligned parallel, the electric resistance of the device with respect to the direction normal to the interfaces of the tunneling junction structure decreases. On the other hand, in the case of antiparallel magnetization alignment where the directions of magnetizations of the first and second ferromagnetic electrodes are aligned antiparallel as shown in Fig. 8(B), the electric resistance with respect to the direction normal to the interfaces of the tunneling junction structure increases. The resistance value does not change in a general state, so that information "1" or "0" can be

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stored depending on whether the resistance value is high or not. Since the parallel and antiparallel magnetization alignments can be stored in a non-volatile fashion, the device can be used as a non-volatile memory device.

[0009] Fig. 9 shows an example of the basic structure of the MRAM. Fig. 9(A) shows a perspective view of the MRAM, and Fig. 9(B) schematically shows a circuit block diagram. Fig. 9(C) is a cross-section of an example of the structure of the MRAM. Referring to Fig. 9(A), in an MRAM, a word line WL and a bit line BL are disposed in an intersecting manner, with an MRAM cell disposed at each intersection. As shown in Fig. 9(B), the MRAM cell disposed at the intersection of a word line and a bit line comprises a MTJ device and a MOSFET directly connected to the MTJ device. Stored information can be read by reading the resistance value of the MTJ device that functions as a load resistance, using the MOSFET. The stored information can be rewritten by applying a magnetic field to the MTJ device, for example. As shown in Fig. 9(C), an MRAM memory cell comprises a MOSFET 100 including a source region 105 and a drain region 103 both formed inside a p-type Si substrate 101, and a gate electrode 111 formed on a channel region that is defined between the source and drain regions. The MRAM also comprises a MTJ device 117. The source region 105 is grounded, and the drain is connected to a bit line BL via the MTJ device. A word line WL is connected to the gate electrode 111 in a region that is not shown.

[0010] Thus, a single non-volatile MRAM memory cell can be formed by a single MOSFET 100 and a single MTJ device 117. The MRAMs are therefore suitable where high levels of integration are required.

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[0011] Non-Patent Document 1: D. Wang, et al.: Science 294 (2001) 1488.

[0012] SUMMARY OF THE INVENTION

[0013] Although there are prospects for achieving MRAMs with capacities on the order of 64Mbits based on the current technologies, the characteristics of the MTJ device, which is the heart of MRAM, needs to be improved if higher levels of integration are to be achieved. In particular, in order to increase the output voltage of the MTJ device, the magnetoresistance must be increased and the bias voltage characteristics must be improved. Fig. 10 illustrates how the magnetoresistance in a conventional MTJ device using an amorphous Al-O as the tunnel barrier changes as a function of the bias voltage (L1). As shown, in the conventional MTJ device, the magnetoresistance is small and, notably, it tends to drastically decrease upon application of bias voltage. With such characteristics, the output voltage when operation margins are taken into consideration is too small for the device to be employed for an actual memory device. Specifically, the magnetoresistance of the current MTJ device is small at approximately 70%, and the output voltage is also small at no more than 200 mV, which is substantially half the output voltage of a DRAM. This has resulted in the problem that as the level of integration increases, signals are increasingly lost in noise and cannot be read.

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[0014] It is an object of the invention to increase the output voltage of a MTJ device. It is another object of the invention to provide a memory device with a high magnetoresistance for stable operation.

[0015] In one aspect, the invention provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising: a tunnel barrier layer; a first ferromagnetic material layer of the BCC structure formed on a first side of the tunnel barrier layer; and a second ferromagnetic material layer of the BCC structure formed on a second side of the tunnel barrier layer, wherein the tunnel barrier layer is formed by a single-crystal MgO_x (001) layer or a poly-crystalline MgO_x ($0 < x < 1$) layer in which the (001) crystal plane is preferentially oriented.

[0016] The invention further provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising: a tunnel barrier layer comprising MgO(001); a first ferromagnetic material layer comprising Fe(001) formed on a first side of the tunnel barrier layer; and a second ferromagnetic material layer comprising Fe(001) formed on a second side of the tunnel barrier layer, wherein the MgO layer is formed by a single-crystalline MgO_x (001) layer or a poly-crystalline MgO_x ($0 < x < 1$) layer in which the (001) crystal plane is preferentially oriented. In a preferred embodiment, the band discontinuity value (the height of the tunnel barrier) between the bottom of the conduction band of the MgO(001) layer and the Fermi energy of the Fe(001) layer is smaller than an ideal value of a perfect single-crystal without defect. These features increase the magnetoresistance and thereby allow the output voltage of the MTJ device to

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be increased. By using any of the aforementioned MTJ devices as a load for a single transistor, a non-volatile memory can be formed.

[0017] In another aspect, the invention provides a method of manufacturing a magnetoresistive device comprising: preparing a substrate; depositing a first Fe(001) layer on the substrate; depositing a tunnel barrier layer on the first Fe(001) layer by electron beam evaporation under high vacuum, the tunnel barrier layer comprising a single-crystalline MgO_x (001) or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented; and forming a second Fe(001) layer on the tunnel barrier layer.

[0018] The invention furthermore provides a method of manufacturing a MTJ device comprising a first step of preparing a substrate comprising a single-crystalline MgO_x(001) or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented, a second step of depositing a first Fe(001) layer on the substrate and performing an annealing process to make the surface flat, a third step of depositing a tunnel barrier layer on the first Fe(001) layer by electron beam evaporation, the tunnel barrier layer comprising a single-crystalline MgO_x(001) or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented, and a fourth step of forming a second Fe(001) layer on the tunnel barrier layer. The method may further comprise the step of growing a seed layer between the first and the second steps, the seed layer comprising a single-crystalline MgO_x(001) or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented. The MgO layer may be deposited using a

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target with the value of x in MgO_x adjusted. The value of x in MgO_x may be adjusted in the step of forming the MgO.

[0019] In yet another aspect, the invention provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising a tunnel barrier layer comprising MgO(001), a first ferromagnetic material layer comprising an amorphous magnetic alloy formed on a first sideof the tunnel barrier layer, and a second ferromagnetic material layer comprising an amorphous magnetic alloy formed on a second side of the tunnel barrier layer, wherein the discontinuous value (the height of the tunnel barrier) between the bottom of the conduction band of the MgO(001) layer and the Fermi energy of the first or the second ferromagnetic material layer comprising the amorphous magnetic alloy is lower than an ideal value of a perfect single-crystal with no defect.

[0020] BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Fig. 1(B) shows the structure of a MTJ device according to a first embodiment of the invention, and Fig. 1(A) shows the energy band structure of a ferromagnetic metal Fe(001), illustrating the $E\text{-}E_F$ relationship with respect to the [001] direction of the momentum space.

[0022] Fig. 2(A) to Fig. 2(D) schematically show the process of manufacturing a MTJ device with a Fe(001)/MgO(001)/Fe(001) structure (to be hereafter referred to as a "Fe(001)/MgO(001)/Fe(001) MTJ device") according to an embodiment of the invention.

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[0023] Fig. 3(A) shows a RHEED image of a Fe(001) lower electrode (a first electrode), and Fig. 3(B) shows a RHEED image of a MgO(001) barrier layer.

[0024] Fig. 4 shows the results of observing the quadrupole mass spectra in the deposition chamber during the MgO evaporation.

[0025] Fig. 5 shows the film deposition rate dependency of the oxygen partial pressure during the MgO evaporation.

[0026] Fig. 6 shows typical magnetoresistance curves of the Fe(001)/MgO(001)/Fe(001) MTJ device.

[0027] Fig. 7(A) shows the bias voltage dependency of the MR ratio at room temperature, and Fig. 7(B) shows the output voltage V_{out} of the MTJ device (=bias voltage × (Rap-Rp)/Rap).

[0028] Fig. 8 shows the structure of the MTJ device and its operating principle.

[0029] Fig. 9 shows an example of the basic structure of an MRAM, Fig. 9(A) showing a perspective view of the MRAM, Fig. 9(B) showing a schematic circuit diagram, and Fig. 9(C) showing a cross-sectional view of an example of its structure.

[0030] Fig. 10 shows how the magnetoresistance of a conventional MTJ device using an amorphous Al-O as the tunnel barrier changes depending on the bias voltage.

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[0031] Fig. 11 shows the structure of a MTJ device according to a variation of the invention, corresponding to Fig. 1(B).

[0032] DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0033] In the context of the present specification, because MgO has a cubic crystal structure (NaCl structure), the (001) plane, the (100) plane, and the (010) plane are all equivalent. The direction perpendicular to the film surface is herein considered to be the z-axis so that the film plane can be uniformly described as (001). Also in the context of the present specification, BCC structure, which the crystalline structure of ferromagnetic electrode layer, means body-centered cubic lattice structure. More specifically, BCC structure includes the BCC structure with no chemical ordering so-called A2-type structure, the BCC structure with chemical ordering such as B2-type structre and $L2_1$-type structure, and also the aforementioned structures with slight lattice distortion.

[0034] The term "ideal value" with regard to a perfect single-crystal without defect herein refers to a value that has been estimated from ultraviolet photoemission spectroscopy experiments (see W. Wulfhekel, et al.: Appl. Phys. Lett. 78 (2001) 509.). The term "ideal value" is used herein because the aforementioned state can be considered to be an upper limit value of the

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potential barrier height of the tunnel barrier of an ideal single-crystal MgO with hardly any oxygen vacancy defect or lattice defect.

[0035] Before describing the preferred embodiments of the invention, an analysis conducted by the inventors is discussed. The magnetoresistance (MR) ratio of a MTJ device can be expressed by the following equation:

[0036] $\Delta R/Rp = (Rap - Rp)/Rp$

[0037] where Rp and Rap indicate the tunnel junction resistance in the cases of parallel and antiparallel magnetization alignments, respectively, of two electrodes. According to the Jullire's formula, the MR ratio at low bias voltage can be expressed by:

[0038] MR ratio $= (Rap - Rp)/Rp = 2P_1P_2/(1-P_1P_2)$, and

[0039] $P\alpha = (D\alpha \uparrow (E_F) - D\alpha \downarrow (E_F))/(D\alpha \uparrow (E_F) + D\alpha \downarrow (E_F)$,

[0040] where $\alpha = 1, 2$ (1)

[0041] In the above equations, $P\alpha$ is the spin polarization of an electrode, and $D\alpha \uparrow (E_F)$ and $D\alpha \downarrow (E_F)$ are the density of state (DOS) at the Fermi energy (E_F) of the majority-spin band and the minority-spin band, respectively. Since the spin polarization of ferromagnetic transition metals and alloys is approximately 0.5 or smaller, the Jullire's formula predicts a highest estimated MR ratio of about 70%.

[0042] Although the MR ratio of approximately 70% has been obtained at room temperature when a MTJ device was made using an amorphous Al-O

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tunnel barrier and polycrystalline electrodes, it has been difficult to obtain the output voltage of 200 mV, which is comparable to the output voltages of DRAMs, thereby preventing the realization of MRAM as mentioned above.

[0043] The inventors tried an approach to deposit a MTJ device in which the tunnel barrier comprises a single-crystal (001) of magnesium oxide (MgO) or a poly-crystalline MgO in which the (001) crystal plane is preferentially oriented. It is the inventors' theory that, because magnesium oxide is a crystal (where the atoms are arranged in an orderly fashion), as opposed to the conventional amorphous Al-O barrier, the electrons are not scattered and the coherent states of electrons are concerved during the tunneling process. Fig. 1(B) shows the MTJ device structure according to an embodiment of the invention. Fig. 1(A) shows the energy band structure of the ferromagnetic Fe(001), that is, the E-E_F relationship with respect to the [001] direction of the momentum space. As shown in Fig. 1(B), the MTJ device structure of the present embodiment comprises a first Fe (001) layer 1, a second Fe (001) layer 5, and a single-crystalline MgO_x (001) layer 3 or a poly-crystalline MgO_x ($0 < x < 1$) layer 3 sandwiched therebetween, the polycrystalline layer having the (001) crystal plane preferentially oriented therein. According to the aforementioned Jullire's model, assuming that the momentum of the conduction electrons is preserved in the tunneling process, the tunneling current that passes through MgO would be dominated by those electrons with wave vector k_z in the direction perpendicular to the tunnel barrier (normal to the junction interfaces). In accordance with the energy band diagram shown in Fig. 1(A) of Fe in the [001] (Γ-H) direction, the density of state (DOS) at the Fermi energy E_F does not exhibit a very high spin polarization due to the fact

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that the sub-bands of the majority-spin and the minority-spin have states at the Fermi energy E_F. However, in case the coherent states of electrons are conserved in the tunneling process, only those conduction electrons that have totally symmetrical wave functions with respect to the axis perpendicular to the barrier would be coupled with the states in the barrier region and come to have a finite tunneling probability. The $\Delta 1$ band in the Fe(001) electrode has such totally symmetric wave functions. As shown in Fig. 1(A), the majority spin $\Delta 1$ band (solid line) has states at the Fermi energy E_F, whereas the minority spin $\Delta 1$ band (broken line) does not have state at the Fermi energy E_F. Because of such half-metallic characteristics of the Fe Δ_1 band, there is the possibility that a very high MR ratio can be obtained in a coherent spin polarized tunneling. Since in an epitaxial (single-crystal, or (001) oriented poly-crystal) MTJ device the scattering of electrons is suppressed during the tunneling process, an epitaxial MTJ device is thought to be ideal for realizing the aforementioned coherent tunneling.

[0044] In the following, a MTJ device according to a first embodiment of the invention and a method of manufacturing the same will be described with reference to the drawings. Figs. 2(A) to 2(D) schematically show the method of manufacturing the MTJ device having the Fe (001)/MgO(001)/Fe(001) structure according to the embodiment (to be hereafter referred to as a "Fe(001)/MgO(001)/Fe(001) MTJ device"). Fe(001) refers to a ferromagnetic material with the BCC structure. First, a single-crystal MgO(001) substrate 11 was prepared. In order to improve the morphology of the surface of the single-crystal MgO(001) substrate 11, a MgO(001) seed layer 15 was grown by the molecular beam epitaxy (MBE) method. This was subsequently

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followed by the growth of an epitaxial Fe(001) lower electrode (first electrode) 17 with the thickness of 50 nm on the MgO(001) seed layer 15 at room temperature, as shown in Fig. 1(B), and then annealing was performed at 350°C under ultrahigh vacuum (2×10^{-8} Pa). Electron-beam evaporation conditions included an acceleration voltage of 8 kV, a growth rate of 0.02 nm/sec, and the growth temperature of room temperature (about 293K). The source material of the electron-beam evaporation was MgO of the stoichiometric composition (the ratio of Mg to O being 1:1), the distance between the source and the substrate was 40 cm, the base vacuum pressure was 1×10^{-8} Pa, and the O_2 partial pressure was 1×10^{-6} Pa. Alternatively, a source with oxygen vacancy defects may be used instead of the MgO of the stoichiometric composition (the ratio of Mg to O is 1:1).

[0045] Fig. 3(A) shows a RHEED image of the Fe(001) lower electrode (a first electrode). The image shows that the Fe(001) lower electrode (first electrode) 17 possesses a good crystallinity and flatness. Thereafter, a MgO(001) barrier layer 21 with the thickness of 2 nm was epitaxially grown on the Fe(001) lower electrode (first electrode) at room temperature, also using the MgO electron-beam evaporation method. Fig. 3(B) shows a RHEED image of the MgO(001) barrier layer 21. The image shows that the MgO(001) barrier layer 21 also possesses a good crystallinity and flatness.

[0046] As shown in Fig. 2(D), a Fe(001) upper electrode (a second electrode) 23 with the thickness of 10 nm was formed on the MgO(001) barrier layer 21 at room temperature. This was successively followed by the deposition of a Co layer 25 with the thickness of 10 nm on the Fe(001) upper electrode

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(second electrode) 23. The Co layer 25 is provided to increase the coercive force of the upper electrode 23 so as to realize the antiparallel magnetization alignment. The thus prepared sample was then processed by microfabrication techniques to obtain the Fe(001)/MgO(001)/Fe(001) MTJ device.

[0047] The aforementioned MgO evaporation using an electron beam involved the formation of a film under ultrahigh vacuum of 10^{-9} Torr. It can be seen that in this method, the film, even when formed on a glass substrate to the thickness of 300 nm, was colorless and transparent, showing that a good crystal film was formed. Fig. 4 shows the results of observing the quadrupole mass spectra in the deposition chamber during the MgO growth. The results show that the partial pressures regarding the spectrum P1 of O and the spectrum P2 of O_2 are high. Fig. 5 shows the film deposition rate dependency of the oxygen partial pressure during MgO evaporation. It will be seen from the figure that the oxygen partial pressure itself is high, and that the oxygen partial pressure increases as the deposition rate increases. These results indicate the separation of oxygen from MgO during the deposition of MgO. Since the separated oxygen is pumped out of the deposition chamber using vacuum pumps, there is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$). When there are oxygen vacancy defects, the potential barrier height of the MgO tunnel barrier is thought to decrease (such as in the range of 0.10 to 0.85 eV; more specifically, 0.2 to 0.5 eV), which is thought to result in an increase in the tunneling current. In the case of a typical Al-O tunnel barrier, the height of the tunnel barrier with respect to Fe(001) electrodes is considered to be 0.7 to

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2.5 eV. An ideal tunnel barrier height of a MgO crystal is 3.6 eV, and experimental values of 0.9 to 3.7 eV have been obtained. Using the method according to the present embodiment of the invention, a tunnel barrier height of approximately 0.3 eV is expected, indicating that the resistance of the tunnel barrier can be lowered. However, it should be noted that other factors, such as the influence of the aforementioned coherent tunneling, might also be involved. The value of x in MgO_x due to oxygen vacancy defects is such that $0.98 < x < 1$, and more preferably $0.99 < x < 1$. These are the ranges such that the sole presence of Mg is excluded and the characteristics of MgO can be basically maintained.

[0048] The aforementioned tunnel barrier height ϕ was determined by fitting the electric conductance characteristics of the MTJ device (the relationship between tunnel current density J and bias voltage V) onto the Simmons' formula (Equation (20) in a non-patent document by J. G. Simmons: J. Appl. Phys. 34, pp. 1793-1803 (1963)) based on the WKB approximation, using the least squares method. The fitting was performed using the free electron mass ($m = 9.11 \times 10^{-31}$ kg) as the electron's effective mass. When a bias voltage V (which is normally on the order of 500 mV to 1000 mV) is applied until non-linearity appears in the J-V characteristics, the height ϕ of the tunnel barrier and the effective thickness Δs of the tunnel barrier can be simultaneously determined by fitting the J-V characteristics using the Simmons' formula.

[0049] The effective thickness Δs of the tunnel barrier was determined to be smaller than the thickness of the actual MgO(001) tunnel barrier layer (t_{MgO})

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determined from a cross-sectional transmission electron microscope image of the MTJ device by approximately 0.5 nm. This is the result of the effective thickness Δs of the tunnel barrier having been reduced from the actual MgO(001) layer thickness by the effect of the image potential produced at the interface between the MgO(001) layer and the alloy layer consisting mainly of Fe and Co.

[0050] It is noted that, in the event that t_{MgO} can be accurately determined using the cross-sectional transmission electron microscope (TEM) image, the height ϕ of the tunnel barrier can be more simply determined by the following technique. Namely, when the bias voltage V applied to the MTJ device is small (normally 100 mV or smaller), the tunnel current density J is proportional to the bias voltage V, such that the J-V characteristics become linear. In such a low-bias voltage region, the Simmons' formula can be described as follows:

[0051] $$J = [(2m\phi)^{1/2}/\Delta s](e/h)^2 \times \exp[-(4\pi\Delta s/h) \times (2m\phi)^{1/2}] \times V \qquad (2)$$

[0052] where m is the mass of the free electron (9.11×10^{-31} kg), e is the elementary electric charge (1.60×10^{-19}C), and h is the Planck's constant (6.63×10^{-34} J·s). The effective thickness of the tunnel barrier Δs is approximately $t_{MgO} - 0.5$ nm. By fitting the J-V characteristics of the MTJ device in the low-bias voltage region onto Equation (2), the height ϕ of the tunnel barrier can be simply and yet accurately estimated.

[0053] Fig. 6 shows a typical magnetoresistance curve of the Fe(001)/MgO(001)/Fe(001) MTJ device produced by the above-described

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method. The MR ratio is 146% at the measurement temperature of 20K and 88% at the measurement temperature of 293K. These values represent the highest MR ratios that have so far been obtained at room temperature. Such high MR ratios cannot be explained by the spin polarization of the Fe(001) electrode and is thought rather to be related to a coherent spin-polarized tunneling. When 160 prototype MTJ devices were made, the variations regarding the MR ratio and tunneling resistance value were not more than 20%. The yield of the MTJ devices was 90% or more at the laboratory stage. These high values suggest the effectiveness of the approach of the invention. The resistance-area (RA) product of the MTJ device was on the order of a few $k\Omega\mu m^2$, which is suitable for MRAM.

[0054] Fig. 7(a) shows the bias voltage dependency of the MR ratio at room temperature. It will be seen that the bias voltage dependency of the MR ratio is fairly small. Although the characteristics are asymmetric, the voltage V_{half} at which the MR ratio is reduced in half of the zero-bias value is 1250 mV, which is a very high value. In this connection, it is noted that the voltage V_{half} at which the MR ratio is reduced in half of the zero-bias value in the conventional MTJs with Al-O tunnel barrier is 300 to 600 mV. Fig. 7(b) shows the output voltage V_{out} of the MTJ device (=bias voltage $\times$ (Rap – Rp)/Rap). The maximum value of the output voltage V_{out} is 380 mV with a positive bias. This value is about twice as large as that (a little less than 200 mV) in the case of the Al-O barrier. These high values in terms of both MR ratio and output voltage suggest the effectiveness of the technique according to the present embodiment.

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[0055] Although in the above-described embodiment Fe(001) of BCC was employed, an Fe alloy of BCC, such as an Fe-Co alloy, Fe-Ni alloy, or Fe-Pt alloy, may be used instead. Alternatively, a layer of Co or Ni with the thickness of one or several monoatomic layers may be inserted between the electrode layer and the MgO(001) layer.

[0056] Hereafter, a MTJ device according to a second embodiment of the invention and a method of manufacturing the same will be described. In the method of manufacturing a Fe(001)/MgO(001)/Fe(001) MTJ device according to the present embodiment, MgO(001) is initially deposited in a poly-crystalline or amorphous state by sputtering or the like, and then an annealing process is performed such that a poly-crystal in which the (001) crystal plane is preferentially oriented or a single-crystal is obtained. The sputtering conditions were such that, for example, the temperature was room temperature (293K), a 2-inch ϕ MgO was used as a target, and sputtering was conducted in an Ar atmosphere. The acceleration power was 200 W and the growth rate was 0.008 nm/s. Because MgO that is deposited under these conditions is in an amorphous state, a crystallized MgO was obtained by increasing the temperature to 300°C from room temperature and maintaining that temperature for a certain duration of time.

[0057] Oxygen vacancy defects may be introduced by a method whereby oxygen vacancy defects is produced during growth, a method whereby oxygen vacancy defects is introduced subsequently, or a method whereby a state with oxygen vacancy defects is subjected to an oxygen plasma process or natural oxidation so as to achieve a certain oxygen deficit level.

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[0058] As described above, in accordance with the MTJ device technology of the present embodiment, an annealing process is carried out for crystallization after an amorphous MgO has been deposited by sputtering, thereby eliminating the need for large-sized equipment.

[0059] Hereafter, a MTJ device according to a variation of the embodiments of the invention will be described with reference to the drawings. Fig. 11 shows the structure of the MTJ device according to the variation, which corresponds to Fig. 1(B). As shown in Fig. 11, the MTJ device of the variation is characterized in that, as in the MTJ device of the above-described embodiments, the electrodes disposed on either side of a single-crystal MgO_x(001) layer 503 or an oxygen-deficit poly-crystal MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented comprises an amorphous ferromagnetic alloy, such as CoFeB layers 501 and 505. The amorphous ferromagnetic alloy can be formed by evaporation or sputtering, for example. The resultant characteristics are substantially identical to those of the first embodiment.

[0060] As the amorphous magnetic alloy, FeCoB, FeCoBSi, FeCoBP, FeZr, and CoZr may be used, for example. Although an anneal process after the preparation of the MTJ device might cause the amorphous magnetic alloy in the electrode layers to be partially or entirely crystallized, this would not lead to a significant deterioration of the MR ratio. Thus, such a crystallized amorphous magnetic alloy may be used in the electrode layers.

[0061] While the MTJ device according to various embodiments of the invention has been described, it should be apparent to those skilled in the art

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that the invention is not limited to those specific embodiments and various other modifications, improvements and combinations are possible. For example, the height of the tunnel barrier may be adjusted by doping Ca or Sr, instead of introducing an oxygen vacancy defects to the MgO layer. Further, while the MgO layer has been described to be deposited by electron-beam evaporation or sputtering, it should be obvious that other deposition methods are also possible. The term "high vacuum" refers to values on the order of no more than 10^{-6} Pa in the case where oxygen is not introduced, for example. In the case where oxygen is introduced, the term refers to values on the order of 10^{-4} Pa.

[0062] In accordance with the invention, a larger magnetoresistance than in the conventional MTJ device can be obtained, and the output voltage of the MTJ device can be increased. At the same time, the resistance value of the MTJ device can be reduced so that it is optimized for MRAM. The invention thus enables the level of integration of MRAM using the MTJ device to be readily increased. In accordance with the invention, the output voltage value of the MRAM roughly doubles over prior art, making the MTJ device of the invention suitable for very large scale integrated MRAMs of gigabit class.

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What is claimed is:

1. A tunnel barrier layer located between a first ferromagnetic material layer and a second ferromagnetic material layer,

wherein the tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented.

2. The tunnel barrier layer according to claim 1, wherein the tunnel barrier layer has a barrier height φ in a range of 0.2 to 0.5 electron volts (eV).

3. The tunnel barrier layer according to claim 2, wherein the tunnel barrier height φ is obtained by fitting J-V characteristics of a tunnel barrier junction structure to an equation (1):

$$J = [(2m\varphi)^{1/2} / \Delta s](e/h)^2 \times \exp[-(4\pi\Delta s/h) \times (2m\varphi)^{1/2}] \times V \qquad (1)$$

where J is a tunnel current density flowing through the tunnel barrier layer, V is an applied bias voltage that is 100 mV or smaller, m is the free electron mass, e is the elementary electric charge, h is the Planck's constant, Δs is an effective thickness of the tunnel barrier layer that is approximately equivalent to (t_{MgO} − 0.5 nm), and t_{MgO} is an actual thickness of the tunnel barrier layer determined using a cross-sectional transmission electron microscope image.

4. A magnetoresistive device having a tunnel barrier junction structure, the magnetoresistive device comprising:

a first ferromagnetic material layer;

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a second ferromagnetic material layer; and

a tunnel barrier layer located between the first and second ferromagnetic material layers, and

wherein the tunnel barrier layer comprises a single-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented or a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented, and

wherein the tunnel barrier layer has a tunnel barrier height φ in a range of 0.2 to 0.5 eV.

5. The magnetoresistive device according to claim 4, wherein at least one of the first and second ferromagnetic material layers comprises CoFeB alloy.

6. The magnetoresistive device according to claim 4, wherein the tunnel barrier height φ is obtained by fitting J-V characteristics of the tunnel barrier junction structure to an equation (1):

$$J = [(2m\varphi)^{1/2} / \Delta s](e/h)^2 \times \exp[-(4\pi\Delta s/h) \times (2m\varphi)^{1/2}] \times V \qquad (1)$$

where J is a tunnel current density flowing through the tunnel barrier layer, V is an applied bias voltage that is 100 mV or smaller, m is the free electron mass, e is the elementary electric charge, h is the Planck's constant, Δs is an effective thickness of the tunnel barrier layer that is approximately equivalent to (t_{MgO} − 0.5 nm), and t_{MgO} is an actual thickness of the tunnel barrier layer determined using a cross-sectional transmission electron microscope image.

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7. The magnetoresistive device according to claim 6, wherein at least one of the first and second ferromagnetic material layers comprises CoFeB alloy.

8. A magnetoresistive device having a tunnel barrier junction structure, the magnetoresistive device comprising:

a first ferromagnetic material layer deposited on a substrate;

a second ferromagnetic material layer; and

a tunnel barrier layer located between the first and second ferromagnetic material layers, and

wherein the tunnel barrier layer comprises a single-crystalline magnesium oxide in which a (001) crystal plane is preferentially oriented or a poly-crystalline magnesium oxide in which a (001) crystal plane is preferentially oriented, and

wherein at least the first ferromagnetic material layer comprises an iron-based alloy and is crystallized.

9. The magnotoresistive device according to claim 8, wherein the second ferromagnetic material layer comprises an iron-based alloy and is crystallized.

10. A magnetoresistive device having a tunnel barrier junction structure, the magnetoresistive device comprising:

a first ferromagnetic material layer deposited on a substrate;

a second ferromagnetic material layer; and

a tunnel barrier layer located between the first and second

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ferromagnetic material layers, and

wherein the tunnel barrier layer comprises a single-crystalline magnesium oxide in which a (001) crystal plane is preferentially oriented or a poly-crystalline magnesium oxide in which a (001) crystal plane is preferentially oriented, and

wherein at least the first ferromagnetic material layer comprises an iron-based alloy and is entirely crystallized.

11. The magnetoresistive device according to claim 10, wherein the second ferromagnetic material layer comprises an iron-based alloy and is entirely crystallized.

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Abstract of the Disclosure

The output voltage of an MRAM is increased by means of an Fe(001)/MgO(001)/Fe(001) MTJ device, which is formed by microfabrication of a sample prepared as follows: A single-crystalline MgO (001) substrate is prepared. An epitaxial Fe(001) lower electrode (a first electrode) is grown on a MgO(001) seed layer at room temperature, followed by annealing under ultrahigh vacuum. A MgO(001) barrier layer is epitaxially formed on the Fe(001) lower electrode (the first electrode) at room temperature, using a MgO electron-beam evaporation. A Fe(001) upper electrode (a second electrode) is then formed on the MgO(001) barrier layer at room temperature. This is successively followed by the deposition of a Co layer on the Fe(001) upper electrode (the second electrode). The Co layer is provided so as to increase the coercive force of the upper electrode in order to realize an antiparallel magnetization alignment.

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FIG. 1 (A)

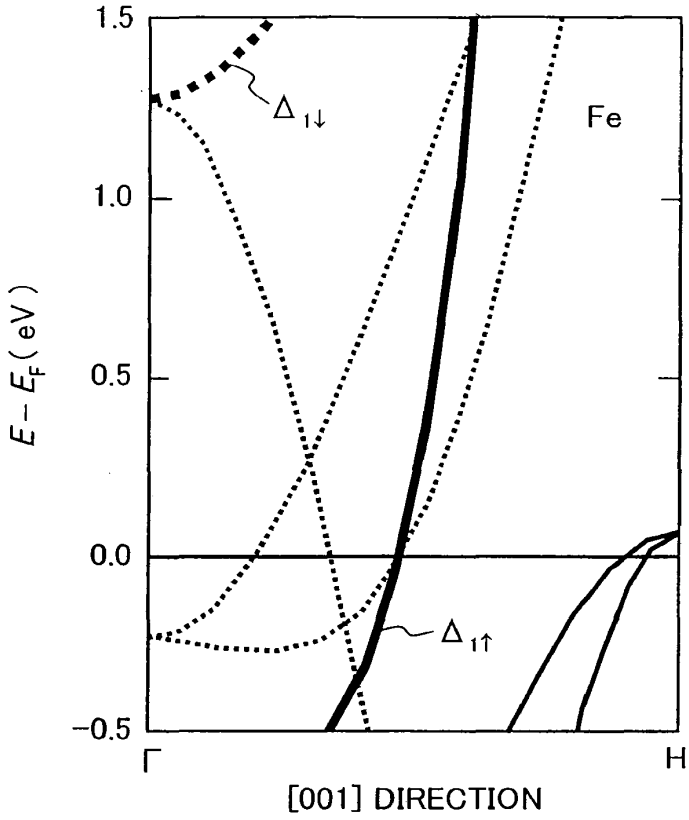

1.5
1.0
0.5
0.0
−0.5
$E - E_F$ (eV)
$\Delta_{1\downarrow}$
$\Delta_{1\uparrow}$
Fe
Γ
H
[001] DIRECTION

FIG. 1 (B)

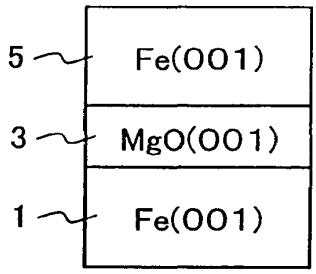

5
Fe(001)
3
MgO(001)
1
Fe(001)

FIG. 2 (A)

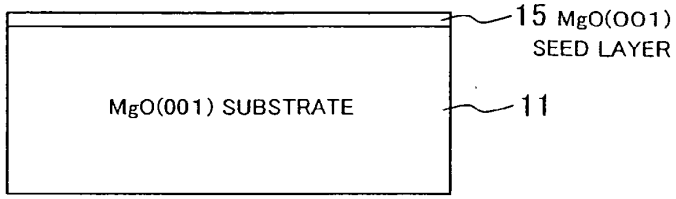


FIG. 2 (B)

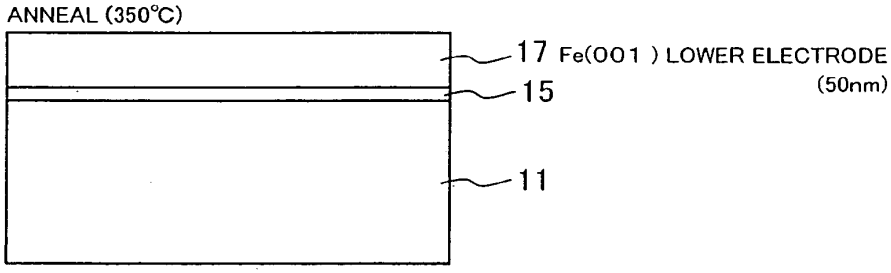


FIG. 2 (C)

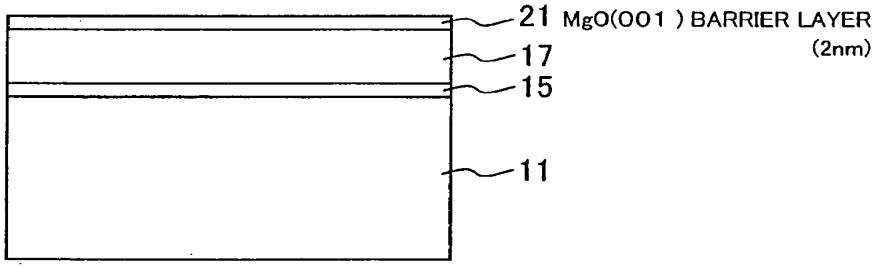


FIG. 2 (D)

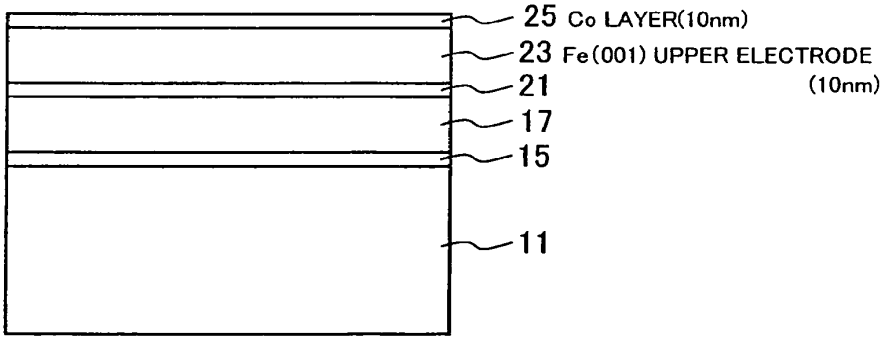


FIG. 3 (A)

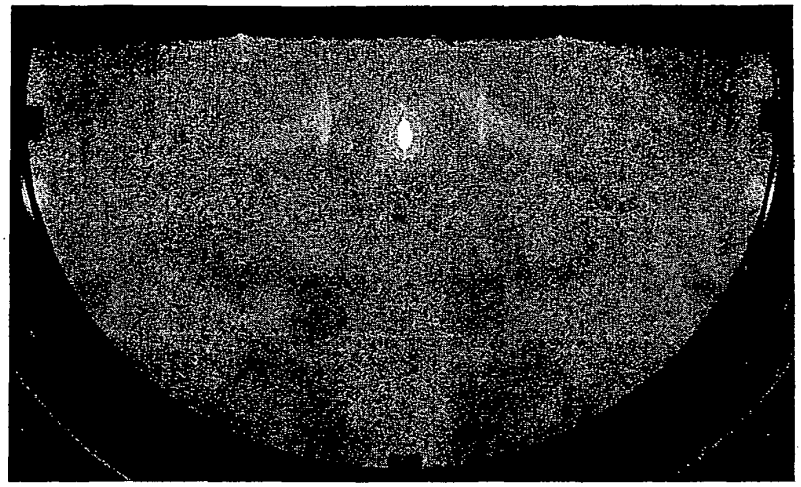


FIG. 3 (B)

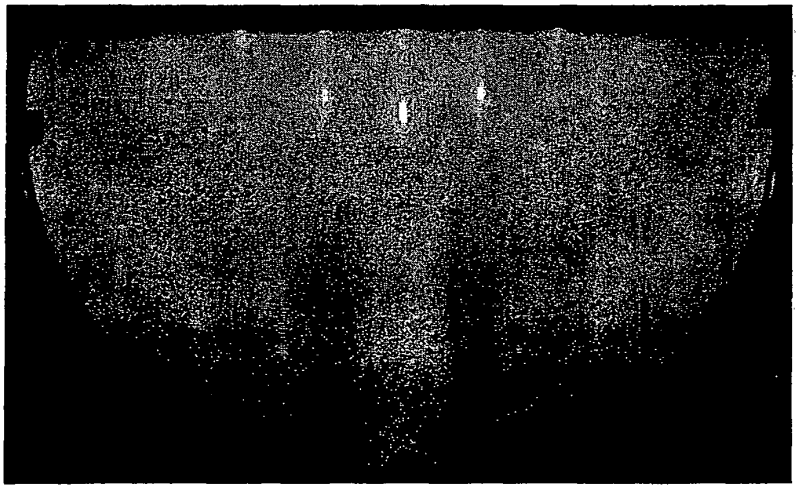
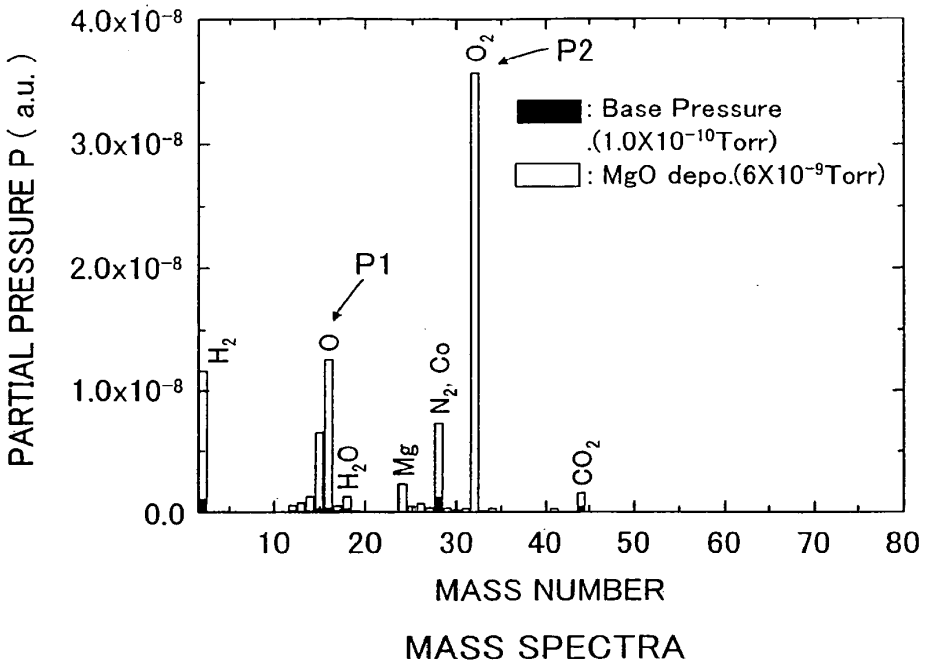
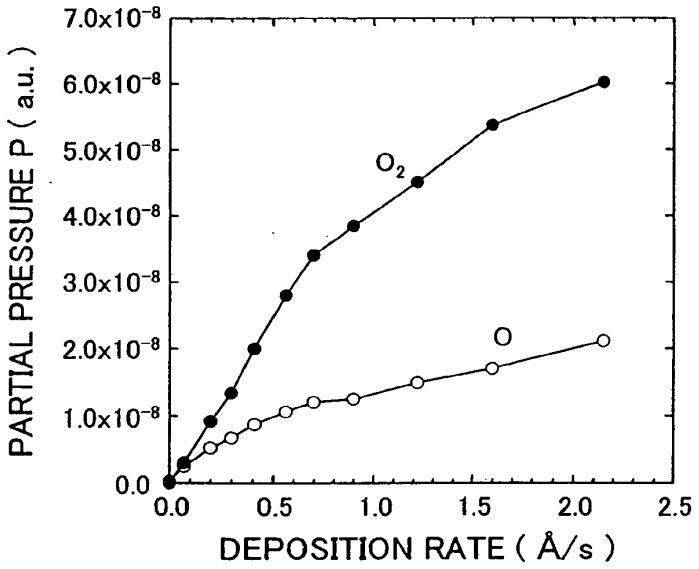


FIG. 4



MASS SPECTRA

FIG. 5



OXYGEN PARTIAL PRESSURE DURING MgO EVAPORATION

FIG. 6

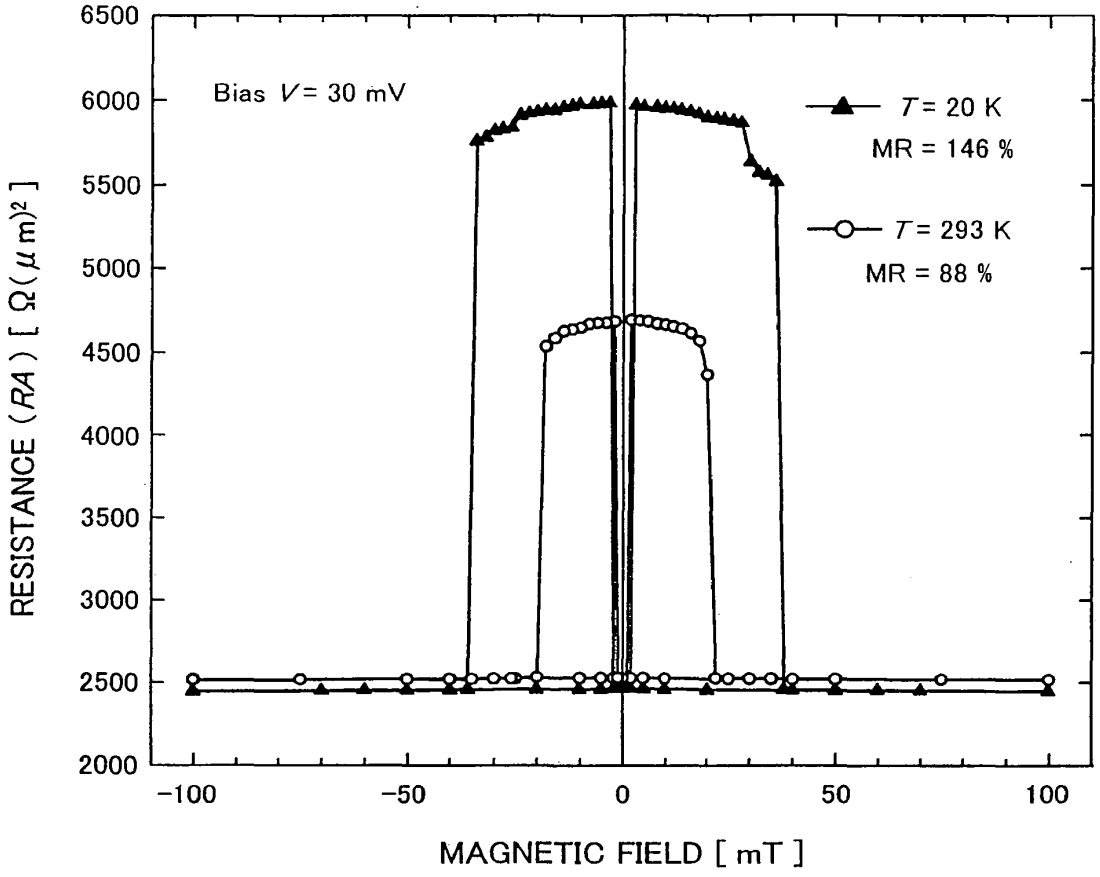

Bias V = 30 mV
T = 20 K
MR = 146 %
T = 293 K
MR = 88 %
RESISTANCE (RA) [Ω(μm)²]
MAGNETIC FIELD [mT]
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
−100
−50
0
50
100

FIG. 7 (A)

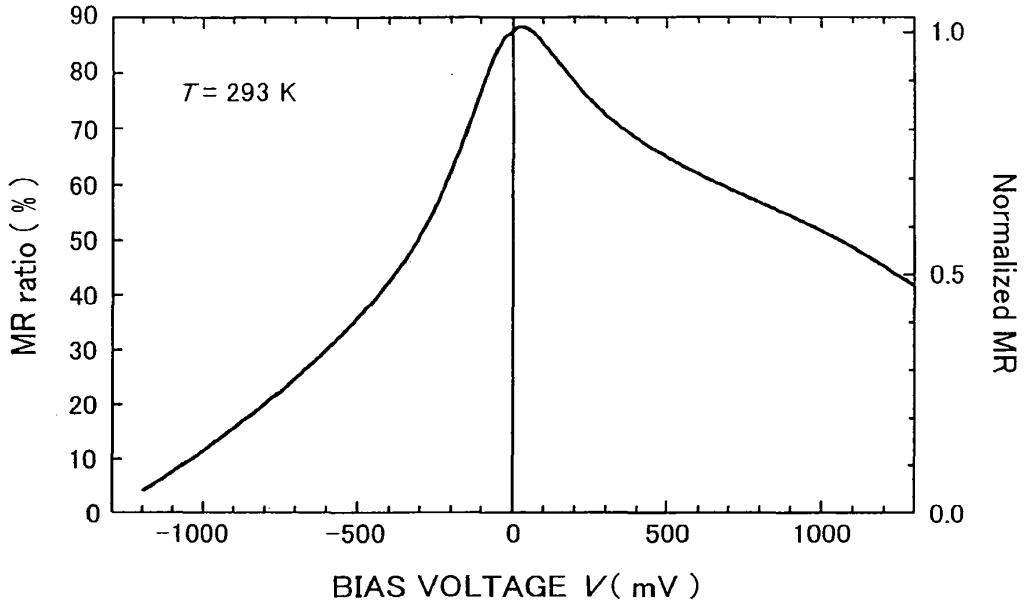

T = 293 K
MR ratio (%)
Normalized MR
BIAS VOLTAGE V (mV)
90
80
70
60
50
40
30
20
10
0
1.0
0.5
0.0
-1000
-500
0
500
1000

FIG. 7 (B)

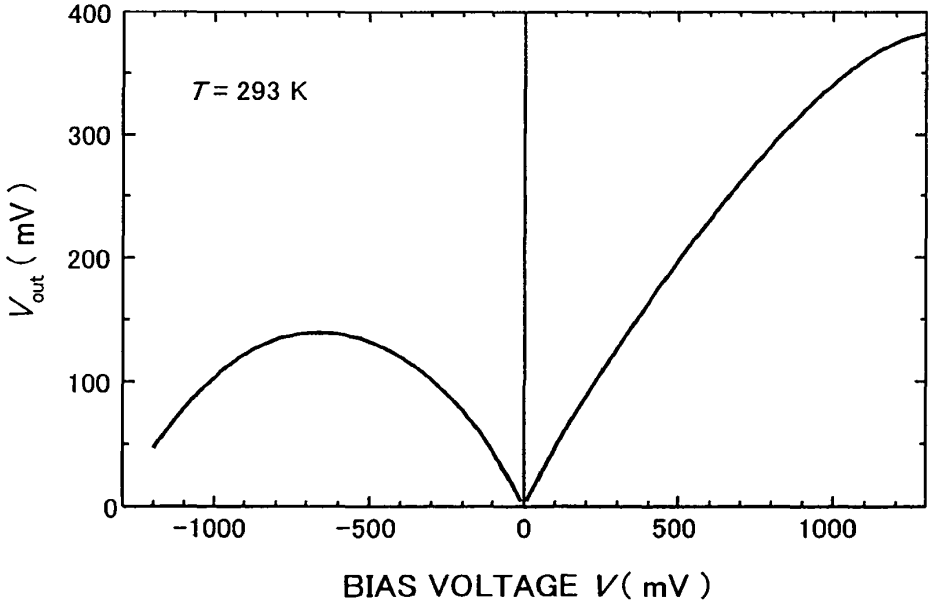
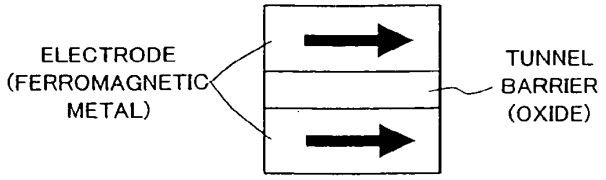
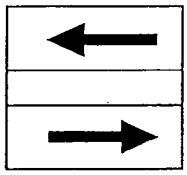

T = 293 K
V_{out} (mV)
BIAS VOLTAGE V (mV)
400
300
200
100
0
-1000
-500
0
500
1000

FIG. 8 (A)



Prior Art

FIG. 8 (B)



Prior Art

FIG. 9 (A)

Prior Art

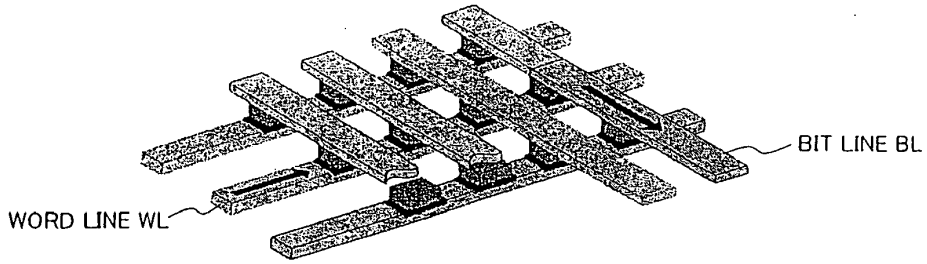


FIG. 9 (B)

Prior Art

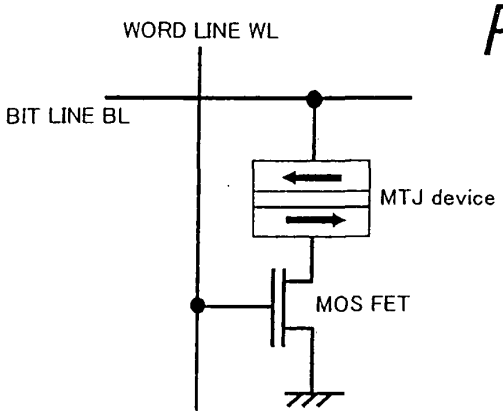
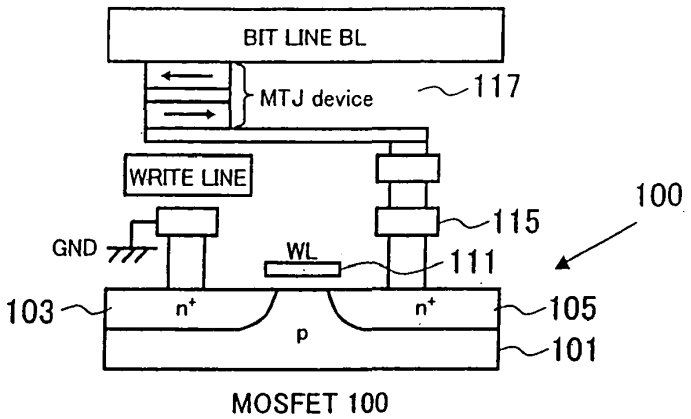


FIG. 9 (C)

Prior Art



MOSFET 100

FIG. 10

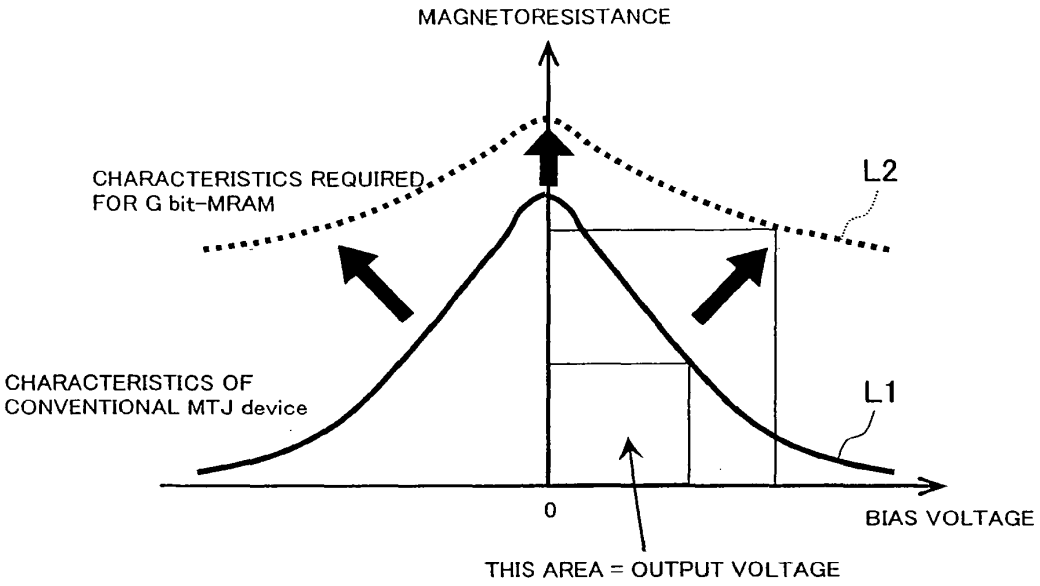
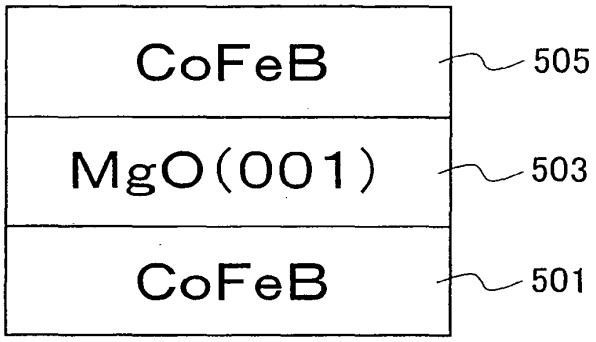

MAGNETORESISTANCE
CHARACTERISTICS REQUIRED FOR G bit-MRAM
L2
CHARACTERISTICS OF CONVENTIONAL MTJ device
L1
0
BIAS VOLTAGE
THIS AREA = OUTPUT VOLTAGE

FIG. 11



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
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005

CONFIRMATION NO. 2082

38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

FORMALITIES LETTER

OC000000059695861

Date Mailed: 03/14/2013

NOTICE TO FILE CORRECTED APPLICATION PAPERS

Filing Date Granted

An application number and filing date have been accorded to this application. The application is informal since it does not comply with the regulations for the reason(s) indicated below. Applicant is given TWO MONTHS from the date of this Notice within which to correct the informalities indicated below. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

The required item(s) identified below must be timely submitted to avoid abandonment:

- A substitute specification in compliance with 37 CFR 1.52, 1.121(b)(3), and 1.125, is required. The substitute specification must be submitted with markings and be accompanied by a clean version (without markings) as set forth in 37 CFR 1.125(c) and a statement that the substitute specification contains no new matter (see 37 CFR 1.125(b)). The specification, claims, and/or abstract page(s) submitted is not acceptable and cannot be scanned or properly stored because:
  - The application contains drawings, but the specification does not contain a brief description of the several views of the drawings as required by 37 CFR 1.74 and 37 CFR 1.77(b)(7).
- Replacement drawings in compliance with 37 CFR 1.84 and 37 CFR 1.121(d) are required. The drawings submitted are not acceptable because:
  - More than one figure is present and each figure is not labeled "Fig." with a consecutive Arabic numeral (1, 2, etc.) or an Arabic numeral and capital letter in the English alphabet (A, B, etc.)(see 37 CFR 1.84(u)(1)). See Figure(s) 8. A brief description of the several views of the drawings (see 37 CFR 1.74) should be added or amended to correspond to the corrected numbering of the figures. See also 37 CFR 1.77(b)(7).

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- A surcharge (for late submission of the basic filing fee, search fee, examination fee or inventor's oath or declaration) as set forth in 37 CFR 1.16(f) of $ **130** for a non-small entity, must be submitted.

SUMMARY OF FEES DUE:

Total fee(s) required within **TWO MONTHS** from the date of this Notice is $ **130** for a non-small entity
- $ **130** Surcharge.

Items Required To Avoid Processing Delays:

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).

- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
  All
  Applicant may submit the inventor's oath or declaration at any time before the Notice of Allowance and Fee(s) Due, PTOL-85, is mailed.

Replies must be received in the USPTO within the set time period or must include a proper Certificate of Mailing or Transmission under 37 CFR 1.8 with a mailing or transmission date within the set time period. For more information and a suggested format, see Form PTO/SB/92 and MPEP 512.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

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If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/afessehaye/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/767,290

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			N/A	390
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	620
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	250
TOTAL CLAIMS (37 CFR 1.16(i))	11 minus 20 =	*			OR	x 62 =	0.00
INDEPENDENT CLAIMS (37 CFR 1.16(h))	4 minus 3 =	* 1				x 250 =	250
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			TOTAL	1510

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
13/767,290	02/14/2013	2686	1510	NAGI-0005	11	4

CONFIRMATION NO. 2082

38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

FILING RECEIPT

OC000000059695860

Date Mailed: 03/14/2013

Receipt is acknowledged of this non-provisional 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 APPLICANT, 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 Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections 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**

Inventor(s)
Shinji YUASA, Ibaraki, JAPAN;

Applicant(s)
Japan Science and Technogy Agency, Kawaguchi-shi, JAPAN

Assignment For Published Patent Application
Japan Science and Technology Agency, Kawaguchi-shi, JAPAN

Power of Attorney: None

Domestic Priority data as claimed by applicant
This application is a CON of 13/400,340 02/20/2012 PAT 8405134
which is a CON of 12/923,643 09/30/2010 PAT 8319263
which is a CON of 10/591,947 09/08/2006 PAT 7884403
which is a 371 of PCT/JP2005/004720 03/10/2005

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)
JAPAN 2004-313350 10/28/2004
JAPAN 2004-071186 03/12/2004

Request to Retrieve - This application either claims priority to one or more applications filed in an intellectual property Office that participates in the Priority Document Exchange (PDX) program or contains a proper **Request to Retrieve Electronic Priority Application(s)** (PTO/SB/38 or its equivalent). Consequently, the USPTO will attempt to electronically retrieve these priority documents.

If Required, Foreign Filing License Granted: 03/05/2013

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/767,290**

Projected Publication Date: To Be Determined - pending completion of Corrected Papers

Non-Publication Request: No

Early Publication Request: No

Title

Magnetic Tunnel Junction Device

Preliminary Class

360

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	
YUASA	)	
	)	**Confirmation No. 2082**
Application Number: 13/767,290	)	
	)	
Filed: February 14, 2013	)	
	)	
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
Attorney Docket No. NAGI-0005	)	

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

LETTER

Sir:

The below-identified communications are submitted in the above-captioned application or proceeding:

(X) Response to Notice to File Corrected Application Papers
(X) Marked Up and Clean version of Specification

(X) The Commissioner is hereby authorized to charge payment of any fees associated with this communication, including fees under 37 C.F.R. § 1.16 and 1.17 or credit any overpayment to **Deposit Account Number 12-0555.**

Respectfully submitted,

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March 25, 2013

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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RESPONSE TO NOTICE TO FILE CORRECTED APPLICATION PAPERS

Upon a review of the Notice to File Corrected Application Papers mailed on March 14, 2013, advising us to correct the specification, submitted herewith are Marked-Up and Clean specifications to comply with the requirements.

The Notice was dated March 14, 2013, the period for response to which is set to expire on May 14, 2013. No fee is required.

Please direct any inquiries in connection with this application to the undersigned.

Respectfully submitted,

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March 25, 2013

SUBSTITUTE SPECIFICATION (Clean Version)

MAGNETIC TUNNEL JUNCTION DEVICE

[0001] CROSS-REFERENCE TO RELATED APPLICATION

[0002] The present application is a Continuation of U.S. Application 13/400,340 filed on February 20, 2012, which is a Continuation of U.S. Application 12/923,643 filed on September 30, 2010, which is a Continuation of U.S. Application 10/591,947 filed on September 8, 2006, which is a National Stage Application of PCT/JP2005/004720 filed on March 10, 2005. Priority is claimed from U.S. Application 13/400,340 filed on February 20, 2012, which claims priority from U.S. Application 12/923,643 filed on September 30, 2010, which claims priority from U.S. Application 10/591,947 filed on September 8, 2006, which claims priority from PCT/JP2005/004720 filed on March 10, 2005, which claims priority from Japanese Application Nos. 2004-313350 and 2004-071186 filed October 28, 2004 and March 12, 2004, respectively, the content of which is hereby incorporated by reference into this application.

[0003] BACKGROUND OF THE INVENTION

[0004] Field of the Invention

[0005] The present invention relates to a magnetic tunnel junction device and a method of manufacturing the same, particularly to a magnetic tunnel

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junction device with a high magnetoresistance and a method of manufacturing the same.

[0006] Description of Related Art

[0007] Magnetoresistive random access memories (MRAMs) refer to a large-scale integrated memory circuit that is expected to replace the currently widely used DRAM memories. Research and development of MRAM devices, which are fast and non-volatile memory devices, are being extensively carried out, and sample products of a 4Mbit MRAM have actually been delivered.

[0008] Figs. 8(A) and 8(B) show the structure and operation principle of a magnetic tunnel junction device (to be hereafter referred to as a "MTJ device"), which is the most important part of the MRAM. As shown in Fig. 8(A), a MTJ device comprises a tunnelling junction structure in which a tunnel barrier (to be hereafter also referred to as a "barrier layer") made of an oxide is sandwiched between a first and a second electrode made of a ferromagnetic metal. The tunnel barrier layer comprises an amorphous Al-O layer (see Non-Patent Document 1). As shown in Fig. 8(A), in the case of parallel magnetization alignment where the directions of magnetizations of the first and second ferromagnetic electrodes are aligned parallel, the electric resistance of the device with respect to the direction normal to the interfaces of the tunneling junction structure decreases. On the other hand, in the case of antiparallel magnetization alignment where the directions of magnetizations of the first and second ferromagnetic electrodes are aligned

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antiparallel as shown in Fig. 8(B), the electric resistance with respect to the direction normal to the interfaces of the tunneling junction structure increases. The resistance value does not change in a general state, so that information "1" or "0" can be stored depending on whether the resistance value is high or not. Since the parallel and antiparallel magnetization alignments can be stored in a non-volatile fashion, the device can be used as a non-volatile memory device.

[0009] Fig. 9 shows an example of the basic structure of the MRAM. Fig. 9(A) shows a perspective view of the MRAM, and Fig. 9(B) schematically shows a circuit block diagram. Fig. 9(C) is a cross-section of an example of the structure of the MRAM. Referring to Fig. 9(A), in an MRAM, a word line WL and a bit line BL are disposed in an intersecting manner, with an MRAM cell disposed at each intersection. As shown in Fig. 9(B), the MRAM cell disposed at the intersection of a word line and a bit line comprises a MTJ device and a MOSFET directly connected to the MTJ device. Stored information can be read by reading the resistance value of the MTJ device that functions as a load resistance, using the MOSFET. The stored information can be rewritten by applying a magnetic field to the MTJ device, for example. As shown in Fig. 9(C), an MRAM memory cell comprises a MOSFET 100 including a source region 105 and a drain region 103 both formed inside a p-type Si substrate 101, and a gate electrode 111 formed on a channel region that is defined between the source and drain regions. The MRAM also comprises a MTJ device 117. The source region 105 is grounded, and the drain is connected to

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a bit line BL via the MTJ device. A word line WL is connected to the gate electrode 111 in a region that is not shown.

[0010] Thus, a single non-volatile MRAM memory cell can be formed by a single MOSFET 100 and a single MTJ device 117. The MRAMs are therefore suitable where high levels of integration are required.

[0011] Non-Patent Document 1: D. Wang, et al.: Science 294 (2001) 1488.

[0012] SUMMARY OF THE INVENTION

[0013] Although there are prospects for achieving MRAMs with capacities on the order of 64Mbits based on the current technologies, the characteristics of the MTJ device, which is the heart of MRAM, needs to be improved if higher levels of integration are to be achieved. In particular, in order to increase the output voltage of the MTJ device, the magnetoresistance must be increased and the bias voltage characteristics must be improved. Fig. 10 illustrates how the magnetoresistance in a conventional MTJ device using an amorphous Al-O as the tunnel barrier changes as a function of the bias voltage (L1). As shown, in the conventional MTJ device, the magnetoresistance is small and, notably, it tends to drastically decrease upon application of bias voltage. With such characteristics, the output voltage when operation margins are taken into consideration is too small for the device to be employed for an actual memory device. Specifically, the magnetoresistance of the current MTJ device is small at approximately 70%,

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and the output voltage is also small at no more than 200 mV, which is substantially half the output voltage of a DRAM. This has resulted in the problem that as the level of integration increases, signals are increasingly lost in noise and cannot be read.

[0014] It is an object of the invention to increase the output voltage of a MTJ device. It is another object of the invention to provide a memory device with a high magnetoresistance for stable operation.

[0015] In one aspect, the invention provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising: a tunnel barrier layer; a first ferromagnetic material layer of the BCC structure formed on a first side of the tunnel barrier layer; and a second ferromagnetic material layer of the BCC structure formed on a second side of the tunnel barrier layer, wherein the tunnel barrier layer is formed by a single-crystal MgO_x (001) layer or a poly-crystalline MgO_x ($0 < x < 1$) layer in which the (001) crystal plane is preferentially oriented.

[0016] The invention further provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising: a tunnel barrier layer comprising MgO(001); a first ferromagnetic material layer comprising Fe(001) formed on a first side of the tunnel barrier layer; and a second ferromagnetic material layer comprising Fe(001) formed on a second side of the tunnel barrier layer, wherein the MgO layer is formed by a single-crystalline MgO_x (001) layer or a poly-crystalline MgO_x ($0 < x < 1$) layer in which the (001) crystal plane is preferentially oriented. In a

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preferred embodiment, the band discontinuity value (the height of the tunnel barrier) between the bottom of the conduction band of the MgO(001) layer and the Fermi energy of the Fe(001) layer is smaller than an ideal value of a perfect single-crystal without defect. These features increase the magnetoresistance and thereby allow the output voltage of the MTJ device to be increased. By using any of the aforementioned MTJ devices as a load for a single transistor, a non-volatile memory can be formed.

[0017] In another aspect, the invention provides a method of manufacturing a magnetoresistive device comprising: preparing a substrate; depositing a first Fe(001) layer on the substrate; depositing a tunnel barrier layer on the first Fe(001) layer by electron beam evaporation under high vacuum, the tunnel barrier layer comprising a single-crystalline MgO_x (001) or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented; and forming a second Fe(001) layer on the tunnel barrier layer.

[0018] The invention furthermore provides a method of manufacturing a MTJ device comprising a first step of preparing a substrate comprising a single-crystalline MgO_x(001) or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented, a second step of depositing a first Fe(001) layer on the substrate and performing an annealing process to make the surface flat, a third step of depositing a tunnel barrier layer on the first Fe(001) layer by electron beam evaporation, the tunnel barrier layer comprising a single-crystalline MgO_x(001) or a poly-crystalline MgO_x ($0 < x <$

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1) in which the (001) crystal plane is preferentially oriented, and a fourth step of forming a second Fe(001) layer on the tunnel barrier layer. The method may further comprise the step of growing a seed layer between the first and the second steps, the seed layer comprising a single-crystalline $MgO_x(001)$ or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented. The MgO layer may be deposited using a target with the value of x in MgO_x adjusted. The value of x in MgO_x may be adjusted in the step of forming the MgO.

[0019] In yet another aspect, the invention provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising a tunnel barrier layer comprising MgO(001), a first ferromagnetic material layer comprising an amorphous magnetic alloy formed on a first sideof the tunnel barrier layer, and a second ferromagnetic material layer comprising an amorphous magnetic alloy formed on a second side of the tunnel barrier layer, wherein the discontinuous value (the height of the tunnel barrier) between the bottom of the conduction band of the MgO(001) layer and the Fermi energy of the first or the second ferromagnetic material layer comprising the amorphous magnetic alloy is lower than an ideal value of a perfect single-crystal with no defect.

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[0020] BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Fig. 1(B) shows the structure of a MTJ device according to a first embodiment of the invention, and Fig. 1(A) shows the energy band structure of a ferromagnetic metal Fe(001), illustrating the E-E_F relationship with respect to the [001] direction of the momentum space.

[0022] Fig. 2(A) to Fig. 2(D) schematically show the process of manufacturing a MTJ device with a Fe(001)/MgO(001)/Fe(001) structure (to be hereafter referred to as a "Fe(001)/MgO(001)/Fe(001) MTJ device") according to an embodiment of the invention.

[0023] Fig. 3(A) shows a RHEED image of a Fe(001) lower electrode (a first electrode), and Fig. 3(B) shows a RHEED image of a MgO(001) barrier layer.

[0024] Fig. 4 shows the results of observing the quadrupole mass spectra in the deposition chamber during the MgO evaporation.

[0025] Fig. 5 shows the film deposition rate dependency of the oxygen partial pressure during the MgO evaporation.

[0026] Fig. 6 shows typical magnetoresistance curves of the Fe(001)/MgO(001)/Fe(001) MTJ device.

[0027] Fig. 7(A) shows the bias voltage dependency of the MR ratio at room temperature, and Fig. 7(B) shows the output voltage V_{out} of the MTJ device (=bias voltage × (Rap-Rp)/Rap).

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[0028] Figs. 8(A) and 8(B) show the structure of the MTJ device and its operating principle.

[0029] Fig. 9 shows an example of the basic structure of an MRAM, Fig. 9(A) showing a perspective view of the MRAM, Fig. 9(B) showing a schematic circuit diagram, and Fig. 9(C) showing a cross-sectional view of an example of its structure.

[0030] Fig. 10 shows how the magnetoresistance of a conventional MTJ device using an amorphous Al-O as the tunnel barrier changes depending on the bias voltage.

[0031] Fig. 11 shows the structure of a MTJ device according to a variation of the invention, corresponding to Fig. 1(B).

[0032] DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0033] In the context of the present specification, because MgO has a cubic crystal structure (NaCl structure), the (001) plane, the (100) plane, and the (010) plane are all equivalent. The direction perpendicular to the film surface is herein considered to be the z-axis so that the film plane can be uniformly described as (001). Also in the context of the present specification, BCC structure, which the crystalline structure of ferromagnetic electrode layer, means body-centered cubic lattice structure. More specifically, BCC structure includes the BCC structure with no chemical ordering so-called A2-type structure, the BCC structure with chemical ordering such as B2-type

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structre and $L2_1$-type structure, and also the aforementioned structures with slight lattice distortion.

[0034] The term "ideal value" with regard to a perfect single-crystal without defect herein refers to a value that has been estimated from ultraviolet photoemission spectroscopy experiments (see W. Wulfhekel, et al.: Appl. Phys. Lett. 78 (2001) 509.). The term "ideal value" is used herein because the aforementioned state can be considered to be an upper limit value of the potential barrier height of the tunnel barrier of an ideal single-crystal MgO with hardly any oxygen vacancy defect or lattice defect.

[0035] Before describing the preferred embodiments of the invention, an analysis conducted by the inventors is discussed. The magnetoresistance (MR) ratio of a MTJ device can be expressed by the following equation:

[0036] $\Delta R/Rp = (Rap - Rp)/Rp$

[0037] where Rp and Rap indicate the tunnel junction resistance in the cases of parallel and antiparallel magnetization alignments, respectively, of two electrodes. According to the Jullire's formula, the MR ratio at low bias voltage can be expressed by:

[0038] MR ratio $= (Rap - Rp)/Rp = 2P_1P_2/(1-P_1P_2)$, and

[0039] $P\alpha = (D\alpha \uparrow (E_F) - D\alpha \downarrow (E_F))/(D\alpha \uparrow (E_F) + D\alpha \downarrow (E_F))$,

[0040] where $\alpha = 1, 2$ (1)

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[0041] In the above equations, $P\alpha$ is the spin polarization of an electrode, and $D\alpha \uparrow (E_F)$ and $D\alpha \downarrow (E_F)$ are the density of state (DOS) at the Fermi energy (E_F) of the majority-spin band and the minority-spin band, respectively. Since the spin polarization of ferromagnetic transition metals and alloys is approximately 0.5 or smaller, the Jullire's formula predicts a highest estimated MR ratio of about 70%.

[0042] Although the MR ratio of approximately 70% has been obtained at room temperature when a MTJ device was made using an amorphous Al-O tunnel barrier and polycrystalline electrodes, it has been difficult to obtain the output voltage of 200 mV, which is comparable to the output voltages of DRAMs, thereby preventing the realization of MRAM as mentioned above.

[0043] The inventors tried an approach to deposit a MTJ device in which the tunnel barrier comprises a single-crystal (001) of magnesium oxide (MgO) or a poly-crystalline MgO in which the (001) crystal plane is preferentially oriented. It is the inventors' theory that, because magnesium oxide is a crystal (where the atoms are arranged in an orderly fashion), as opposed to the conventional amorphous Al-O barrier, the electrons are not scattered and the coherent states of electrons are concerved during the tunneling process. Fig. 1(B) shows the MTJ device structure according to an embodiment of the invention. Fig. 1(A) shows the energy band structure of the ferromagnetic Fe(001), that is, the $E\text{-}E_F$ relationship with respect to the [001] direction of the momentum space. As shown in Fig. 1(B), the MTJ device structure of the present embodiment comprises a first Fe (001) layer 1, a second Fe (001)

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layer 5, and a single-crystalline MgO_x (001) layer 3 or a poly-crystalline MgO_x ($0 < x < 1$) layer 3 sandwiched therebetween, the polycrystalline layer having the (001) crystal plane preferentially oriented therein. According to the aforementioned Jullire's model, assuming that the momentum of the conduction electrons is preserved in the tunneling process, the tunneling current that passes through MgO would be dominated by those electrons with wave vector k_z in the direction perpendicular to the tunnel barrier (normal to the junction interfaces). In accordance with the energy band diagram shown in Fig. 1(A) of Fe in the [001] (Γ-H) direction, the density of state (DOS) at the Fermi energy E_F does not exhibit a very high spin polarization due to the fact that the sub-bands of the majority-spin and the minority-spin have states at the Fermi energy E_F. However, in case the coherent states of electrons are conserved in the tunneling process, only those conduction electrons that have totally symmetrical wave functions with respect to the axis perpendicular to the barrier would be coupled with the states in the barrier region and come to have a finite tunneling probability. The $\Delta 1$ band in the Fe(001) electrode has such totally symmetric wave functions. As shown in Fig. 1(A), the majority spin $\Delta 1$ band (solid line) has states at the Fermi energy E_F, whereas the minority spin $\Delta 1$ band (broken line) does not have state at the Fermi energy E_F. Because of such half-metallic characteristics of the Fe Δ_1 band, there is the possibility that a very high MR ratio can be obtained in a coherent spin polarized tunneling. Since in an epitaxial (single-crystal, or (001) oriented poly-crystal) MTJ device the scattering of electrons is suppressed during the

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tunneling process, an epitaxial MTJ device is thought to be ideal for realizing the aforementioned coherent tunneling.

[0044] In the following, a MTJ device according to a first embodiment of the invention and a method of manufacturing the same will be described with reference to the drawings. Figs. 2(A) to 2(D) schematically show the method of manufacturing the MTJ device having the Fe (001)/MgO(001)/Fe(001) structure according to the embodiment (to be hereafter referred to as a "Fe(001)/MgO(001)/Fe(001) MTJ device"). Fe(001) refers to a ferromagnetic material with the BCC structure. First, a single-crystal MgO(001) substrate 11 was prepared. In order to improve the morphology of the surface of the single-crystal MgO(001) substrate 11, a MgO(001) seed layer 15 was grown by the molecular beam epitaxy (MBE) method. This was subsequently followed by the growth of an epitaxial Fe(001) lower electrode (first electrode) 17 with the thickness of 50 nm on the MgO(001) seed layer 15 at room temperature, as shown in Fig. 1(B), and then annealing was performed at 350°C under ultrahigh vacuum (2×10^{-8} Pa). Electron-beam evaporation conditions included an acceleration voltage of 8 kV, a growth rate of 0.02 nm/sec, and the growth temperature of room temperature (about 293K). The source material of the electron-beam evaporation was MgO of the stoichiometric composition (the ratio of Mg to O being 1:1), the distance between the source and the substrate was 40 cm, the base vacuum pressure was 1×10^{-8} Pa, and the O_2 partial pressure was 1×10^{-6} Pa. Alternatively, a source with oxygen vacancy defects may be used instead of the MgO of the stoichiometric composition (the ratio of Mg to O is 1:1).

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[0045] Fig. 3(A) shows a RHEED image of the Fe(001) lower electrode (a first electrode). The image shows that the Fe(001) lower electrode (first electrode) 17 possesses a good crystallinity and flatness. Thereafter, a MgO(001) barrier layer 21 with the thickness of 2 nm was epitaxially grown on the Fe(001) lower electrode (first electrode) at room temperature, also using the MgO electron-beam evaporation method. Fig. 3(B) shows a RHEED image of the MgO(001) barrier layer 21. The image shows that the MgO(001) barrier layer 21 also possesses a good crystallinity and flatness.

[0046] As shown in Fig. 2(D), a Fe(001) upper electrode (a second electrode) 23 with the thickness of 10 nm was formed on the MgO(001) barrier layer 21 at room temperature. This was successively followed by the deposition of a Co layer 25 with the thickness of 10 nm on the Fe(001) upper electrode (second electrode) 23. The Co layer 25 is provided to increase the coercive force of the upper electrode 23 so as to realize the antiparallel magnetization alignment. The thus prepared sample was then processed by microfabrication techniques to obtain the Fe(001)/MgO(001)/Fe(001) MTJ device.

[0047] The aforementioned MgO evaporation using an electron beam involved the formation of a film under ultrahigh vacuum of 10^{-9} Torr. It can be seen that in this method, the film, even when formed on a glass substrate to the thickness of 300 nm, was colorless and transparent, showing that a good crystal film was formed. Fig. 4 shows the results of observing the quadrupole mass spectra in the deposition chamber during the MgO growth.

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The results show that the partial pressures regarding the spectrum P1 of O and the spectrum P2 of O_2 are high. Fig. 5 shows the film deposition rate dependency of the oxygen partial pressure during MgO evaporation. It will be seen from the figure that the oxygen partial pressure itself is high, and that the oxygen partial pressure increases as the deposition rate increases. These results indicate the separation of oxygen from MgO during the deposition of MgO. Since the separated oxygen is pumped out of the deposition chamber using vacuum pumps, there is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$). When there are oxygen vacancy defects, the potential barrier height of the MgO tunnel barrier is thought to decrease (such as in the range of 0.10 to 0.85 eV; more specifically, 0.2 to 0.5 eV), which is thought to result in an increase in the tunneling current. In the case of a typical Al-O tunnel barrier, the height of the tunnel barrier with respect to Fe(001) electrodes is considered to be 0.7 to 2.5 eV. An ideal tunnel barrier height of a MgO crystal is 3.6 eV, and experimental values of 0.9 to 3.7 eV have been obtained. Using the method according to the present embodiment of the invention, a tunnel barrier height of approximately 0.3 eV is expected, indicating that the resistance of the tunnel barrier can be lowered. However, it should be noted that other factors, such as the influence of the aforementioned coherent tunneling, might also be involved. The value of x in MgO_x due to oxygen vacancy defects is such that $0.98 < x < 1$, and more preferably $0.99 < x < 1$. These are the ranges such that the sole presence of Mg is excluded and the characteristics of MgO can be basically maintained.

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[0048] The aforementioned tunnel barrier height ϕ was determined by fitting the electric conductance characteristics of the MTJ device (the relationship between tunnel current density J and bias voltage V) onto the Simmons' formula (Equation (20) in a non-patent document by J. G. Simmons: J. Appl. Phys. 34, pp. 1793-1803 (1963)) based on the WKB approximation, using the least squares method. The fitting was performed using the free electron mass ($m = 9.11 \times 10^{-31}$ kg) as the electron's effective mass. When a bias voltage V (which is normally on the order of 500 mV to 1000 mV) is applied until non-linearity appears in the J-V characteristics, the height ϕ of the tunnel barrier and the effective thickness Δs of the tunnel barrier can be simultaneously determined by fitting the J-V characteristics using the Simmons' formula.

[0049] The effective thickness Δs of the tunnel barrier was determined to be smaller than the thickness of the actual MgO(001) tunnel barrier layer (t_{MgO}) determined from a cross-sectional transmission electron microscope image of the MTJ device by approximately 0.5 nm. This is the result of the effective thickness Δs of the tunnel barrier having been reduced from the actual MgO(001) layer thickness by the effect of the image potential produced at the interface between the MgO(001) layer and the alloy layer consisting mainly of Fe and Co.

[0050] It is noted that, in the event that t_{MgO} can be accurately determined using the cross-sectional transmission electron microscope (TEM) image, the height ϕ of the tunnel barrier can be more simply determined by the following

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technique. Namely, when the bias voltage V applied to the MTJ device is small (normally 100 mV or smaller), the tunnel current density J is proportional to the bias voltage V, such that the J-V characteristics become linear. In such a low-bias voltage region, the Simmons' formula can be described as follows:

[0051] $J = [(2m\phi)^{1/2}/\Delta s](e/h)^2 \times \exp[-(4\pi\Delta s/h) \times (2m\phi)^{1/2}] \times V$ (2)

[0052] where m is the mass of the free electron (9.11×10^{-31} kg), e is the elementary electric charge (1.60×10^{-19}C), and h is the Planck's constant (6.63×10^{-34} J·s). The effective thickness of the tunnel barrier Δs is approximately t_{MgO} – 0.5 nm. By fitting the J-V characteristics of the MTJ device in the low-bias voltage region onto Equation (2), the height ϕ of the tunnel barrier can be simply and yet accurately estimated.

[0053] Fig. 6 shows a typical magnetoresistance curve of the Fe(001)/MgO(001)/Fe(001) MTJ device produced by the above-described method. The MR ratio is 146% at the measurement temperature of 20K and 88% at the measurement temperature of 293K. These values represent the highest MR ratios that have so far been obtained at room temperature. Such high MR ratios cannot be explained by the spin polarization of the Fe(001) electrode and is thought rather to be related to a coherent spin-polarized tunneling. When 160 prototype MTJ devices were made, the variations regarding the MR ratio and tunneling resistance value were not more than 20%. The yield of the MTJ devices was 90% or more at the laboratory stage. These high values suggest the effectiveness of the approach of the invention.

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The resistance-area (RA) product of the MTJ device was on the order of a few $k\Omega\mu m^2$, which is suitable for MRAM.

[0054] Fig. 7(a) shows the bias voltage dependency of the MR ratio at room temperature. It will be seen that the bias voltage dependency of the MR ratio is fairly small. Although the characteristics are asymmetric, the voltage V_{half} at which the MR ratio is reduced in half of the zero-bias value is 1250 mV, which is a very high value. In this connection, it is noted that the voltage V_{half} at which the MR ratio is reduced in half of the zero-bias value in the conventional MTJs with Al-O tunnel barrier is 300 to 600 mV. Fig. 7(b) shows the output voltage V_{out} of the MTJ device (=bias voltage × (Rap – Rp)/Rap). The maximum value of the output voltage V_{out} is 380 mV with a positive bias. This value is about twice as large as that (a little less than 200 mV) in the case of the Al-O barrier. These high values in terms of both MR ratio and output voltage suggest the effectiveness of the technique according to the present embodiment.

[0055] Although in the above-described embodiment Fe(001) of BCC was employed, an Fe alloy of BCC, such as an Fe-Co alloy, Fe-Ni alloy, or Fe-Pt alloy, may be used instead. Alternatively, a layer of Co or Ni with the thickness of one or several monoatomic layers may be inserted between the electrode layer and the MgO(001) layer.

[0056] Hereafter, a MTJ device according to a second embodiment of the invention and a method of manufacturing the same will be described. In the method of manufacturing a Fe(001)/MgO(001)/Fe(001) MTJ device according

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to the present embodiment, MgO(001) is initially deposited in a poly-crystalline or amorphous state by sputtering or the like, and then an annealing process is performed such that a poly-crystal in which the (001) crystal plane is preferentially oriented or a single-crystal is obtained. The sputtering conditions were such that, for example, the temperature was room temperature (293K), a 2-inch ϕ MgO was used as a target, and sputtering was conducted in an Ar atmosphere. The acceleration power was 200 W and the growth rate was 0.008 nm/s. Because MgO that is deposited under these conditions is in an amorphous state, a crystallized MgO was obtained by increasing the temperature to 300°C from room temperature and maintaining that temperature for a certain duration of time.

[0057] Oxygen vacancy defects may be introduced by a method whereby oxygen vacancy defects is produced during growth, a method whereby oxygen vacancy defects is introduced subsequently, or a method whereby a state with oxygen vacancy defects is subjected to an oxygen plasma process or natural oxidation so as to achieve a certain oxygen deficit level.

[0058] As described above, in accordance with the MTJ device technology of the present embodiment, an annealing process is carried out for crystallization after an amorphous MgO has been deposited by sputtering, thereby eliminating the need for large-sized equipment.

[0059] Hereafter, a MTJ device according to a variation of the embodiments of the invention will be described with reference to the drawings. Fig. 11 shows the structure of the MTJ device according to the variation, which

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corresponds to Fig. 1(B). As shown in Fig. 11, the MTJ device of the variation is characterized in that, as in the MTJ device of the above-described embodiments, the electrodes disposed on either side of a single-crystal $MgO_x(001)$ layer 503 or an oxygen-deficit poly-crystal MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented comprises an amorphous ferromagnetic alloy, such as CoFeB layers 501 and 505. The amorphous ferromagnetic alloy can be formed by evaporation or sputtering, for example. The resultant characteristics are substantially identical to those of the first embodiment.

[0060] As the amorphous magnetic alloy, FeCoB, FeCoBSi, FeCoBP, FeZr, and CoZr may be used, for example. Although an anneal process after the preparation of the MTJ device might cause the amorphous magnetic alloy in the electrode layers to be partially or entirely crystallized, this would not lead to a significant deterioration of the MR ratio. Thus, such a crystallized amorphous magnetic alloy may be used in the electrode layers.

[0061] While the MTJ device according to various embodiments of the invention has been described, it should be apparent to those skilled in the art that the invention is not limited to those specific embodiments and various other modifications, improvements and combinations are possible. For example, the height of the tunnel barrier may be adjusted by doping Ca or Sr, instead of introducing an oxygen vacancy defects to the MgO layer. Further, while the MgO layer has been described to be deposited by electron-beam evaporation or sputtering, it should be obvious that other deposition methods

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are also possible. The term "high vacuum" refers to values on the order of no more than 10^{-6} Pa in the case where oxygen is not introduced, for example. In the case where oxygen is introduced, the term refers to values on the order of 10^{-4} Pa.

[0062] In accordance with the invention, a larger magnetoresistance than in the conventional MTJ device can be obtained, and the output voltage of the MTJ device can be increased. At the same time, the resistance value of the MTJ device can be reduced so that it is optimized for MRAM. The invention thus enables the level of integration of MRAM using the MTJ device to be readily increased. In accordance with the invention, the output voltage value of the MRAM roughly doubles over prior art, making the MTJ device of the invention suitable for very large scale integrated MRAMs of gigabit class.

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SUBSTITUTE SPECIFICATION (Marked-up Version)

MAGNETIC TUNNEL JUNCTION DEVICE

[0001] CROSS-REFERENCE TO RELATED APPLICATION

[0002] The present application is a Continuation of U.S. Application 13/400,340 filed on February 20, 2012, which is a Continuation of U.S. Application 12/923,643 filed on September 30, 2010, which is a Continuation of U.S. Application 10/591,947 filed on September 8, 2006, which is a National Stage Application of PCT/JP2005/004720 filed on March 10, 2005. Priority is claimed from U.S. Application 13/400,340 filed on February 20, 2012, which claims priority from U.S. Application 12/923,643 filed on September 30, 2010, which claims priority from U.S. Application 10/591,947 filed on September 8, 2006, which claims priority from PCT/JP2005/004720 filed on March 10, 2005, which claims priority from Japanese Application Nos. 2004-313350 and 2004-071186 filed October 28, 2004 and March 12, 2004, respectively, the content of which is hereby incorporated by reference into this application.

[0003] BACKGROUND OF THE INVENTION

[0004] Field of the Invention

[0005] The present invention relates to a magnetic tunnel junction device and a method of manufacturing the same, particularly to a magnetic tunnel

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junction device with a high magnetoresistance and a method of manufacturing the same.

[0006] Description of Related Art

[0007] Magnetoresistive random access memories (MRAMs) refer to a large-scale integrated memory circuit that is expected to replace the currently widely used DRAM memories. Research and development of MRAM devices, which are fast and non-volatile memory devices, are being extensively carried out, and sample products of a 4Mbit MRAM have actually been delivered.

[0008] ~~Fig. 8 shows~~ Figs. 8(A) and 8(B) show the structure and operation principle of a magnetic tunnel junction device (to be hereafter referred to as a "MTJ device"), which is the most important part of the MRAM. As shown in Fig. 8(A), a MTJ device comprises a tunnelling junction structure in which a tunnel barrier (to be hereafter also referred to as a "barrier layer") made of an oxide is sandwiched between a first and a second electrode made of a ferromagnetic metal. The tunnel barrier layer comprises an amorphous Al-O layer (see Non-Patent Document 1). As shown in Fig. 8(A), in the case of parallel magnetization alignment where the directions of magnetizations of the first and second ferromagnetic electrodes are aligned parallel, the electric resistance of the device with respect to the direction normal to the interfaces of the tunneling junction structure decreases. On the other hand, in the case of antiparallel magnetization alignment where the directions of magnetizations of the first and second ferromagnetic electrodes are aligned

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antiparallel as shown in Fig. 8(B), the electric resistance with respect to the direction normal to the interfaces of the tunneling junction structure increases. The resistance value does not change in a general state, so that information "1" or "0" can be stored depending on whether the resistance value is high or not. Since the parallel and antiparallel magnetization alignments can be stored in a non-volatile fashion, the device can be used as a non-volatile memory device.

[0009] Fig. 9 shows an example of the basic structure of the MRAM. Fig. 9(A) shows a perspective view of the MRAM, and Fig. 9(B) schematically shows a circuit block diagram. Fig. 9(C) is a cross-section of an example of the structure of the MRAM. Referring to Fig. 9(A), in an MRAM, a word line WL and a bit line BL are disposed in an intersecting manner, with an MRAM cell disposed at each intersection. As shown in Fig. 9(B), the MRAM cell disposed at the intersection of a word line and a bit line comprises a MTJ device and a MOSFET directly connected to the MTJ device. Stored information can be read by reading the resistance value of the MTJ device that functions as a load resistance, using the MOSFET. The stored information can be rewritten by applying a magnetic field to the MTJ device, for example. As shown in Fig. 9(C), an MRAM memory cell comprises a MOSFET 100 including a source region 105 and a drain region 103 both formed inside a p-type Si substrate 101, and a gate electrode 111 formed on a channel region that is defined between the source and drain regions. The MRAM also comprises a MTJ device 117. The source region 105 is grounded, and the drain is connected to

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a bit line BL via the MTJ device. A word line WL is connected to the gate electrode 111 in a region that is not shown.

[0010] Thus, a single non-volatile MRAM memory cell can be formed by a single MOSFET 100 and a single MTJ device 117. The MRAMs are therefore suitable where high levels of integration are required.

[0011] Non-Patent Document 1: D. Wang, et al.: Science 294 (2001) 1488.

[0012] SUMMARY OF THE INVENTION

[0013] Although there are prospects for achieving MRAMs with capacities on the order of 64Mbits based on the current technologies, the characteristics of the MTJ device, which is the heart of MRAM, needs to be improved if higher levels of integration are to be achieved. In particular, in order to increase the output voltage of the MTJ device, the magnetoresistance must be increased and the bias voltage characteristics must be improved. Fig. 10 illustrates how the magnetoresistance in a conventional MTJ device using an amorphous Al-O as the tunnel barrier changes as a function of the bias voltage (L1). As shown, in the conventional MTJ device, the magnetoresistance is small and, notably, it tends to drastically decrease upon application of bias voltage. With such characteristics, the output voltage when operation margins are taken into consideration is too small for the device to be employed for an actual memory device. Specifically, the magnetoresistance of the current MTJ device is small at approximately 70%,

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and the output voltage is also small at no more than 200 mV, which is substantially half the output voltage of a DRAM. This has resulted in the problem that as the level of integration increases, signals are increasingly lost in noise and cannot be read.

[0014] It is an object of the invention to increase the output voltage of a MTJ device. It is another object of the invention to provide a memory device with a high magnetoresistance for stable operation.

[0015] In one aspect, the invention provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising: a tunnel barrier layer; a first ferromagnetic material layer of the BCC structure formed on a first side of the tunnel barrier layer; and a second ferromagnetic material layer of the BCC structure formed on a second side of the tunnel barrier layer, wherein the tunnel barrier layer is formed by a single-crystal MgO_x (001) layer or a poly-crystalline MgO_x ($0 < x < 1$) layer in which the (001) crystal plane is preferentially oriented.

[0016] The invention further provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising: a tunnel barrier layer comprising MgO(001); a first ferromagnetic material layer comprising Fe(001) formed on a first side of the tunnel barrier layer; and a second ferromagnetic material layer comprising Fe(001) formed on a second side of the tunnel barrier layer, wherein the MgO layer is formed by a single-crystalline MgO_x (001) layer or a poly-crystalline MgO_x ($0 < x < 1$) layer in which the (001) crystal plane is preferentially oriented. In a

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preferred embodiment, the band discontinuity value (the height of the tunnel barrier) between the bottom of the conduction band of the MgO(001) layer and the Fermi energy of the Fe(001) layer is smaller than an ideal value of a perfect single-crystal without defect. These features increase the magnetoresistance and thereby allow the output voltage of the MTJ device to be increased. By using any of the aforementioned MTJ devices as a load for a single transistor, a non-volatile memory can be formed.

[0017] In another aspect, the invention provides a method of manufacturing a magnetoresistive device comprising: preparing a substrate; depositing a first Fe(001) layer on the substrate; depositing a tunnel barrier layer on the first Fe(001) layer by electron beam evaporation under high vacuum, the tunnel barrier layer comprising a single-crystalline MgO_x (001) or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented; and forming a second Fe(001) layer on the tunnel barrier layer.

[0018] The invention furthermore provides a method of manufacturing a MTJ device comprising a first step of preparing a substrate comprising a single-crystalline MgO_x(001) or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented, a second step of depositing a first Fe(001) layer on the substrate and performing an annealing process to make the surface flat, a third step of depositing a tunnel barrier layer on the first Fe(001) layer by electron beam evaporation, the tunnel barrier layer comprising a single-crystalline MgO_x(001) or a poly-crystalline MgO_x ($0 < x <$

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1) in which the (001) crystal plane is preferentially oriented, and a fourth step of forming a second Fe(001) layer on the tunnel barrier layer. The method may further comprise the step of growing a seed layer between the first and the second steps, the seed layer comprising a single-crystalline $MgO_x(001)$ or a poly-crystalline MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented. The MgO layer may be deposited using a target with the value of x in MgO_x adjusted. The value of x in MgO_x may be adjusted in the step of forming the MgO.

[0019] In yet another aspect, the invention provides a magnetoresistive device comprising a magnetic tunnel junction structure comprising a tunnel barrier layer comprising MgO(001), a first ferromagnetic material layer comprising an amorphous magnetic alloy formed on a first sideof the tunnel barrier layer, and a second ferromagnetic material layer comprising an amorphous magnetic alloy formed on a second side of the tunnel barrier layer, wherein the discontinuous value (the height of the tunnel barrier) between the bottom of the conduction band of the MgO(001) layer and the Fermi energy of the first or the second ferromagnetic material layer comprising the amorphous magnetic alloy is lower than an ideal value of a perfect single-crystal with no defect.

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[0020] BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Fig. 1(B) shows the structure of a MTJ device according to a first embodiment of the invention, and Fig. 1(A) shows the energy band structure of a ferromagnetic metal Fe(001), illustrating the E-E_F relationship with respect to the [001] direction of the momentum space.

[0022] Fig. 2(A) to Fig. 2(D) schematically show the process of manufacturing a MTJ device with a Fe(001)/MgO(001)/Fe(001) structure (to be hereafter referred to as a "Fe(001)/MgO(001)/Fe(001) MTJ device") according to an embodiment of the invention.

[0023] Fig. 3(A) shows a RHEED image of a Fe(001) lower electrode (a first electrode), and Fig. 3(B) shows a RHEED image of a MgO(001) barrier layer.

[0024] Fig. 4 shows the results of observing the quadrupole mass spectra in the deposition chamber during the MgO evaporation.

[0025] Fig. 5 shows the film deposition rate dependency of the oxygen partial pressure during the MgO evaporation.

[0026] Fig. 6 shows typical magnetoresistance curves of the Fe(001)/MgO(001)/Fe(001) MTJ device.

[0027] Fig. 7(A) shows the bias voltage dependency of the MR ratio at room temperature, and Fig. 7(B) shows the output voltage V_{out} of the MTJ device (=bias voltage × (Rap-Rp)/Rap).

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[0028] ~~Fig. 8 shows~~ Figs. 8(A) and 8(B) show the structure of the MTJ device and its operating principle.

[0029] Fig. 9 shows an example of the basic structure of an MRAM, Fig. 9(A) showing a perspective view of the MRAM, Fig. 9(B) showing a schematic circuit diagram, and Fig. 9(C) showing a cross-sectional view of an example of its structure.

[0030] Fig. 10 shows how the magnetoresistance of a conventional MTJ device using an amorphous Al-O as the tunnel barrier changes depending on the bias voltage.

[0031] Fig. 11 shows the structure of a MTJ device according to a variation of the invention, corresponding to Fig. 1(B).

[0032] DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0033] In the context of the present specification, because MgO has a cubic crystal structure (NaCl structure), the (001) plane, the (100) plane, and the (010) plane are all equivalent. The direction perpendicular to the film surface is herein considered to be the z-axis so that the film plane can be uniformly described as (001). Also in the context of the present specification, BCC structure, which the crystalline structure of ferromagnetic electrode layer, means body-centered cubic lattice structure. More specifically, BCC structure includes the BCC structure with no chemical ordering so-called A2-type structure, the BCC structure with chemical ordering such as B2-type

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structre and $L2_1$-type structure, and also the aforementioned structures with slight lattice distortion.

[0034] The term "ideal value" with regard to a perfect single-crystal without defect herein refers to a value that has been estimated from ultraviolet photoemission spectroscopy experiments (see W. Wulfhekel, et al.: Appl. Phys. Lett. 78 (2001) 509.). The term "ideal value" is used herein because the aforementioned state can be considered to be an upper limit value of the potential barrier height of the tunnel barrier of an ideal single-crystal MgO with hardly any oxygen vacancy defect or lattice defect.

[0035] Before describing the preferred embodiments of the invention, an analysis conducted by the inventors is discussed. The magnetoresistance (MR) ratio of a MTJ device can be expressed by the following equation:

[0036] $\Delta R/Rp = (Rap - Rp)/Rp$

[0037] where Rp and Rap indicate the tunnel junction resistance in the cases of parallel and antiparallel magnetization alignments, respectively, of two electrodes. According to the Jullire's formula, the MR ratio at low bias voltage can be expressed by:

[0038] MR ratio $= (Rap - Rp)/Rp = 2P_1P_2/(1-P_1P_2)$, and

[0039] $P\alpha = (D\alpha \uparrow (E_F) - D\alpha \downarrow (E_F))/(D\alpha \uparrow (E_F) + D\alpha \downarrow (E_F))$,

[0040] where $\alpha = 1, 2$ (1)

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[0041] In the above equations, $P\alpha$ is the spin polarization of an electrode, and $D\alpha \uparrow (E_F)$ and $D\alpha \downarrow (E_F)$ are the density of state (DOS) at the Fermi energy (E_F) of the majority-spin band and the minority-spin band, respectively. Since the spin polarization of ferromagnetic transition metals and alloys is approximately 0.5 or smaller, the Jullire's formula predicts a highest estimated MR ratio of about 70%.

[0042] Although the MR ratio of approximately 70% has been obtained at room temperature when a MTJ device was made using an amorphous Al-O tunnel barrier and polycrystalline electrodes, it has been difficult to obtain the output voltage of 200 mV, which is comparable to the output voltages of DRAMs, thereby preventing the realization of MRAM as mentioned above.

[0043] The inventors tried an approach to deposit a MTJ device in which the tunnel barrier comprises a single-crystal (001) of magnesium oxide (MgO) or a poly-crystalline MgO in which the (001) crystal plane is preferentially oriented. It is the inventors' theory that, because magnesium oxide is a crystal (where the atoms are arranged in an orderly fashion), as opposed to the conventional amorphous Al-O barrier, the electrons are not scattered and the coherent states of electrons are concerved during the tunneling process. Fig. 1(B) shows the MTJ device structure according to an embodiment of the invention. Fig. 1(A) shows the energy band structure of the ferromagnetic Fe(001), that is, the $E\text{-}E_F$ relationship with respect to the [001] direction of the momentum space. As shown in Fig. 1(B), the MTJ device structure of the present embodiment comprises a first Fe (001) layer 1, a second Fe (001)

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layer 5, and a single-crystalline MgO_x (001) layer 3 or a poly-crystalline MgO_x ($0 < x < 1$) layer 3 sandwiched therebetween, the polycrystalline layer having the (001) crystal plane preferentially oriented therein. According to the aforementioned Jullire's model, assuming that the momentum of the conduction electrons is preserved in the tunneling process, the tunneling current that passes through MgO would be dominated by those electrons with wave vector k_z in the direction perpendicular to the tunnel barrier (normal to the junction interfaces). In accordance with the energy band diagram shown in Fig. 1(A) of Fe in the [001] (Γ-H) direction, the density of state (DOS) at the Fermi energy E_F does not exhibit a very high spin polarization due to the fact that the sub-bands of the majority-spin and the minority-spin have states at the Fermi energy E_F. However, in case the coherent states of electrons are conserved in the tunneling process, only those conduction electrons that have totally symmetrical wave functions with respect to the axis perpendicular to the barrier would be coupled with the states in the barrier region and come to have a finite tunneling probability. The $\Delta 1$ band in the Fe(001) electrode has such totally symmetric wave functions. As shown in Fig. 1(A), the majority spin $\Delta 1$ band (solid line) has states at the Fermi energy E_F, whereas the minority spin $\Delta 1$ band (broken line) does not have state at the Fermi energy E_F. Because of such half-metallic characteristics of the Fe Δ_1 band, there is the possibility that a very high MR ratio can be obtained in a coherent spin polarized tunneling. Since in an epitaxial (single-crystal, or (001) oriented poly-crystal) MTJ device the scattering of electrons is suppressed during the

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tunneling process, an epitaxial MTJ device is thought to be ideal for realizing the aforementioned coherent tunneling.

[0044] In the following, a MTJ device according to a first embodiment of the invention and a method of manufacturing the same will be described with reference to the drawings. Figs. 2(A) to 2(D) schematically show the method of manufacturing the MTJ device having the Fe (001)/MgO(001)/Fe(001) structure according to the embodiment (to be hereafter referred to as a "Fe(001)/MgO(001)/Fe(001) MTJ device"). Fe(001) refers to a ferromagnetic material with the BCC structure. First, a single-crystal MgO(001) substrate 11 was prepared. In order to improve the morphology of the surface of the single-crystal MgO(001) substrate 11, a MgO(001) seed layer 15 was grown by the molecular beam epitaxy (MBE) method. This was subsequently followed by the growth of an epitaxial Fe(001) lower electrode (first electrode) 17 with the thickness of 50 nm on the MgO(001) seed layer 15 at room temperature, as shown in Fig. 1(B), and then annealing was performed at 350°C under ultrahigh vacuum (2×10^{-8} Pa). Electron-beam evaporation conditions included an acceleration voltage of 8 kV, a growth rate of 0.02 nm/sec, and the growth temperature of room temperature (about 293K). The source material of the electron-beam evaporation was MgO of the stoichiometric composition (the ratio of Mg to O being 1:1), the distance between the source and the substrate was 40 cm, the base vacuum pressure was 1×10^{-8} Pa, and the O_2 partial pressure was 1×10^{-6} Pa. Alternatively, a source with oxygen vacancy defects may be used instead of the MgO of the stoichiometric composition (the ratio of Mg to O is 1:1).

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[0045] Fig. 3(A) shows a RHEED image of the Fe(001) lower electrode (a first electrode). The image shows that the Fe(001) lower electrode (first electrode) 17 possesses a good crystallinity and flatness. Thereafter, a MgO(001) barrier layer 21 with the thickness of 2 nm was epitaxially grown on the Fe(001) lower electrode (first electrode) at room temperature, also using the MgO electron-beam evaporation method. Fig. 3(B) shows a RHEED image of the MgO(001) barrier layer 21. The image shows that the MgO(001) barrier layer 21 also possesses a good crystallinity and flatness.

[0046] As shown in Fig. 2(D), a Fe(001) upper electrode (a second electrode) 23 with the thickness of 10 nm was formed on the MgO(001) barrier layer 21 at room temperature. This was successively followed by the deposition of a Co layer 25 with the thickness of 10 nm on the Fe(001) upper electrode (second electrode) 23. The Co layer 25 is provided to increase the coercive force of the upper electrode 23 so as to realize the antiparallel magnetization alignment. The thus prepared sample was then processed by microfabrication techniques to obtain the Fe(001)/MgO(001)/Fe(001) MTJ device.

[0047] The aforementioned MgO evaporation using an electron beam involved the formation of a film under ultrahigh vacuum of 10^{-9} Torr. It can be seen that in this method, the film, even when formed on a glass substrate to the thickness of 300 nm, was colorless and transparent, showing that a good crystal film was formed. Fig. 4 shows the results of observing the quadrupole mass spectra in the deposition chamber during the MgO growth.

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The results show that the partial pressures regarding the spectrum P1 of O and the spectrum P2 of O_2 are high. Fig. 5 shows the film deposition rate dependency of the oxygen partial pressure during MgO evaporation. It will be seen from the figure that the oxygen partial pressure itself is high, and that the oxygen partial pressure increases as the deposition rate increases. These results indicate the separation of oxygen from MgO during the deposition of MgO. Since the separated oxygen is pumped out of the deposition chamber using vacuum pumps, there is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$). When there are oxygen vacancy defects, the potential barrier height of the MgO tunnel barrier is thought to decrease (such as in the range of 0.10 to 0.85 eV; more specifically, 0.2 to 0.5 eV), which is thought to result in an increase in the tunneling current. In the case of a typical Al-O tunnel barrier, the height of the tunnel barrier with respect to Fe(001) electrodes is considered to be 0.7 to 2.5 eV. An ideal tunnel barrier height of a MgO crystal is 3.6 eV, and experimental values of 0.9 to 3.7 eV have been obtained. Using the method according to the present embodiment of the invention, a tunnel barrier height of approximately 0.3 eV is expected, indicating that the resistance of the tunnel barrier can be lowered. However, it should be noted that other factors, such as the influence of the aforementioned coherent tunneling, might also be involved. The value of x in MgO_x due to oxygen vacancy defects is such that $0.98 < x < 1$, and more preferably $0.99 < x < 1$. These are the ranges such that the sole presence of Mg is excluded and the characteristics of MgO can be basically maintained.

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[0048] The aforementioned tunnel barrier height ϕ was determined by fitting the electric conductance characteristics of the MTJ device (the relationship between tunnel current density J and bias voltage V) onto the Simmons' formula (Equation (20) in a non-patent document by J. G. Simmons: J. Appl. Phys. 34, pp. 1793-1803 (1963)) based on the WKB approximation, using the least squares method. The fitting was performed using the free electron mass ($m = 9.11 \times 10^{-31}$ kg) as the electron's effective mass. When a bias voltage V (which is normally on the order of 500 mV to 1000 mV) is applied until non-linearity appears in the J-V characteristics, the height ϕ of the tunnel barrier and the effective thickness Δs of the tunnel barrier can be simultaneously determined by fitting the J-V characteristics using the Simmons' formula.

[0049] The effective thickness Δs of the tunnel barrier was determined to be smaller than the thickness of the actual MgO(001) tunnel barrier layer (t_{MgO}) determined from a cross-sectional transmission electron microscope image of the MTJ device by approximately 0.5 nm. This is the result of the effective thickness Δs of the tunnel barrier having been reduced from the actual MgO(001) layer thickness by the effect of the image potential produced at the interface between the MgO(001) layer and the alloy layer consisting mainly of Fe and Co.

[0050] It is noted that, in the event that t_{MgO} can be accurately determined using the cross-sectional transmission electron microscope (TEM) image, the height ϕ of the tunnel barrier can be more simply determined by the following

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technique. Namely, when the bias voltage V applied to the MTJ device is small (normally 100 mV or smaller), the tunnel current density J is proportional to the bias voltage V, such that the J-V characteristics become linear. In such a low-bias voltage region, the Simmons' formula can be described as follows:

[0051] $J = [(2m\phi)^{1/2}/\Delta s](e/h)^2 \times \exp[-(4\pi\Delta s/h) \times (2m\phi)^{1/2}] \times V$ (2)

[0052] where m is the mass of the free electron (9.11×10^{-31} kg), e is the elementary electric charge (1.60×10^{-19}C), and h is the Planck's constant (6.63×10^{-34} J·s). The effective thickness of the tunnel barrier Δs is approximately t_{MgO} – 0.5 nm. By fitting the J-V characteristics of the MTJ device in the low-bias voltage region onto Equation (2), the height ϕ of the tunnel barrier can be simply and yet accurately estimated.

[0053] Fig. 6 shows a typical magnetoresistance curve of the Fe(001)/MgO(001)/Fe(001) MTJ device produced by the above-described method. The MR ratio is 146% at the measurement temperature of 20K and 88% at the measurement temperature of 293K. These values represent the highest MR ratios that have so far been obtained at room temperature. Such high MR ratios cannot be explained by the spin polarization of the Fe(001) electrode and is thought rather to be related to a coherent spin-polarized tunneling. When 160 prototype MTJ devices were made, the variations regarding the MR ratio and tunneling resistance value were not more than 20%. The yield of the MTJ devices was 90% or more at the laboratory stage. These high values suggest the effectiveness of the approach of the invention.

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Page 108

The resistance-area (RA) product of the MTJ device was on the order of a few $k\Omega\mu m^2$, which is suitable for MRAM.

[0054] Fig. 7(a) shows the bias voltage dependency of the MR ratio at room temperature. It will be seen that the bias voltage dependency of the MR ratio is fairly small. Although the characteristics are asymmetric, the voltage V_{half} at which the MR ratio is reduced in half of the zero-bias value is 1250 mV, which is a very high value. In this connection, it is noted that the voltage V_{half} at which the MR ratio is reduced in half of the zero-bias value in the conventional MTJs with Al-O tunnel barrier is 300 to 600 mV. Fig. 7(b) shows the output voltage V_{out} of the MTJ device (=bias voltage × (Rap – Rp)/Rap). The maximum value of the output voltage V_{out} is 380 mV with a positive bias. This value is about twice as large as that (a little less than 200 mV) in the case of the Al-O barrier. These high values in terms of both MR ratio and output voltage suggest the effectiveness of the technique according to the present embodiment.

[0055] Although in the above-described embodiment Fe(001) of BCC was employed, an Fe alloy of BCC, such as an Fe-Co alloy, Fe-Ni alloy, or Fe-Pt alloy, may be used instead. Alternatively, a layer of Co or Ni with the thickness of one or several monoatomic layers may be inserted between the electrode layer and the MgO(001) layer.

[0056] Hereafter, a MTJ device according to a second embodiment of the invention and a method of manufacturing the same will be described. In the method of manufacturing a Fe(001)/MgO(001)/Fe(001) MTJ device according

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to the present embodiment, MgO(001) is initially deposited in a poly-crystalline or amorphous state by sputtering or the like, and then an annealing process is performed such that a poly-crystal in which the (001) crystal plane is preferentially oriented or a single-crystal is obtained. The sputtering conditions were such that, for example, the temperature was room temperature (293K), a 2-inch ϕ MgO was used as a target, and sputtering was conducted in an Ar atmosphere. The acceleration power was 200 W and the growth rate was 0.008 nm/s. Because MgO that is deposited under these conditions is in an amorphous state, a crystallized MgO was obtained by increasing the temperature to 300°C from room temperature and maintaining that temperature for a certain duration of time.

[0057] Oxygen vacancy defects may be introduced by a method whereby oxygen vacancy defects is produced during growth, a method whereby oxygen vacancy defects is introduced subsequently, or a method whereby a state with oxygen vacancy defects is subjected to an oxygen plasma process or natural oxidation so as to achieve a certain oxygen deficit level.

[0058] As described above, in accordance with the MTJ device technology of the present embodiment, an annealing process is carried out for crystallization after an amorphous MgO has been deposited by sputtering, thereby eliminating the need for large-sized equipment.

[0059] Hereafter, a MTJ device according to a variation of the embodiments of the invention will be described with reference to the drawings. Fig. 11 shows the structure of the MTJ device according to the variation, which

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corresponds to Fig. 1(B). As shown in Fig. 11, the MTJ device of the variation is characterized in that, as in the MTJ device of the above-described embodiments, the electrodes disposed on either side of a single-crystal $MgO_x(001)$ layer 503 or an oxygen-deficit poly-crystal MgO_x ($0 < x < 1$) in which the (001) crystal plane is preferentially oriented comprises an amorphous ferromagnetic alloy, such as CoFeB layers 501 and 505. The amorphous ferromagnetic alloy can be formed by evaporation or sputtering, for example. The resultant characteristics are substantially identical to those of the first embodiment.

[0060] As the amorphous magnetic alloy, FeCoB, FeCoBSi, FeCoBP, FeZr, and CoZr may be used, for example. Although an anneal process after the preparation of the MTJ device might cause the amorphous magnetic alloy in the electrode layers to be partially or entirely crystallized, this would not lead to a significant deterioration of the MR ratio. Thus, such a crystallized amorphous magnetic alloy may be used in the electrode layers.

[0061] While the MTJ device according to various embodiments of the invention has been described, it should be apparent to those skilled in the art that the invention is not limited to those specific embodiments and various other modifications, improvements and combinations are possible. For example, the height of the tunnel barrier may be adjusted by doping Ca or Sr, instead of introducing an oxygen vacancy defects to the MgO layer. Further, while the MgO layer has been described to be deposited by electron-beam evaporation or sputtering, it should be obvious that other deposition methods

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Page 111

are also possible. The term "high vacuum" refers to values on the order of no more than 10^{-6} Pa in the case where oxygen is not introduced, for example. In the case where oxygen is introduced, the term refers to values on the order of 10^{-4} Pa.

[0062] In accordance with the invention, a larger magnetoresistance than in the conventional MTJ device can be obtained, and the output voltage of the MTJ device can be increased. At the same time, the resistance value of the MTJ device can be reduced so that it is optimized for MRAM. The invention thus enables the level of integration of MRAM using the MTJ device to be readily increased. In accordance with the invention, the output voltage value of the MRAM roughly doubles over prior art, making the MTJ device of the invention suitable for very large scale integrated MRAMs of gigabit class.

Electronic Acknowledgement Receipt

EFS ID:	15338990
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	38327
Filer:	Juan Carlos A. Marquez/Linda Greene
Filer Authorized By:	Juan Carlos A. Marquez
Attorney Docket Number:	NAGI-0005
Receipt Date:	25-MAR-2013
Filing Date:	14-FEB-2013
Time Stamp:	09:33:39
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	Transmittal Letter	restocorrect.pdf	66079 b141fa4482bc3a1dc8b9ccb35f568f00d9454ca1	no	2

Warnings:	
Information:	

2	Specification	clean.pdf	1016230 9102ad1b57d3d82a3e9f56bb1351c1833e675233	no	21
Warnings:					
Information:					
3	Specification	marked.pdf	1022719 1c25016057f7e2391162c602f95dbe3c7b073137	no	21
Warnings:					
Information:					
			Total Files Size (in bytes):	2105028	

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.

Document code: WFEE

United States Patent and Trademark Office
Sales Receipt for Accounting Date: 09/16/2013

MTEKLEMI ADJ #00000006 Mailroom Dt: 03/25/2013
Seq No: 9 Sales Acctg Dt: 04/12/2013 110600 13767290
01 FC : 1051 140.00 CR

LETTER – REQUEST FOR CORRECTED FILING RECEIPT		
	Application #	13/767,290
	Confirmation #	2082
	Filing Date	February 14, 2013
	First Inventor	YUASA
	Art Unit	2686
	Examiner	
	Docket #	NAGI-0005/JCM

Commissioner for Patents
Office of Initial Patent Examination
Customer Service Center
P.O. Box 1450
Alexandria, Virginia 22313

S I R:

Correction of the Filing Receipt is requested.

Submitted herewith is a copy of the Filing Receipt for the above-identified application showing the requested corrections in boldface type. The corrections are readily apparent from the application papers.

It is respectfully requested that the records of the Patent Office be corrected and that a Corrected Filing Receipt be sent to the undersigned.

Respectfully submitted,

Douglas E Jackson for #28,518

Date: April 1, 2013

Signed By
Attorney of Record

Name: Juan Carlos A. Marquez
Registration No.:

STITES & HARBISON PLLC • 1199 North Fairfax Street • Suite 900 • Alexandria, VA 22314
TELEPHONE: 703-739-4900 • FAX: 703-739-9577 • CUSTOMER NO. 38327

283831:1:ALEXANDRIA

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
13/767,290	02/14/2013	2686	1510	NAGI-0005	11	4

CONFIRMATION NO. 2082

RECEIVED
MAR 14 2013
STITES & HARBISON, PLLC

FILING RECEIPT



38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

Date Mailed: 03/14/2013

Receipt is acknowledged of this non-provisional 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 APPLICANT, 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 Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections 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**

Inventor(s)
Shinji YUASA, Ibaraki, JAPAN;

Applicant(s)
Japan Science and Technogy Agency, Kawaguchi-shi, JAPAN

Assignment For Published Patent Application
Japan Science and Technology Agency, Kawaguchi-shi, JAPAN

Power of Attorney: None

Domestic Priority data as claimed by applicant
This application is a CON of 13/400,340 02/20/2012 PAT 8405134
which is a CON of 12/923,643 09/30/2010 PAT 8319263
which is a CON of 10/591,947 09/08/2006 PAT 7884403
which is a 371 of PCT/JP2005/004720 03/10/2005

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)
JAPAN 2004-313350 10/28/2004
JAPAN 2004-071186 03/12/2004

Request to Retrieve - This application either claims priority to one or more applications filed in an intellectual property Office that participates in the Priority Document Exchange (PDX) program or contains a proper **Request to Retrieve Electronic Priority Application(s)** (PTO/SB/38 or its equivalent). Consequently, the USPTO will attempt to electronically retrieve these priority documents.

If Required, Foreign Filing License Granted: 03/05/2013

National Institute of Advanced Industrial Science and Technology, Chiyoda-ku, Japan

Electronic Acknowledgement Receipt

EFS ID:	15402349
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	38327
Filer:	Juan Carlos A. Marquez/Tynisha Purifoy
Filer Authorized By:	Juan Carlos A. Marquez
Attorney Docket Number:	NAGI-0005
Receipt Date:	01-APR-2013
Filing Date:	14-FEB-2013
Time Stamp:	16:41:47
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	Request for Corrected Filing Receipt	NAGI-0005_RequestCorrectedFilingReceipt.pdf	111543 4df7b42a3fc9f3f87f52c71d4f434ba2a95301ee	no	2

Warnings:	
Information:	

Total Files Size (in bytes):	111543

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.

Document code: WFEE

United States Patent and Trademark Office
Sales Receipt for Accounting Date: 09/16/2013

MTEKLEMI SALE #00000006 Mailroom Dt: 04/01/2013 120555 13767290
01 FC : 1051 140.00 DA

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
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005

CONFIRMATION NO. 2082

38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

MISCELLANEOUS NOTICE



Date Mailed: 04/22/2013

A communication which cannot be delivered in electronic form has been mailed to the applicant.

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/767,290

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			N/A	280
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	600
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	720
TOTAL CLAIMS (37 CFR 1.16(i))	11 minus 20 =	*			OR	x 80 =	0.00
INDEPENDENT CLAIMS (37 CFR 1.16(h))	4 minus 3 =	* 1				x 420 =	420
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			TOTAL	2020

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.

UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005

CONFIRMATION NO. 2082

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Juan Carlos A. Marquez
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1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

FORMALITIES LETTER

OC000000060470699

Date Mailed: 04/22/2013

NOTICE OF INCOMPLETE REPLY (NONPROVISIONAL)

Filing Date Granted

The U.S. Patent and Trademark Office has received your reply on 03/25/2013 to the Notice to File Missing Parts (Notice) mailed 03/14/2013 and it has been entered into the nonprovisional application. The reply, however, does not include the following items required in the Notice. A complete reply must be timely filed to prevent ABANDONMENT of the above-identified application. Replies should be mailed to: Mail Stop Missing Parts, Commissioner for Patents, P.O. Box 1450, Alexandria VA 22313-1450.

Applicant is given **TWO MONTHS** from the date of the Notice to File Missing Parts (Notice) mailed 03/14/2013 within which to file all required items and pay any fees required below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

Items Required to Avoid Abandonment:

The required items noted below SHOULD be filed along with any items required above. The filing date of this nonprovisional application will be the date of receipt of the items required above.

The application is informal since it does not comply with the regulations for the reason(s) indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- A substitute specification in compliance with 37 CFR 1.52, 1.121(b)(3), and 1.125, is required. The substitute specification must be submitted with markings and be accompanied by a clean version (without markings) as set forth in 37 CFR 1.125(c) and a statement that the substitute specification contains no new matter (see 37 CFR 1.125(b)). The specification, claims, and/or abstract page(s) submitted is not acceptable and cannot be scanned or properly stored because:
  - The application contains drawings, but the specification does not contain a brief description of the several views of the drawings as required by 37 CFR 1.74 and 37 CFR 1.77(b)(7).

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

Items Required To Avoid Processing Delays:

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).

- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
  All
  Applicant may submit the inventor's oath or declaration at any time before the Notice of Allowance and Fee(s) Due, PTOL-85, is mailed.

Replies must be received in the USPTO within the set time period or must include a proper Certificate of Mailing or Transmission under 37 CFR 1.8 with a mailing or transmission date within the set time period. For more information and a suggested format, see Form PTO/SB/92 and MPEP 512.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/mbayou/

Office of Data Management, 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
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P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005

CONFIRMATION NO. 2082

OC000000060200312

38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

Date Mailed: 04/22/2013

NOTICE OF INCOMPLETE REPLY

Filing Date Granted

Applicant's reply to the Notice mailed on 03/14/13 was received in the U.S. Patent and Trademark Office on 03/25/13 and has been entered into the application. The reply, however, does not include the following item(s) required in the Notice.

The period for reply continues to run from the mailing date of the prior Notice. The item(s) listed below must be timely filed to avoid abandonment of the application. No new time period for reply is provided in this communication. If the period for reply set forth in the prior Notice has expired, this application will become abandoned unless applicant: (1) submits the following checked item(s), **and** (2) obtains an extension of time under 37 CFR 1. 136(a) (including the appropriate fee (37 CFR 1.17(a)). In no case may an applicant obtain an extension of time for more than FIVE (5) MONTHS beyond the date for reply set forth in the prior Notice.

A complete reply which includes the following checked item(s) must be timely filed to prevent ABANDONMENT of the above-identified application:

- ☐ A substitute specification.
- ☒ A statement that the substitute specification contains no new matter.
- ☐ A replacement abstract commencing on a separate sheet in compliance with 37 CFR 1.72(b) and 1.121 (deleting the drawings or flow diagrams).
- ☐ New and replacement drawing sheets.
- ☐ Replacement drawing sheets with the figures renumbered.
- ☐ A complete claim listing or a replacement claim listing with the claims renumbered.
- ☐ An amendment to the claims in compliance with 37 CFR 1.121 (deleting the drawings or flow diagrams).
- ☐ A replacement transmittal letter listing all of the files except the missing or unreadable file.
- ☐ A duplicate copy of the CD.
- ☐ A statement that the replacement CD contains no new matter.

Rev. 12/2008

Replies should be mailed to: Mail Stop Missing Parts
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Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
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For more information about EFS-Web, please call the USPTO Electronic Business Center at 1-866-217-9197 or visit our website at http://www.uspto.gov/ebc.

Mesdelawit Bayou
Application Assistance Unit (571) 272-4200

Rev. 12/2008

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	
YUASA	)	**Confirmation No.: 2082**
	)	
U.S. Application No.: 13/767,290	)	**Art Unit 2686**
	)	
Filed: February 14, 2013	)	
	)	
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
Attorney Docket No.: NAGI-0005	)	

Honorable Assistant Commissioner
for Patents
Washington, D.C. 20231

RESPONSE TO NOTICE OF INCOMPLETE REPLY

This is in response to the Notice of Incomplete Reply mailed on April 22, 2013, advising Applicant to submit a statement that the substitute specification contains no new matter. The Notice of Incomplete Reply was dated April 22, 2013, and the prior Notice was dated March 14, 2013. The period for response is set to expire on May 14, 2013.

Applicant hereby states that the substitute specification filed on March 25, 2013 contains no new matter; and hereby complies with the requirements.

Please direct any inquiries in connection with this application to the undersigned.

The Commissioner is hereby authorized to charge payment of any fees associated with this communication, including fees under 37 C.F.R. § 1.16 and 1.17 or credit any overpayment to **Deposit Account Number 12-0555.**

Respectfully submitted,

Juan Carlos A. Marquez
Registration Number 34,072

STITES & HARBISON, PLLC
1199 North Fairfax Street, Suite 900
Alexandria, VA 22314-1437
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Customer No. 38327
May 13, 2013

288625:2:ALEXANDRIA

Electronic Acknowledgement Receipt

EFS ID:	15763669
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	38327
Filer:	Juan Carlos A. Marquez/Janice Rosier
Filer Authorized By:	Juan Carlos A. Marquez
Attorney Docket Number:	NAGI-0005
Receipt Date:	13-MAY-2013
Filing Date:	14-FEB-2013
Time Stamp:	18:09:38
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	Applicant Response to Pre-Exam Formalities Notice	NAGI-0005_Response_to_Notice_of_Incomplete_Reply.pdf	42516 48083624e64a8f65f572b344bc069e0be9fc0644	no	1

Warnings:	
Information:	

Total Files Size (in bytes):	42516

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
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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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PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/767,290

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			N/A	280
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	600
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	720
TOTAL CLAIMS (37 CFR 1.16(i))	11 minus 20 =	*			OR	x 80 =	0.00
INDEPENDENT CLAIMS (37 CFR 1.16(h))	4 minus 3 =	* 1				x 420 =	420
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			TOTAL	2020

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.

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
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005

CONFIRMATION NO. 2082

38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
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Alexandria, VA 22314-1437

NOTICE

OC000000061402876

Date Mailed: 05/29/2013

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):
  All
  Applicant may submit the inventor's oath or declaration at any time before the Notice of Allowance and Fee(s) Due, PTOL-85, is mailed.

UNITED STATES PATENT AND TRADEMARK OFFICE

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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
13/767,290	02/14/2013	2686	1650	NAGI-0005	11	4

CONFIRMATION NO. 2082

UPDATED FILING RECEIPT

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OC000000061402875

Date Mailed: 05/29/2013

Receipt is acknowledged of this non-provisional 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 APPLICANT, 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 Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections 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**

Inventor(s)

Shinji YUASA, Ibaraki, JAPAN;

Applicant(s)

Japan Science and Technogy Agency, Kawaguchi-shi, JAPAN
National Institute of Advanced Industrial Science and Technology, Tokyo, JAPAN

Assignment For Published Patent Application

Japan Science and Technology Agency, Kawaguchi-shi, JAPAN
National Institute of Advanced Industrial Science and Technology, Tokyo, JAPAN

Power of Attorney: None

Domestic Priority data as claimed by applicant

This application is a CON of 13/400,340 02/20/2012 PAT 8405134
which is a CON of 12/923,643 09/30/2010 PAT 8319263
which is a CON of 10/591,947 09/08/2006 PAT 7884403
which is a 371 of PCT/JP2005/004720 03/10/2005

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)
JAPAN 2004-313350 10/28/2004
JAPAN 2004-071186 03/12/2004

Request to Retrieve - This application either claims priority to one or more applications filed in an intellectual property Office that participates in the Priority Document Exchange (PDX) program or contains a proper **Request to**

Retrieve Electronic Priority Application(s) (PTO/SB/38 or its equivalent). Consequently, the USPTO will attempt to electronically retrieve these priority documents.

If Required, Foreign Filing License Granted: 03/05/2013

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/767,290**

Projected Publication Date: 09/05/2013

Non-Publication Request: No

Early Publication Request: No

Title

Magnetic Tunnel Junction Device

Preliminary Class

360

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications:

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 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 (1-866-999-4158).

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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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LETTER – REQUEST FOR CORRECTED FILING RECEIPT		
	Application #	13/767,290
	Confirmation #	2082
	Filing Date	February 14, 2013
	First Inventor	YUASA
	Art Unit	2686
	Examiner	
	Docket #	NAGI-0005/JCM

Commissioner for Patents
Office of Initial Patent Examination
Customer Service Center
P.O. Box 1450
Alexandria, Virginia 22313

S I R:

Correction of the Filing Receipt is requested.

Submitted herewith is a copy of the Filing Receipt for the above-identified application showing the requested corrections in boldface type. The corrections are readily apparent from the application papers.

It is respectfully requested that the records of the Patent Office be corrected and that a Corrected Filing Receipt be sent to the undersigned.

Respectfully submitted,

Date: June 14, 2013

Signed By
Attorney of Record

Name: Juan Carlos A. Marquez
Registration No.: **34,072**

STITES & HARBISON PLLC ◆ 1199 North Fairfax Street ◆ Suite 900 ◆ Alexandria, VA 22314
TELEPHONE: 703-739-4900 ◆ FAX: 703-739-9577 ◆ CUSTOMER NO. 38327

293101:1:ALEXANDRIA

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
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13/767,290	02/14/2013	2686	1650	NAGI-0005	11	4

CONFIRMATION NO. 2082

UPDATED FILING RECEIPT

38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

RECEIVED
MAY 29 2013
STITES & HARBISON, PLLC

OC000000061402875

Date Mailed: 05/29/2013

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Inventor(s)

Shinji YUASA, Ibaraki, JAPAN;

Applicant(s)

Japan Science and ~~Technogy~~ Agency, Kawaguchi-shi, JAPAN **Technology**
National Institute of Advanced Industrial Science and Technology, Tokyo, JAPAN

Assignment For Published Patent Application

Japan Science and Technology Agency, Kawaguchi-shi, JAPAN
National Institute of Advanced Industrial Science and Technology, Tokyo, JAPAN

Power of Attorney: None

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Electronic Acknowledgement Receipt

EFS ID:	16047072
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	38327
Filer:	Juan Carlos A. Marquez/Jovelita Fonseca
Filer Authorized By:	Juan Carlos A. Marquez
Attorney Docket Number:	NAGI-0005
Receipt Date:	14-JUN-2013
Filing Date:	14-FEB-2013
Time Stamp:	16:13:48
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	Request for Corrected Filing Receipt	NAGI-0005_LetterRequestForCorrectedFilingReceipt.pdf	111312 44ae26cd7531daf4d59fd17ebc4d0a87694ede0f	no	2

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Information:	

Total Files Size (in bytes):	111312

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日　本　国　特　許　庁
JAPAN PATENT OFFICE

別紙添付の書類に記載されている事項は下記の出願書類に記載されている事項と同一であることを証明する。

This is to certify that the annexed is a true copy of the following application as filed with this Office.

出願年月日 Date of Application:	２００４年　３月１２日
出願番号 Application Number:	特願２００４－０７１１８６
パリ条約による外国への出願に用いる優先権の主張の基礎となる出願の国コードと出願番号 The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is	ＪＰ２００４－０７１１８６
出願人 Applicant(s):	独立行政法人科学技術振興機構 独立行政法人産業技術総合研究所

２０１３年　６月１４日

特許庁長官
Commissioner,
Japan Patent Office　深野弘行

【書類名】　特許願
【整理番号】　P04-0204
【提出日】　平成16年 3月12日
【あて先】　特許庁長官　殿
【国際特許分類】　H01L 43/00
【発明者】
　【住所又は居所】　茨城県つくば市東１－１－１　独立行政法人産業技術総合研究所
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　【氏名又は名称】　独立行政法人産業技術総合研究所
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【選任した代理人】
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　【氏名又は名称】　渡辺　敏章
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　【識別番号】　100108394
　【弁理士】
　【氏名又は名称】　今村　健一
【持分の割合】　50/100
【手数料の表示】
　【予納台帳番号】　015244
　【納付金額】　10,500円
【提出物件の目録】
　【物件名】　特許請求の範囲　1
　【物件名】　明細書　1
　【物件名】　図面　1
　【物件名】　要約書　1

【書類名】特許請求の範囲
【請求項１】
トンネル障壁層と、該トンネル障壁層の第１面側に形成されたＢＣＣ構造を有する第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＢＣＣ構造を有する第２の強磁性体層と、を有する磁気トンネル接合構造であって、
前記トンネル障壁層が、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子。
【請求項２】
ＭｇＯ（１００）からなるトンネル障壁層と、該トンネル障壁層の第１面側に形成されたＦｅ（１００）からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＦｅ（１００）からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、
前記ＭｇＯ層が、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子。
【請求項３】
ＭｇＯ（１００）からなるトンネル障壁層と、該トンネル障壁層の第１面側に形成されたＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、
前記ＭｇＯ（１００）層の伝導帯下端と前記Ｆｅ（１００）層のフェルミ準位の間の不連続値（トンネル障壁の高さ）を単結晶における理想的な値よりも低くしたことを特徴とする磁気抵抗素子。
【請求項４】
前記不連続値は、０．２～０．５ｅＶの範囲内であることを特徴とする請求項３に記載の磁気抵抗素子。
【請求項５】
前記不連続値は、０．１０～０．８５ｅＶの範囲内であることを特徴とする請求項３に記載の磁気抵抗素子。
【請求項６】
１つのトランジスタと、該トランジスタの負荷として用いられる請求項１から５までのいずれか１項に記載の磁気抵抗素子と
を有する記憶素子。
【請求項７】
基板を準備する工程と、
該基板上に第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を堆積する工程と、
前記第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の（１００）層上に電子ビーム蒸着法により、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなるトンネル障壁層を高真空下において堆積する工程と、
該トンネル障壁層上に第２のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を形成する工程と
を有することを特徴とする磁気抵抗素子の製造方法。
【請求項８】
単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなる基板を準備する第１工程と、
該基板上に第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を堆積し、次いで、結晶化のためのアニール

を行う第２工程と、
　前記第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の（１００）層上に電子ビーム蒸着法により単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなるトンネル障壁層を高真空下において堆積する第３工程と、
　該トンネル障壁層上に第２のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を形成する第４工程と
を有することを特徴とする磁気抵抗素子の製造方法。
【請求項９】
　前記第１工程と第２工程との間に、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなるシード層を成長する工程を有することを特徴とする請求項７又は８に記載の磁気抵抗素子の製造方法。
【請求項１０】
　前記単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなるトンネル障壁層を形成する工程中に、MgO_xのｘ値を調整する工程を含むことを特徴とする請求項７又は８に記載の磁気抵抗素子の製造方法。
【請求項１１】
　基板を準備する工程と、
　該基板上に第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を堆積する工程と、
　前記第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の（１００）層上にスパッタリング法によりアモルファスＭｇＯ層を形成し、アニールにより該アモルファスＭｇＯ層を結晶化して単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなるトンネル障壁層を形成する工程と、
　該トンネル障壁層上に第２のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を形成する工程と
を有することを特徴とする磁気抵抗素子の製造方法。
【請求項１２】
　前記アモルファスＭｇＯ層を、MgO_xのｘ値を調整済みのターゲットを用いて堆積することを特徴とする請求項１１に記載の磁気抵抗素子の製造方法。
【請求項１３】
　前記アモルファスＭｇＯを形成する工程中に、MgO_xのｘ値を調整する工程を含むことを特徴とする請求項１１に記載の磁気抵抗素子の製造方法。

【書類名】明細書
【発明の名称】磁気抵抗素子及びその製造方法
【技術分野】
【０００１】
本発明は、磁気抵抗素子及びその製造方法に関し、特に、高い磁気抵抗を有する磁気抵抗素子及びその製造方法に関する。
【背景技術】
【０００２】
MRAM（Magnetoresistive Random Access Memory）は、現在広く用いられている記憶素子であるＤＲＡＭに代わる大容量向け記憶素子であり、かつ、高速な不揮発性メモリとして広く研究開発が行われており、例えば、4MbitのMRAMがサンプル出荷されたという実績がある。
【０００３】
図８は、ＭＲＡＭの心臓部であるＴＭＲ素子の構造と、その動作原理を示す図である。図８（Ａ）に示すように、ＴＭＲ素子においては、酸化物からなるトンネル障壁の両側を強磁性金属からなる第１及び第２の２つの電極により挟んだトンネル構造を有している。トンネル障壁層としては、アモルファスのＡｌ－Ｏ層が用いられている（非特許文献１参照）。図８（Ａ）に示すように、第１の強磁性電極と第２の強磁性電極との磁化の向きが平行な平行磁化の場合には、トンネル構造の界面における法線方向に関する素子の電気抵抗が小さくなる。一方、図８（Ｂ）に示すように、第１の強磁性電極と第２の強磁性電極との磁化の向きが平行な反平行磁化の場合には、トンネル構造の界面における法線方向に関する素子の電気抵抗が大きくなる。この抵抗値は、一般的な状態では変化せず、抵抗値が高いか低いかに基づいて情報“１”、“０”として記憶される。平行磁化と反平行磁化とは不揮発に記憶されるため、不揮発性メモリの基本素子として用いることができる。
【０００４】
図９は、ＭＲＡＭの基本構造例を示す図であり、図９（Ａ）はＭＲＡＭの斜視図であり、図９（Ｂ）は模式的な回路構成図であり、図９（Ｃ）は、構造例を示す断面図である。図９（Ａ）に示すように、ＭＲＡＭにおいてはワード線ＷＬとビット線ＢＬとが交差するように配置され、交差部にＭＲＡＭセルが配置されている。図９（Ｂ）に示すように、ワード線とビット線との交差部に配置されたＭＲＡＭセルは、ＴＭＲ素子と、このＴＭＲ素子と直列接続されたＭＯＳＦＥＴとを有しており、負荷抵抗として機能するＴＭＲ素子の抵抗値をＭＯＳＦＥＴにより読み取ることにより、記憶情報を読み出すことができる。尚、情報の書き換えは、例えば、ＴＭＲ素子への磁場の印加により行うことができる。図９（Ｃ）に示すように、ＭＲＡＭメモリセルは、ｐ型Ｓｉ基板１０１内に形成されたソース領域１０５とドレイン領域１０３と、その間に画定されるチャネル領域に対して形成されたゲート電極１１１とを有するＭＯＳＦＥＴ１００と、ＴＭＲ素子１１７とを有している。ソース領域１０５は接地（ＧＮＤ）され、ドレインは、ＴＭＲ素子を介してビット線ＢＬに接続されている。ワード線ＷＬはゲート電極１１１に対して図示しない領域において接続されている。
【０００５】
以上に説明したように、不揮発性メモリＭＲＡＭは、１つのＭＯＳＦＥＴ１００とＴＭＲ素子１１７とにより１つのメモリセルを形成することができるため、高集積化に適したメモリ素子ということができる。
【０００６】
【非特許文献１】D.Wang, et al.:Science 294 (2001) 1488.
【発明の開示】
【発明が解決しようとする課題】
【０００７】
現状の技術を用いることにより６４Ｍｂｉｔ程度のＭＲＡＭを実現する見通しは立っているが、それ以上の高集積化のためには、ＭＲＡＭの心臓部であるＴＭＲ素子の特性を向

上させる必要がある。特に、全素子の出力電圧を向上させるには、磁気抵抗の増大と電圧特性の改善の両方が必要である。図１０は、アモルファスＡｌ－Ｏをトンネル障壁とした従来型ＴＭＲ素子の磁気抵抗の印加電圧による変化を示す図である（Ｌ１）。図１０に示すように、従来型ＴＭＲ素子においては、磁気抵抗が小さく、特に電圧を印加することにより磁気抵抗が急激に小さくなる傾向がみられる。このような特性では、動作マージンを考慮した出力電圧が小さすぎるため、実際の記憶素子に用いるのが難しい。より具体的には、現状のＴＭＲ素子の磁気抵抗は約70％と低く、また出力電圧も200 ｍＶ以下と低いため、ＤＲＡＭの出力電圧に比べて実質的に半分であり、集積度を上げるに従い信号がノイズに埋もれて読み出せなくなってしまうという問題があった。

【０００８】

本発明は、ＴＭＲ素子における出力電圧を大きくすることを目的とする。さらに、大きな磁気抵抗により、安定に動作する記憶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】

【０００９】

本発明の一観点によれば、トンネル障壁層と、該トンネル障壁層の第１面側に形成されたＢＣＣ構造を有する第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＢＣＣ構造を有する第２の強磁性体層と、を有する磁気トンネル接合構造であって、前記トンネル障壁層が、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子が提供される。

【００１０】

また、ＭｇＯ（１００）からなるトンネル障壁層と、該トンネル障壁層の第１面側に形成されたＦｅ（１００）からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＦｅ（１００）からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、前記ＭｇＯ層が、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子が提供される。前記ＭｇＯ（１００）層の伝導帯下端と前記Ｆｅ（１００）層のフェルミエネルギーの間の不連続値（トンネル障壁高さ）を単結晶における値よりも低くしたことを特徴とする。上記構成を用いると、磁気抵抗が増大しＴＭＲ素子の出力電圧を大きくすることができた。１つのトランジスタの負荷として上記磁気抵抗素子を用いると、不揮発性の記憶素子を形成することができた。

【００１１】

本発明の他の観点によれば、基板を準備する工程と、該基板上に第１のＦｅ（１００）層を堆積する工程と、前記第１のＦｅ（１００）層上に電子ビーム蒸着法により単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなるトンネル障壁層を高真空下において堆積する工程と、該トンネル障壁層上に第２のＦｅ（１００）層を形成する工程とを有することを特徴とする磁気抵抗素子の製造方法が提供される。

【００１２】

また、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなる基板を準備する第１工程と、該基板上に第１のＦｅ（１００）層を堆積し、次いで、結晶化のためのアニールを行う第２工程と、前記第１のＦｅ（１００）層上に電子ビーム蒸着法により単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなるトンネル障壁層を高真空下において堆積する第３工程と、該トンネル障壁層上に第２のＦｅ（１００）層を形成する第４工程とを有することを特徴とする磁気抵抗素子の製造方法が提供される。尚、前記第１工程と第２工程との間に、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）からなるシード層を成長する工程を有していても良い。また、前記アモルファスＭｇＯ層を、MgO_xのｘ値を調整済みのターゲットを用いて堆積しても良い。この際、前記アモルファスＭｇＯを形成する工程中に、MgO_xのｘ値を調整しても

良い。
【発明の効果】
【００１３】
本発明によれば、従来のＴＭＲ素子に比べて大きな磁気抵抗を得ることができ、ＴＭＲ素子の出力電圧を大きくすることができる。従って、ＴＭＲ素子を用いたＭＲＡＭの高集積化が容易になるという利点がある。
【発明を実施するための最良の形態】
【００１４】
本明細書において用いた単結晶における「理想的な値」との用語は、紫外線光電子分光の実験から推測した値である（参考文献：W. Wulfhekel, et al.: Appl. Phys. Lett. 78 (2001) 509.）。このような状態では、酸素欠損や格子欠陥がほとんど無い理想的な単結晶ＭｇＯのトンネル障壁の上限値と言うことができるため、理想的な値という用語を用いた。
【００１５】
発明の実施の形態について説明する前に、発明者の行った考察について説明を行う。ＭＴＪの磁気抵抗（ＭＲ）比は、以下の式で表される。
ΔＲ／Ｒｐ＝（Ｒａｐ－Ｒｐ）／Ｒｐ
ここで、Ｒｐ及びＲａｐは、２つの電極の磁化が平行と反平行の場合のトンネル接合抵抗である。Ｊｕｌｌｉｒｅの公式によれば、低バイアス電圧におけるＭＲ比は、以下のように表される。
ＭＲ比＝（Ｒａｐ－Ｒｐ）／Ｒｐ＝$2P_1P_2/(1-P_1P_2)$であり
ここで、$P\alpha=(D\alpha\uparrow(E_F)-D\alpha\downarrow(E_F))/(D\alpha\uparrow(E_F)+D\alpha\downarrow(E_F))$、α＝１，２　　（１）と表される。
【００１６】
ここで、Ｐαは、電子のスピン分極率であり、$D\alpha\uparrow(E_F)$と$D\alpha\downarrow(E_F)$とは、それぞれ、多数スピンバンドと少数スピンバンドのフェルミエネルギー（E_F）における状態密度（Ｄｅｎｓｉｔｙ　ｏｆ　ｓｔａｔｅ：ＤＯＳ）である。強磁性遷移金属及び合金のスピンの偏極は０．５以下であるため、Ｊｕｌｌｉｒｅの公式によれば、最も高い推定ＭＲ比として７０％が予測される。
【００１７】
ＭＴＪ素子をアモルファスのＡｌ－Ｏのトンネル障壁と多結晶電極とを用いて作成すると、室温でのＭＲ比として約７０％という値が得られているが、ＤＲＡＭ並の出力電圧である２００ｍＶを得るのは難しく、上述のようにＭＲＡＭ実現の対する問題点となっている。
【００１８】
発明者は、酸化マグネシウムの単結晶（１００）あるいは（１００）結晶面が優先配向した多結晶ＭｇＯをトンネル障壁として用いたＭＴＪを成長するアプローチを試みている。従来のアモルファスのアルミナ障壁とは異なり、酸化マグネシウムは結晶（原子が規則正しく配列した物質）であるため、電子が散乱されず、電子のコヒーレント状態がトンネル過程のおいて保存されることが予測される。図１は、本実施の形態によるＭＴＪ素子構造（図１（Ｂ））と、強磁性体金属であるＦｅ（１００）のエネルギーバンド構造を示す図であり、波数空間の［１００］方向に対するＥ－E_Fの関係を示す図（図１（Ａ））である。図１（Ｂ）に示すように、本実施の形態によるＭＴＪ素子構造は、第１のＦｅ（１００）層１と、第２のＦｅ（１００）層５と、これらの間に挟まれた単結晶MgO_x（１００）層あるいは（１００）結晶面が優先配向した多結晶MgO_x（ｘ＜１）層３と、を有して構成されている。上記Ｊｕｌｌｉｒｅのモデルによれば、伝導電子のモメンタムがトンネルプロセス中において保存されるとすると、ＭｇＯを透過するトンネル電流はトンネル障壁に垂直な方向（接合界面に対する法線方向）の波数ベクトルk_Zを有する電子が支配的になる。図１（Ａ）に示す［１００］（Γ－Ｈ）方向におけるＦｅのエネルギーバンド図によれば、フェルミ準位E_Fにおける状態密度（ＤＯＳ）は、多数スピンと少数スピ

ンのサブバンドがフェルミ準位E_Fにおいて状態を有しているため、それほど高い偏極率を示さない。しかしながら、電子のコヒーレント状態がトンネル過程のおいて保存される場合には、障壁に垂直な軸に関してトータルに対称な波動関数を有する伝導電子のみが障壁領域における状態と関連し、ある一定のトンネル確率を持つことになる。図１（Ａ）に示すように、多数スピン$\Delta_1\uparrow$バンド（実線）がフェルミ準位E_Fに状態を有するが、少数スピン$\Delta_1\downarrow$バンド（破線）はフェルミ準位E_Fに状態を有しない。このようなＦｅ$\Delta_1\downarrow$バンドのハーフメタル的な特徴により、非常に高いＭＲ比がコヒーレントなスピン偏極トンネルにおいて得られる可能性がある。エピタキシャル（単結晶あるいは（１００）配向多結晶）のＭＴＪは、トンネル過程中における電子の散乱が抑制されるため、上記のようなコヒーレントなトンネルを実現するためには理想的であると考えられる。

【００１９】

以下、本発明の第１の実施の形態による磁気抵抗素子及びその製造方法について図面を参照しつつ説明を行う。図２（Ａ）から図２（Ｄ）までは、本発明の実施の形態によるＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）構造を有する磁気抵抗素子（以下、「Ｆｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ」と称する。）の製造工程を模式的に示す図である。Ｆｅ（１００）は、ＢＣＣ構造を有する強磁性体である。まず、単結晶ＭｇＯ（１００）基板１１を準備し、ＭＢＥ法（分子線エピタキシー法）により、単結晶ＭｇＯ（１００）基板１１の表面のモフォロジーを改善するため、ＭｇＯ（１００）シード層１５を成長する。連続して、図１（Ｂ）に示すように、５０ｎｍ厚のエピタキシャルＦｅ（１００）下部電極（第１電極）１７をＭｇＯ（１００）シード層１５上に室温で成長し、次いで、超高真空下（2×10^{-8}Ｐａ）において、３５０℃でアニールを行う。尚、電子線蒸着における条件は、加速電圧が８ｋＶであり、成長速度が０．０２ｎｍ／秒、成長温度が室温（２９３Ｋ）、ソースとしては化学量論的組成のＭｇＯ（ＭｇとＯとの比が１：１）を用い、ソースと基板との距離を４０ｃｍとし、バックグラウンドの真空度が1×10^{-8}Ｐａ、O_2分圧が1×10^{-6}Ｐａである。尚、化学量論的組成のＭｇＯ（ＭｇとＯとの比が１：１）の代わりに、Ｏ欠損を有するソースを使用することも可能である。

【００２０】

図３（Ａ）は、この際のＦｅ（１００）下部電極（第１電極）１７のＲＨＥＥＤイメージを示す図である。図３（Ａ）に示すように、Ｆｅ（１００）下部電極（第１電極）１７は良好な結晶性と平坦性を有していることを示している。次いで、図２（Ｃ）に示すように、２ｎｍ厚のＭｇＯ（１００）バリア層２１をＦｅ（１００）下部電極（第１電極）１７上に室温でエピタキシャル成長する。この際も、ＭｇＯの電子ビーム蒸着法を用いた。図３（Ｂ）は、この際のＭｇＯ（１００）バリア層２１のＲＨＥＥＤイメージを示す図である。図３（Ｂ）に示すように、ＭｇＯ（１００）バリア層２１も良好な結晶性と平坦性を有していることを示している。

【００２１】

図２（Ｄ）に示すように、ＭｇＯ（１００）バリア層２１上に、室温で厚さ１０ｎｍのＦｅ（１００）上部電極（第２電極）２３を形成した。連続して、１０ｎｍ厚さのＣｏ層２５をＦｅ（１００）上部電極（第２電極）２３上に堆積した。Ｃｏ層２５は、上部電極２３の保持力を高めることによって反平行磁化配置を実現するためのものである。次いで、上記の作成試料を微細加工してＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ素子を形成する。

【００２２】

上記ＥＢによるＭｇＯ蒸着は、10^{-9}Ｔｏｒｒの超高真空状態で成膜を行った。この方法では、例えばガラス基板上に３００ｎｍの成膜を行った場合でも、無色透明であり、良好な単結晶膜が形成されていることがわかる。図４は、ＭｇＯ成長時における四重極Ｍａｓｓスペクトルの観測結果を示す図である。図４に示すように、ＯのスペクトルＰ１とO_2のスペクトルＰ２とに関する分圧が高いことがわかる。図５は、ＭｇＯ蒸着中の酸素分圧の膜堆積速度依存を示す図である。図５に示すように、酸素分圧自体がかなり高いこ

と、堆積速度とともに酸素分圧も高くなること、などは、ＭｇＯの堆積時におけるＭｇＯ単結晶からの酸素の離脱を示唆するものであり、MgO_x（０．９＜ｘ＜１）のように酸素欠損が生じている可能性がある。酸素欠損が生じるとＭｇＯトンネル障壁の高さが低くなると考えられ（例えば、０．１０～０．８５ｅＶ（より詳細には０．２～０．５ｅＶの範囲内））、これにより、トンネル電流が増加するものと考えられる。尚、一般的なＡｌ－Ｏトンネル障壁の場合、Ｆｅ（１００）との間のトンネル障壁の高さは、０．７～２．５ｅＶと考えられる。これに対して、ＭｇＯ結晶は理想的なトンネル障壁の高さは３．６ｅＶであり、実験値としては０．９～３．７ｅＶの値が得られている。本実施の形態による方法を用いると、０．３ｅＶ程度のトンネル障壁の高さが推定され、トンネル障壁の低抵抗化が可能であることがわかる。但し、その他の要因、例えば前述のコヒーレントなトンネルの影響も関連している可能性がある。

【００２３】

図６は、上記の方法により製造したＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ素子の典型的な磁気抵抗曲線を示す図である。測定温度２０ＫにおいてＭＲ比１４６％であり、測定温度２９３ＫにおいてＭＲ比は８８％であった。この値は、現在までに室温において得られた最も高いＭＲ比である。このような高いＭＲ比は、Ｆｅ（１００）電極のスピン分極率によって説明することはできず、むしろ、コヒーレントなスピン偏極トンネリングに関連すると考えられる。１６０のＭＴＪ素子を試作した結果、ＭＲ比とトンネル抵抗値とに関するばらつきは、２０％以内であった。ＭＴＪの歩留まりも実験室段階で９０％以上であった。このような高い値は、本アプローチの有効性を示唆している。ＭＴＪの抵抗ーエリア積（ＲＡ）は、数$k\Omega\mu m^2$であり、この値は、ＭＲＡＭに適した値である。

【００２４】

図７（ａ）は、室温におけるＭＲ比のバイアス電圧依存性を示す図である。図７（ａ）に示すように、ＭＲ比のバイアス電圧依存性はかなり低いことがわかる。非対称な特性を示すが、ＭＲ比が半減する電圧V_{half}は１２５０ｍＶという非常に高い値が得られている。尚、従来のＡｌ－Ｏ系におけるＭＲ比の半減する電圧V_{half}は３００～６００ｍＶである。図７（ｂ）に、ＭＴＪの出力電圧V_{out}は（＝バイアス電圧×（Ｒａｐ－Ｒｐ）／Ｒａｐ）を示す。出力電圧V_{out}の最大値は順バイアスにおいて３８０ｍＶの値が得られている。この値は、Ａｌ－Ｏバリアの場合の値（２００ｍＶ）の約２倍の値である。このように、ＭＲ比と出力電圧との両方で高い値が得られたことは、本実施の形態による技術の有効性を示している。

【００２５】

尚、上記実施の形態においては、ＢＣＣのＦｅ（１００）を用いたが、代わりにＢＣＣのＦｅ系合金、例えば、Ｆｅ－Ｃｏ合金、Ｆｅ－Ｎｉ合金、Ｆｅ－Ｐｔ合金を用いることもできる。或いはＦｅ（１００）層とＭｇＯ（１００）層との間に、１原子層又は数原子層程度の厚さのＣｏ、Ｎｉなどを挿入しても良い。

【００２６】

次に、本発明の第２の実施の形態による磁気抵抗素子及びその製造方法について説明を行う。本実施の形態によるＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＴＭＲ素子の製造方法では、まずスパッタリング法などによりＭｇＯ（１００）を多結晶またはアモルファス状態で堆積し、その後にアニール処理を行うことにより（１００）結晶面が配向した多結晶または単結晶化する点を特徴とする。スパッタリング条件は、例えば。温度が室温（２９３Ｋ）であり、ターゲットとしては２インチφのＭｇＯを用い、Ａｒ雰囲気中でスパッタリングを行った。加速電力は２００Ｗであり、成長速度は０．００８ｎｍ／ｓである。この条件で堆積したＭｇＯはアモルファス状態であるため、室温から３００℃まで温度を上昇させ、３００℃において一定時間保持をすることにより、結晶化されたＭｇＯを得ることが出来る。

【００２７】

尚、Ｏ欠損の導入方法としては、成長時にＯ欠損が生じる条件で成長を行う方法、Ｏ欠

損を後から導入する方法、Ｏ欠損のある状態から例えば酸素プラズマ処理又は自然酸化などにより酸化を行ってある程度のＯ欠陥まで調整する方法のいずれを用いても良い。

【００２８】

以上、本実施の形態による磁気抵抗素子技術によれば、スパッタリング法を用いてアモルファスＭｇＯを堆積した後にアニール処理により結晶化するため、それほど大がかりな装置が必要ないという利点がある。

【００２９】

以上、本実施の形態による磁気抵抗素子について説明したが、本発明はこれらに制限されるものではない。その他、種々の変更、改良、組み合わせが可能なことは当業者に自明であろう。例えば、ＭｇＯ層に酸素欠陥を導入する代わりに、例えばＣａやＳｒをドービングすることでトンネル障壁の高さを調整する方法を用いても良い。また、ＭｇＯ層の堆積方法として、電子ビーム蒸着法又はスパッタリング法を例にして説明したが、その他の堆積法も適用可能であることは言うまでもない。また、高真空との用語は、例えば酸素を導入しない場合において、概ね１０－６Ｐａ以下の値を指し、一方、酸素を積極的に導入する場合でも、１０－４Ｐａ程度の値を指す。

【産業上の利用可能性】

【００３０】

ＭＲＡＭの出力電圧値が従来の約２倍に向上し、ギガビット級の超高集積ＭＲＡＭに適した構造となっている。

【図面の簡単な説明】

【００３１】

【図１】本発明の第１の実施の形態によるＭＴＪ素子構造（図１（Ｂ））と、強磁性体金属であるＦｅ（１００）のエネルギーバンド構造を示す図であり、波数空間の［１００］方向に対するＥ－$Ｅ_Ｆ$の関係を示す図（図１（Ａ））である。

【図２】図２（Ａ）から図２（Ｄ）までは、本発明の実施の形態によるＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）構造を有する磁気抵抗素子（以下、「Ｆｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ」と称する。）の製造工程を模式的に示す図である。

【図３】図３（Ａ）は、Ｆｅ（１００）下部電極（第１電極）のＲＨＥＥＤイメージを示す図であり、図３（Ｂ）は、この際のＭｇＯ（１００）バリア層のＲＨＥＥＤイメージを示す図である。

【図４】ＭｇＯ成長時における四重極Ｍａｓｓスペクトルの観測結果を示す図である。

【図５】ＭｇＯ蒸着中の酸素分圧の膜堆積速度依存を示す図である。

【図６】Ｆｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ素子の典型的な磁気抵抗曲線を示す図である。

【図７】図７（Ａ）は、室温におけるＭＲ比のバイアス電圧依存性を示す図である。図７（Ｂ）は、ＭＴＪの出力電圧$Ｖ_{ｏｕｔ}$は（＝バイアス電圧×（Ｒａｐ－Ｒｐ）／Ｒａｐ）を示す図である。

【図８】ＴＭＲ素子の構造と、その動作原理を示す図である。

【図９】ＭＲＡＭの基本構造例を示す図であり、図９（Ａ）はＭＲＡＭの斜視図であり、図９（Ｂ）は模式的な回路構成図であり、図９（Ｃ）は、構造例を示す断面図である。

【図１０】アモルファスＡｌ－Ｏをトンネル障壁とした従来型ＴＭＲ素子の磁気抵抗の印加電圧による変化を示す図である

【符号の説明】

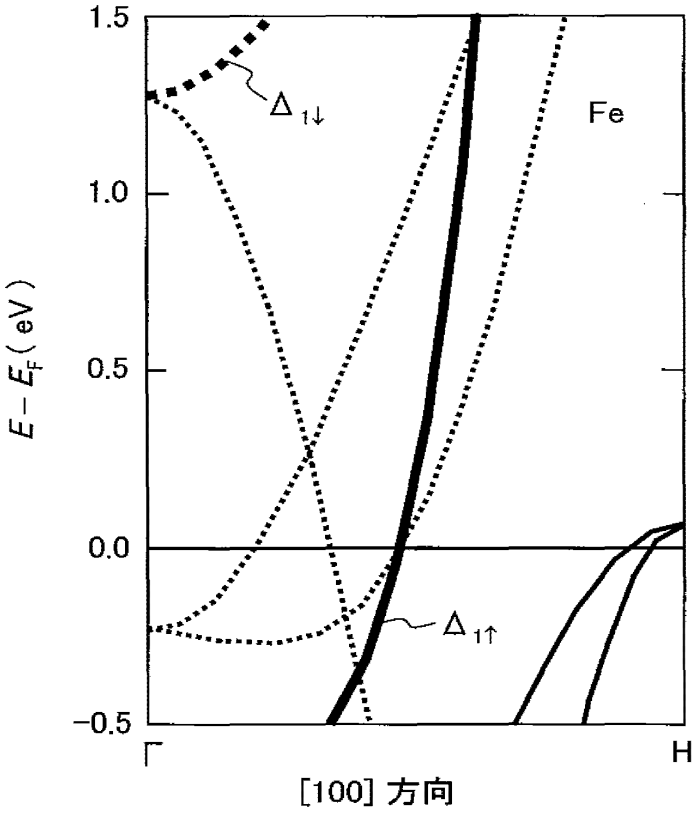
【００３２】

１…第１のＦｅ（１００）層、３…単結晶$ＭｇＯ_ｘ$（１００）あるいは（１００）結晶面が優先配向した多結晶$ＭｇＯ_ｘ$層（ｘ＜１）、５…第２のＦｅ（１００）層、１１…単結晶$ＭｇＯ_ｘ$（１００）あるいは（１００）結晶面が優先配向した多結晶$ＭｇＯ_ｘ$基板（

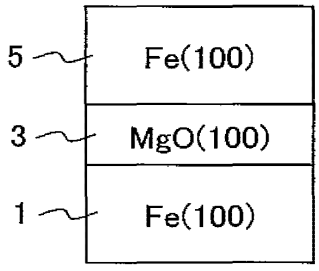
ｘ＜１）、１５…ＭｇＯ（１００）シード層、１７…エピタキシャルＦｅ（１００）下部電極（第１電極）、２１…ＭｇＯ（１００）バリア層、２３…エピタキシャルＦｅ（１００）上部電極（第２電極）。

【書類名】図面
【図１】

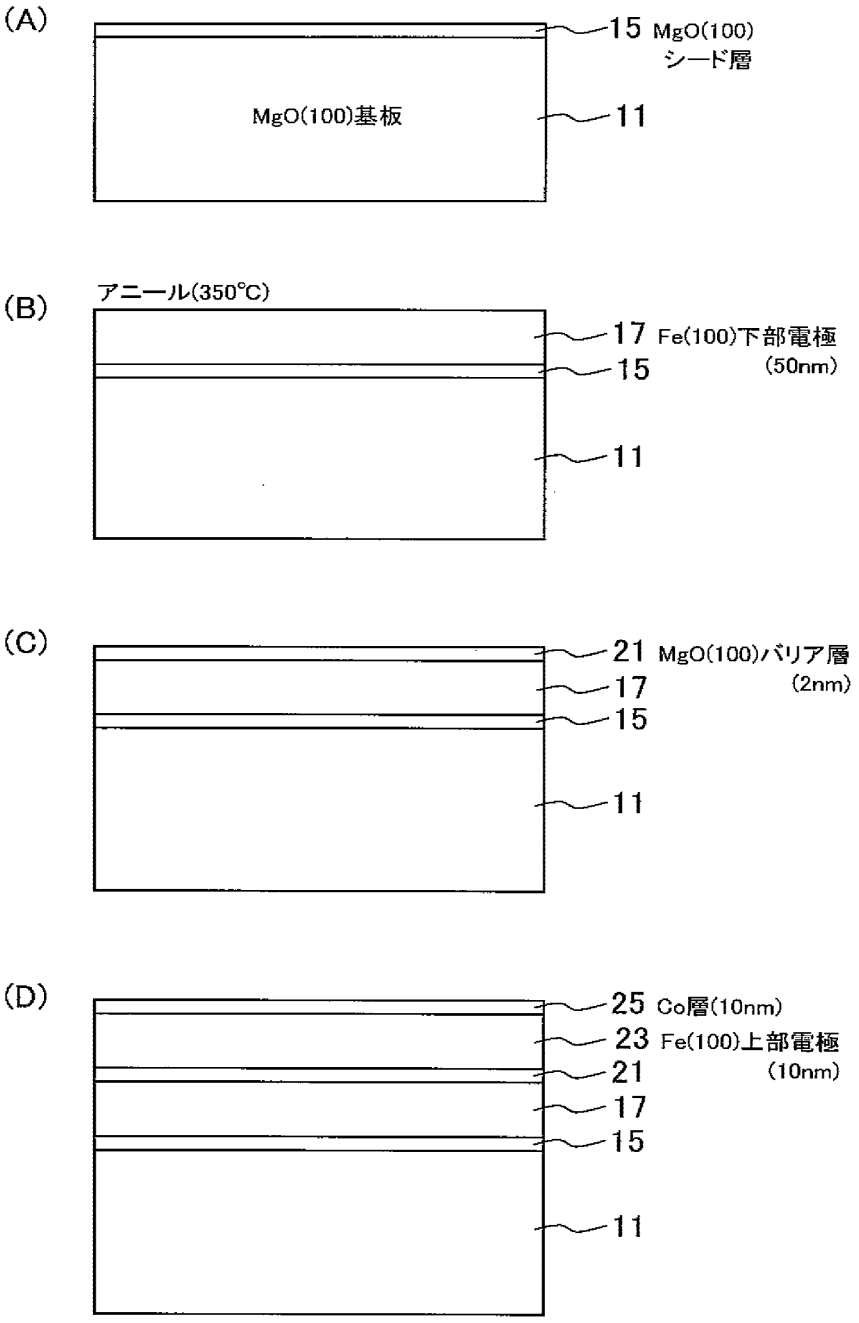
(A)


1.5
1.0
0.5
0.0
−0.5
$E-E_F$(eV)
$\Delta_{1\downarrow}$
$\Delta_{1\uparrow}$
Fe
Γ
H
[100] 方向

(B)

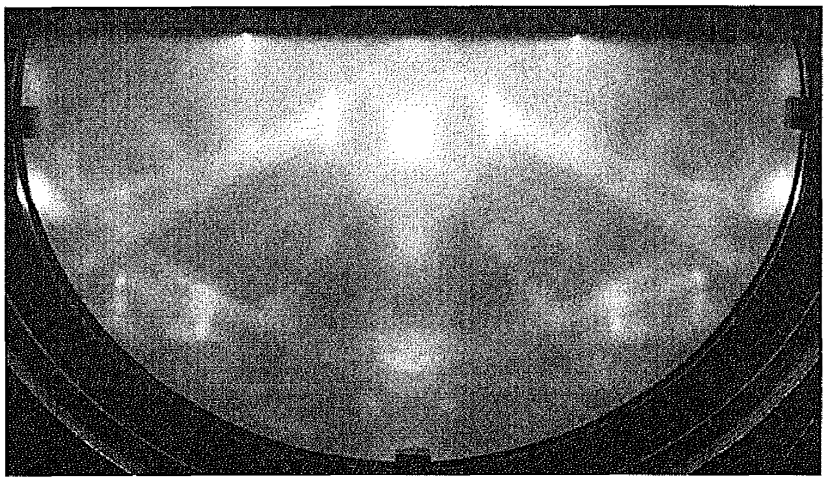

5
Fe(100)
3
MgO(100)
1
Fe(100)

【図２】

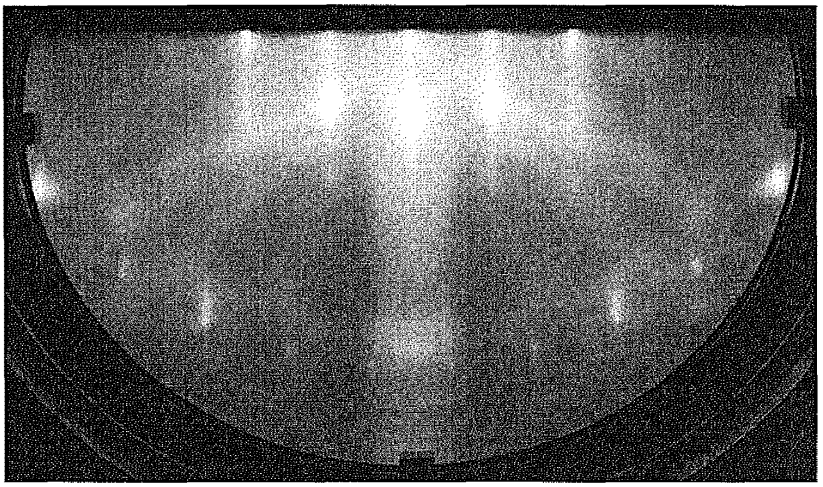

(A)
15 MgO(100)
シード層
MgO(100)基板
11
(B)
アニール(350℃)
17 Fe(100)下部電極
(50nm)
15
11
(C)
21 MgO(100)バリア層
(2nm)
17
15
11
(D)
25 Co層(10nm)
23 Fe(100)上部電極
(10nm)
21
17
15
11

【図３】

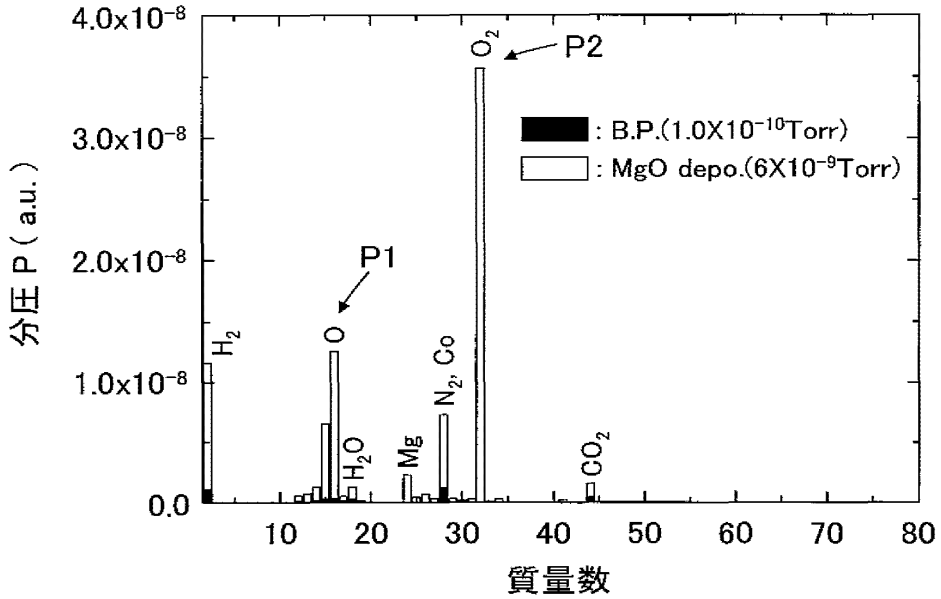
(a)



(b)

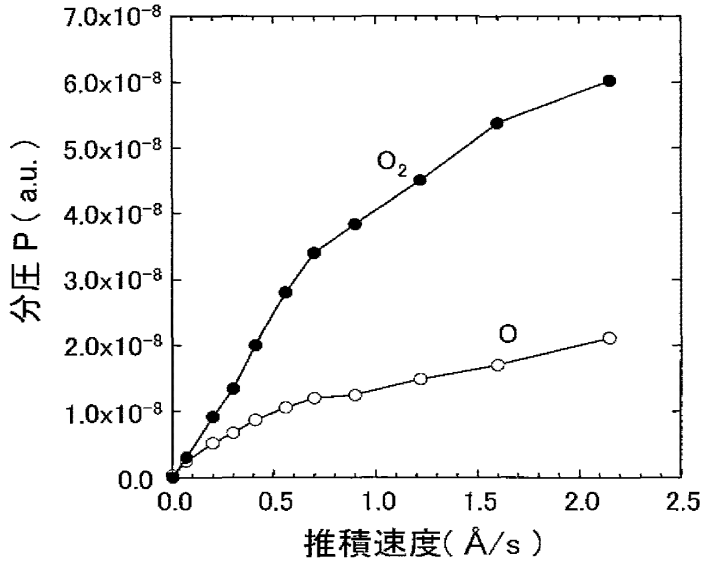


【図４】



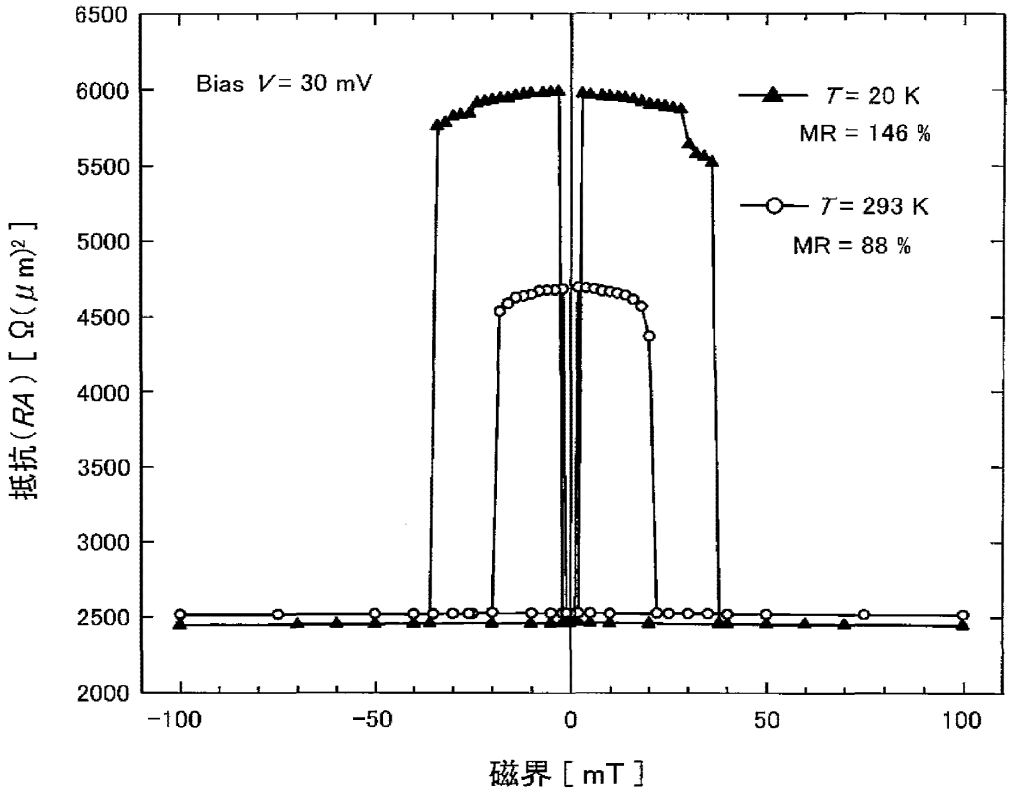
Massスペクトル

【図５】

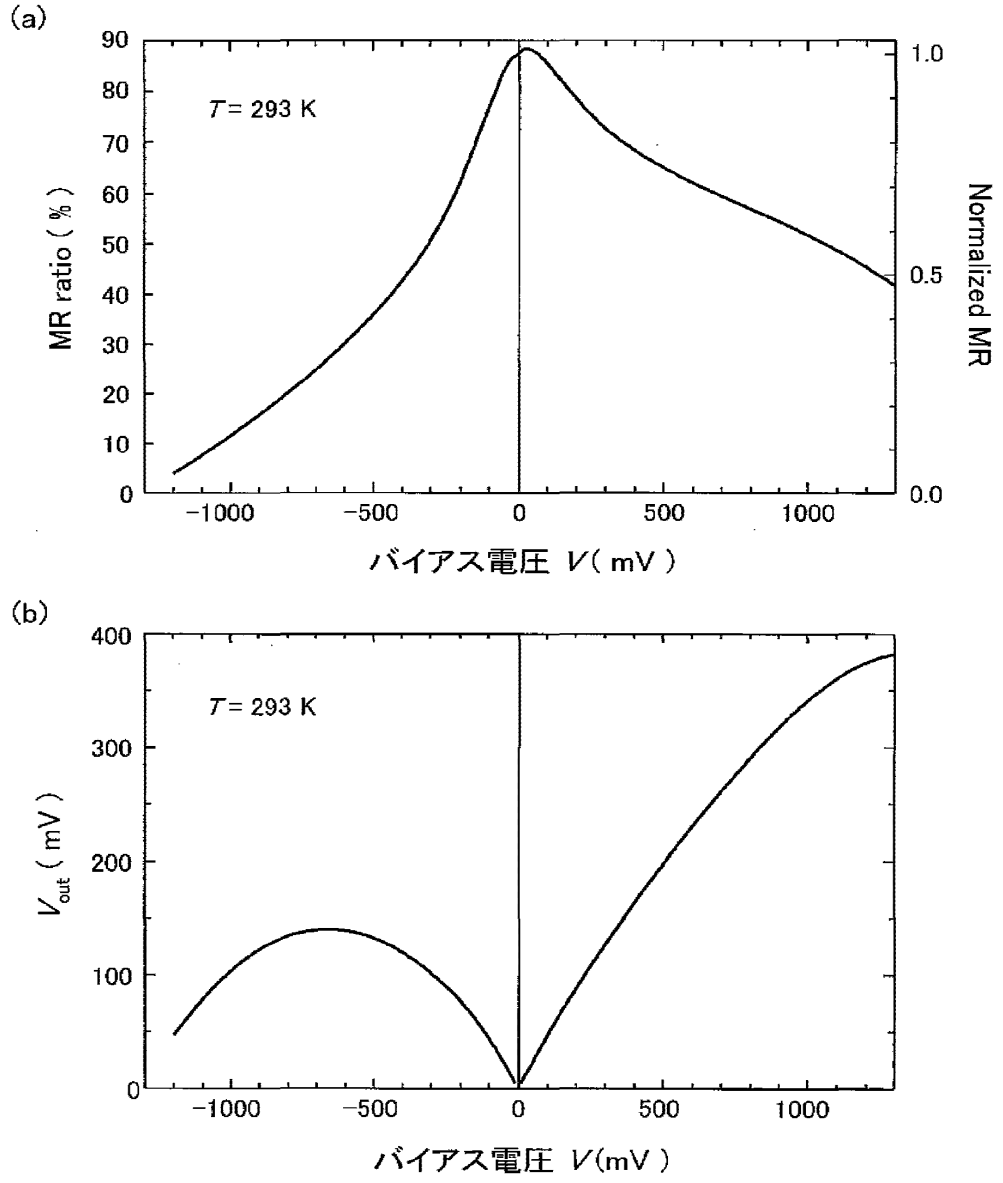


MgO蒸着中の酸素分圧

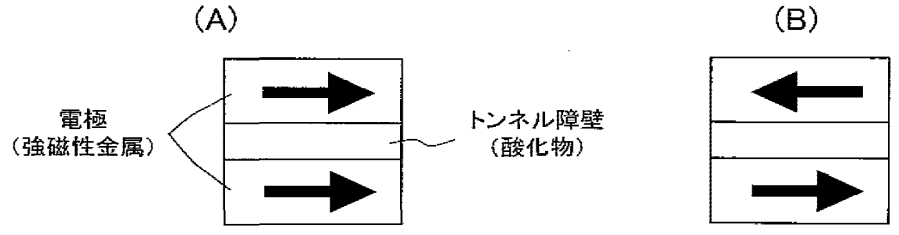
【図６】


Bias V = 30 mV
T = 20 K
MR = 146 %
T = 293 K
MR = 88 %
抵抗(RA)[Ω(μm)²]
磁界[mT]
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
−100
−50
0
50
100

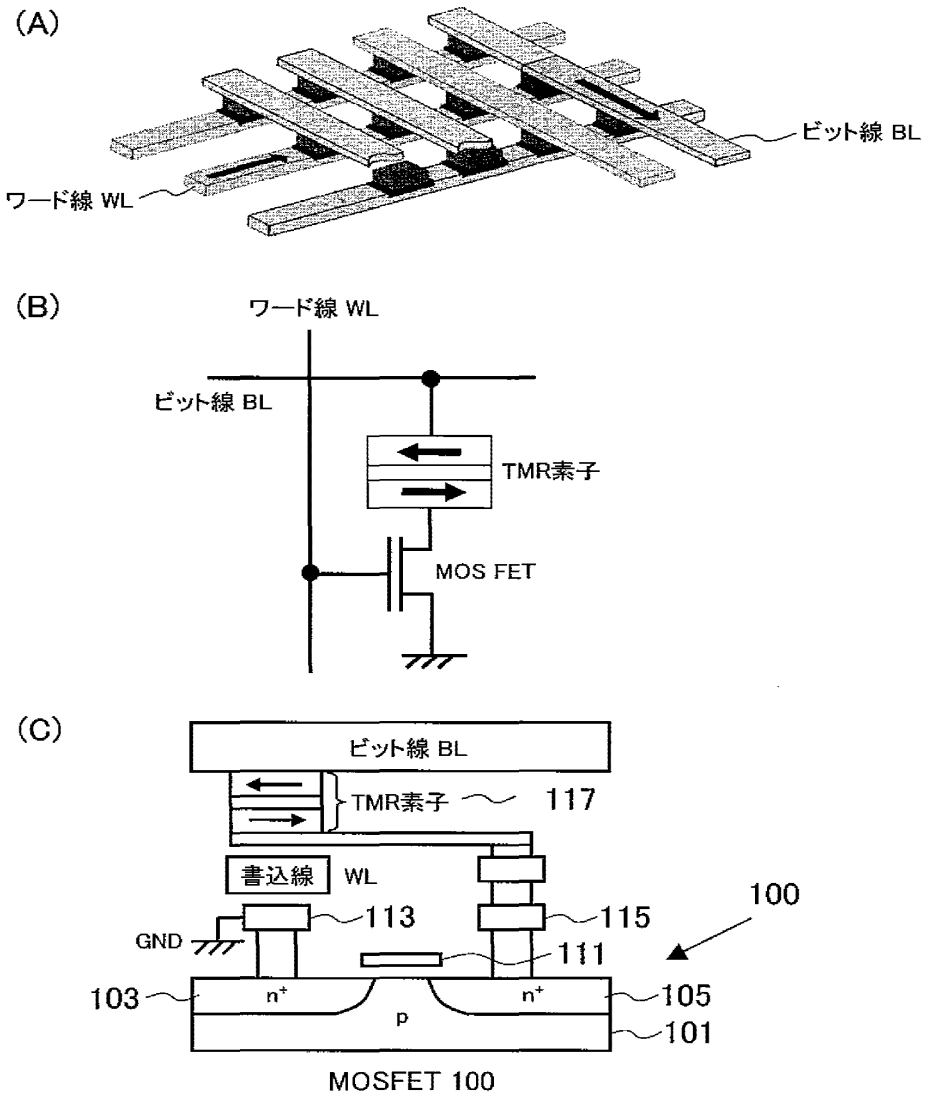
【図７】


(a)
T = 293 K
MR ratio (%)
Normalized MR
90
80
70
60
50
40
30
20
10
0
1.0
0.5
0.0
−1000
−500
0
500
1000
バイアス電圧 V(mV)
(b)
T = 293 K
V_{out} (mV)
400
300
200
100
0
−1000
−500
0
500
1000
バイアス電圧 V(mV)

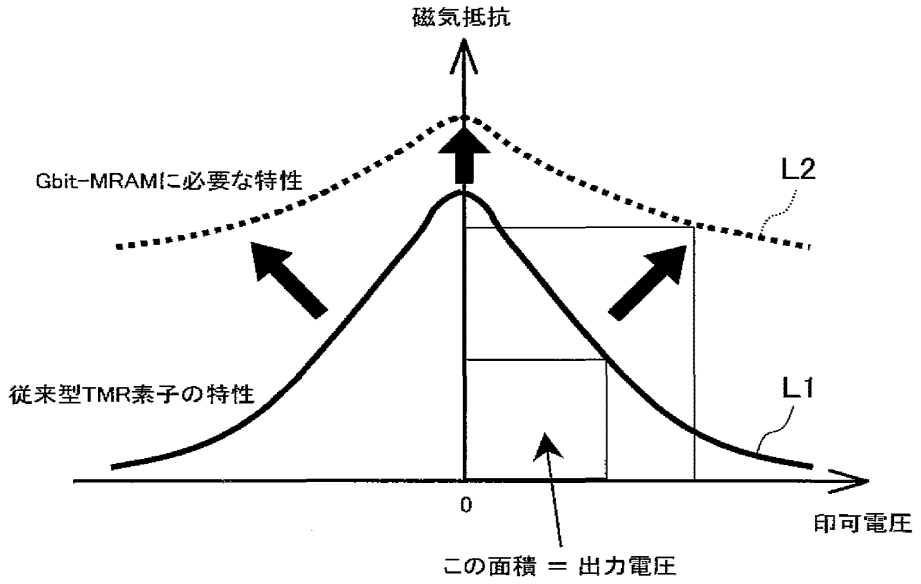
【図８】


(A)
(B)
電極
（強磁性金属）
トンネル障壁
（酸化物）

【図９】


(A)
ビット線 BL
ワード線 WL
(B)
ワード線 WL
ビット線 BL
TMR素子
MOS FET
(C)
ビット線 BL
TMR素子
117
書込線
WL
100
113
115
GND
111
103
n+
n+
105
p
101
MOSFET 100

【図１０】



【書類名】要約書
【要約】
【課題】　ＭＲＡＭの出力電圧値を高める。
【解決手段】　単結晶ＭｇＯ（１００）基板１１を準備し、５０ｎｍ厚のエピタキシャルＦｅ（１００）下部電極（第１電極）１７をＭｇＯ（１００）シード層１５上に室温で成長し、次いで、超高真空（２×１０－８Ｐａ）において、３５０℃でアニールを行う。２ｎｍ厚のＭｇＯ（１００）バリア層２１をＦｅ（１００）下部電極（第１電極）１７上に室温でエピタキシャル成長する。この際、ＭｇＯの電子ビーム蒸着を用いた。ＭｇＯ（１００）バリア層２１上に室温で、厚さ１０ｎｍのＦｅ（１００）上部電極（第２電極）２３を形成した。連続して、１０ｎｍ厚さのＣｏ層２１をＦｅ（１００）上部電極（第２電極）２３上に堆積した。Ｃｏ層２１は、上部電極２３の強制的な磁界をエンハンスするための反平行磁化配置を実現するためのものである。次いで、上記の作成試料を微細加工してＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ素子を形成する。
【選択図】　図２

【書類名】　　手続補正書
【整理番号】　　P04-0204
【提出日】　　平成16年 4月 8日
【あて先】　　特許庁長官　殿
【事件の表示】
　【出願番号】　　特願2004- 71186
【補正をする者】
　【識別番号】　　503360115
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【手続補正1】
　【補正対象書類名】　特許願
　【補正対象項目名】　提出物件の目録
　【補正方法】　　追加
　【補正の内容】
　　【提出物件の目録】
　　【物件名】　　知的財産権持分契約書　1

【物件名】　知的財産権持分契約書

【添付書類】

知的財産権持分契約書

独立行政法人産業技術総合研究所理事長　吉川　弘之（以下「甲」という。）及び独立行政法人科学技術振興機構理事長　沖村　憲樹（以下「乙」という。）は、乙の戦略的創造研究推進事業において、共同で行った発明等に係る知的財産権（以下「本知的財産権」という。）の持分及び取り扱いに関し次のとおり契約する。

（知的財産権の持分）

第１条　甲及び乙は、持分を以下のとおり所有する。

発明等の名称　：磁気抵抗素子及びその製造方法
整理番号等　：Ｐ０４－０２０４
持　　分　：甲　５０％　、乙　５０％

（知的財産権の管理費用）

第２条　甲及び乙は、管理（取得に係る費用を含む。）に要する費用を、持分に応じて負担するものとする。

（協議）

第３条　この契約で定めるもののほか、その取り扱い及びその他必要な事項については、甲乙が協議して定める。

この契約の締結を証するため、本契約書を３通作成し、双方記名押印の上、甲及び乙それぞれ１通を保有するとともに、１通を出願の手続きのために使用する。

平成１６年３月１２日

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　　理事長　沖村憲樹

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新規登録

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20040401

名称変更

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５０３３６０１１５

20090820

住所変更

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住所変更

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新規登録

５０３０６３７６６

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独立行政法人産業技術総合研究所

日　本　国　特　許　庁
JAPAN PATENT OFFICE

別紙添付の書類に記載されている事項は下記の出願書類に記載されている事項と同一であることを証明する。

This is to certify that the annexed is a true copy of the following application as filed with this Office.

出願年月日 Date of Application:	２００４年１０月２８日
出願番号 Application Number:	特願２００４－３１３３５０
パリ条約による外国への出願に用いる優先権の主張の基礎となる出願の国コードと出願番号 The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is	ＪＰ２００４－３１３３５０
出願人 Applicant(s):	独立行政法人科学技術振興機構 独立行政法人産業技術総合研究所

２０１３年　６月１４日

特許庁長官
Commissioner,
Japan Patent Office　深野弘行

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【国際特許分類】　H01L 43/00
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　【連絡先】　担当
【先の出願に基づく優先権主張】
　【出願番号】　特願2004- 71186
　【出願日】　平成16年 3月12日
【手数料の表示】
　【予納台帳番号】　015244
　【納付金額】　16,000円
【提出物件の目録】
　【物件名】　特許請求の範囲　1
　【物件名】　明細書　1
　【物件名】　図面　1
　【物件名】　要約書　1

【書類名】特許請求の範囲
【請求項１】
トンネル障壁層と、該トンネル障壁層の第１面側に形成されたＢＣＣ構造を有する第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＢＣＣ構造を有する第２の強磁性体層と、を有する磁気トンネル接合構造であって、
前記トンネル障壁層が、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子。
【請求項２】
ＭｇＯ（１００）からなるトンネル障壁層と、該トンネル障壁層の第１面側に形成されたＦｅ（１００）からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＦｅ（１００）からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、
前記ＭｇＯ層が、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子。
【請求項３】
ＭｇＯ（１００）からなるトンネル障壁層と、該トンネル障壁層の第１面側に形成されたＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、
前記ＭｇＯ（１００）層の伝導帯下端と前記Ｆｅ（１００）層のフェルミ準位の間の不連続値（トンネル障壁の高さ）を単結晶における理想的な値よりも低くしたことを特徴とする磁気抵抗素子。
【請求項４】
前記不連続値は、０．２～０．５ｅＶの範囲内であることを特徴とする請求項３に記載の磁気抵抗素子。
【請求項５】
前記不連続値は、０．１０～０．８５ｅＶの範囲内であることを特徴とする請求項３に記載の磁気抵抗素子。
【請求項６】
１つのトランジスタと、該トランジスタの負荷として用いられる請求項１から５までのいずれか１項に記載の磁気抵抗素子と
を有する記憶素子。
【請求項７】
基板を準備する工程と、
該基板上に第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を堆積する工程と、
前記第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の（１００）層上に、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）からなるトンネル障壁層を高真空下において堆積する工程と、
該トンネル障壁層上に第２のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を形成する工程と
を有することを特徴とする磁気抵抗素子の製造方法。
【請求項８】
単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）からなる基板を準備する第１工程と、
該基板上に第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を堆積し、次いで、結晶化のためのアニール

を行う第２工程と、
　前記第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の（１００）層上に単結晶ＭｇＯ$_x$（１００）あるいは（１００）結晶面が優先配向した多結晶ＭｇＯ$_x$（０＜ｘ＜１）からなるトンネル障壁層を高真空下において堆積する第３工程と、
　該トンネル障壁層上に第２のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を形成する第４工程と
を有することを特徴とする磁気抵抗素子の製造方法。
【請求項９】
　前記第１工程と第２工程との間に、単結晶ＭｇＯ$_x$（１００）あるいは（１００）結晶面が優先配向した多結晶ＭｇＯ$_x$（０＜ｘ＜１）からなるシード層を成長する工程を有することを特徴とする請求項７又は８に記載の磁気抵抗素子の製造方法。
【請求項１０】
　前記単結晶ＭｇＯ$_x$（１００）あるいは（１００）結晶面が優先配向した多結晶ＭｇＯ$_x$（０＜ｘ＜１）からなるトンネル障壁層を形成する工程中に、ＭｇＯ$_x$のｘ値を調整する工程を含むことを特徴とする請求項７又は８に記載の磁気抵抗素子の製造方法。
【請求項１１】
　基板を準備する工程と、
　該基板上に第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を堆積する工程と、
　前記第１のＦｅまたはＢＣＣ構造を有するＦｅ系合金の（１００）層上にアモルファスＭｇＯ層を形成し、アニールにより該アモルファスＭｇＯ層を結晶化して単結晶ＭｇＯ$_x$（１００）あるいは（１００）結晶面が優先配向した多結晶ＭｇＯ$_x$（０＜ｘ＜１）からなるトンネル障壁層を形成する工程と、
　該トンネル障壁層上に第２のＦｅまたはＢＣＣ構造を有するＦｅ系合金の単結晶（１００）層または（１００）結晶面が優先配向した多結晶層を形成する工程と
を有することを特徴とする磁気抵抗素子の製造方法。
【請求項１２】
　前記アモルファスＭｇＯ層をスパッタリング法により、ＭｇＯ$_x$のｘ値を調整済みのターゲットを用いて堆積することを特徴とする請求項１１に記載の磁気抵抗素子の製造方法。
【請求項１３】
　前記アモルファスＭｇＯを形成する工程中に、ＭｇＯ$_x$のｘ値を調整する工程を含むことを特徴とする請求項１１に記載の磁気抵抗素子の製造方法。
【請求項１４】
　トンネル障壁層と、該トンネル障壁層の第１面側に形成されたアモルファス磁性合金からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたアモルファス磁性合金からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、
　前記トンネル障壁層が、単結晶ＭｇＯ$_x$（１００）あるいは（１００）結晶面が優先配向した多結晶ＭｇＯ$_x$（０＜ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子。
【請求項１５】
　ＭｇＯ（１００）からなるトンネル障壁層と、該トンネル障壁層の第１面側に形成されたアモルファス磁性合金からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたアモルファス磁性合金からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、
　前記ＭｇＯ（１００）層の伝導帯下端と前記アモルファス磁性合金からなる第１又は第２の強磁性体層とのフェルミ準位の間の不連続値（トンネル障壁の高さ）を単結晶における理想的な値よりも低くしたことを特徴とする磁気抵抗素子。
【請求項１６】
　前記不連続値は、０．２～０．５ｅＶの範囲内であることを特徴とする請求項１４又は

１５に記載の磁気抵抗素子。
【請求項１７】
前記不連続値は、０．１０～０．８５ｅＶの範囲内であることを特徴とする請求項１４又は１５に記載の磁気抵抗素子。
【請求項１８】
１つのトランジスタと、該トランジスタの負荷として用いられる請求項１４から１７までのいずれか１項に記載の磁気抵抗素子と
を有する記憶素子。
【請求項１９】
基板を準備する工程と、
該基板上にアモルファス磁性合金からなる第１の強磁性体層を堆積する工程と、
該第１の強磁性体層上にアモルファスＭｇＯ層を形成し、アニールにより該アモルファスＭｇＯ層を結晶化して単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）からなるトンネル障壁層を形成する工程と、
該トンネル障壁層上にアモルファス磁性合金からなる第２の強磁性体層を堆積する工程を有することを特徴とする磁気抵抗素子の製造方法。
【請求項２０】
前記単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）からなるトンネル障壁層を形成する工程中は、スパッタリング法によりMgO_xのｘ値を調整済みのターゲットを用いて堆積することを特徴とする磁気抵抗素子の製造方法。

【書類名】明細書
【発明の名称】磁気抵抗素子及びその製造方法
【技術分野】
【０００１】
本発明は、磁気抵抗素子及びその製造方法に関し、特に、高い磁気抵抗を有する磁気抵抗素子及びその製造方法に関する。
【背景技術】
【０００２】
MRAM（Magnetoresistive Random Access Memory）は、現在広く用いられている記憶素子であるＤＲＡＭに代わる大容量向け記憶素子であり、かつ、高速な不揮発性メモリとして広く研究開発が行われており、例えば、4MbitのMRAMがサンプル出荷されたという実績がある。
【０００３】
図８は、ＭＲＡＭの心臓部であるＴＭＲ素子の構造と、その動作原理を示す図である。図８（Ａ）に示すように、ＴＭＲ素子においては、酸化物からなるトンネル障壁の両側を強磁性金属からなる第１及び第２の２つの電極により挟んだトンネル構造を有している。トンネル障壁層としては、アモルファスのＡｌ－Ｏ層が用いられている（非特許文献１参照）。図８（Ａ）に示すように、第１の強磁性電極と第２の強磁性電極との磁化の向きが平行な平行磁化の場合には、トンネル構造の界面における法線方向に関する素子の電気抵抗が小さくなる。一方、図８（Ｂ）に示すように、第１の強磁性電極と第２の強磁性電極との磁化の向きが平行な反平行磁化の場合には、トンネル構造の界面における法線方向に関する素子の電気抵抗が大きくなる。この抵抗値は、一般的な状態では変化せず、抵抗値が高いか低いかに基づいて情報“１”、“０”として記憶される。平行磁化と反平行磁化とは不揮発に記憶されるため、不揮発性メモリの基本素子として用いることができる。
図９は、ＭＲＡＭの基本構造例を示す図であり、図９（Ａ）はＭＲＡＭの斜視図であり、図９（Ｂ）は模式的な回路構成図であり、図９（Ｃ）は、構造例を示す断面図である。図９（Ａ）に示すように、ＭＲＡＭにおいてはワード線ＷＬとビット線ＢＬとが交差するように配置され、交差部にＭＲＡＭセルが配置されている。図９（Ｂ）に示すように、ワード線とビット線との交差部に配置されたＭＲＡＭセルは、ＴＭＲ素子と、このＴＭＲ素子と直列接続されたＭＯＳＦＥＴとを有しており、負荷抵抗として機能するＴＭＲ素子の抵抗値をＭＯＳＦＥＴにより読み取ることにより、記憶情報を読み出すことができる。尚、情報の書き換えは、例えば、ＴＭＲ素子への磁場の印加により行うことができる。図９（Ｃ）に示すように、ＭＲＡＭメモリセルは、ｐ型Ｓｉ基板１０１内に形成されたソース領域１０３とドレイン領域１０５と、その間に画定されるチャネル領域に対して形成されたゲート電極１１１とを有するＭＯＳＦＥＴ１００と、ＴＭＲ素子１１７とを有している。ソース領域１０３はソース電極１１３を介して接地（ＧＮＤ）され、ドレイン領域１０５は、ドレイン電極１１５とＴＭＲ素子とを介してビット線ＢＬに接続されている。ワード線ＷＬはゲート電極１１１に対して図示しない領域において接続されている。
【０００４】
以上に説明したように、不揮発性メモリＭＲＡＭは、１つのＭＯＳＦＥＴ１００とＴＭＲ素子１１７とにより１つのメモリセルを形成することができるため、高集積化に適したメモリ素子ということができる。
【０００５】
【非特許文献１】D.Wang, et al.:Science 294 (2001) 1488.
【発明の開示】
【発明が解決しようとする課題】
【０００６】
現状の技術を用いることにより６４Ｍｂｉｔ程度のＭＲＡＭを実現する見通しは立っているが、それ以上の高集積化のためには、ＭＲＡＭの心臓部であるＴＭＲ素子の特性を向上させる必要がある。特に、ＴＭＲ素子の出力電圧を向上させるには、磁気抵抗の増大と電

圧特性の改善の両方が必要である。図１０は、アモルファスＡｌ－Ｏをトンネル障壁とした従来型ＴＭＲ素子の磁気抵抗の印加電圧による変化を示す図である（Ｌ１）。図１０に示すように、従来型ＴＭＲ素子においては、磁気抵抗が小さく、特に電圧を印加することにより磁気抵抗が急激に小さくなる傾向がみられる。このような特性では、動作マージンを考慮した出力電圧が小さすぎるため、実際の記憶素子に用いるのが難しい。より具体的には、現状のＴＭＲ素子の磁気抵抗は約70％と低く、また出力電圧も200 ｍＶ以下と低いため、ＤＲＡＭの出力電圧に比べて実質的に半分であり、集積度を上げるに従い信号がノイズに埋もれて読み出せなくなってしまうという問題があった。

【０００７】

本発明は、ＴＭＲ素子における出力電圧を大きくすることを目的とする。さらに、大きな磁気抵抗により、安定に動作する記憶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】

【０００８】

本発明の一観点によれば、トンネル障壁層と、該トンネル障壁層の第１面側に形成されたＢＣＣ構造を有する第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＢＣＣ構造を有する第２の強磁性体層と、を有する磁気トンネル接合構造であって、前記トンネル障壁層が、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子が提供される。

【０００９】

また、ＭｇＯ（１００）からなるトンネル障壁層と、該トンネル障壁層の第１面側に形成されたＦｅ（１００）からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたＦｅ（１００）からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、前記ＭｇＯ層が、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）層により形成されていることを特徴とする磁気抵抗素子が提供される。前記ＭｇＯ（１００）層の伝導帯下端と前記Ｆｅ（１００）層のフェルミエネルギーの間の不連続値（トンネル障壁高さ）を単結晶における値よりも低くしたことを特徴とする。上記構成を用いると、磁気抵抗が増大しＴＭＲ素子の出力電圧を大きくすることができた。１つのトランジスタの負荷として上記磁気抵抗素子を用いると、不揮発性の記憶素子を形成することができた。

【００１０】

本発明の他の観点によれば、基板を準備する工程と、該基板上に第１のＦｅ（１００）層を堆積する工程と、前記第１のＦｅ（１００）層上に電子ビーム蒸着法により単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）からなるトンネル障壁層を高真空下において堆積する工程と、該トンネル障壁層上に第２のＦｅ（１００）層を形成する工程とを有することを特徴とする磁気抵抗素子の製造方法が提供される。

【００１１】

また、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）からなる基板を準備する第１工程と、該基板上に第１のＦｅ（１００）層を堆積し、次いで、結晶化のためのアニールを行う第２工程と、前記第１のＦｅ（１００）層上に電子ビーム蒸着法により単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）からなるトンネル障壁層を高真空下において堆積する第３工程と、該トンネル障壁層上に第２のＦｅ（１００）層を形成する第４工程とを有することを特徴とする磁気抵抗素子の製造方法が提供される。尚、前記第１工程と第２工程との間に、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）からなるシード層を成長する工程を有していても良い。また、前記アモルファスＭｇＯ層を、MgO_xのｘ値を調整済みのターゲットを用いて堆積しても良い。この際、前記アモルファスＭｇＯを形成する工程中に、MgO_xのｘ値を調整しても良い。

【００１２】
本発明のさらに別の観点によれば、ＭｇＯ（１００）からなるトンネル障壁層と、該トンネル障壁層の第１面側に形成されたアモルファス磁性合金からなる第１の強磁性体層と、前記トンネル障壁層の第２面側に形成されたアモルファス磁性合金からなる第２の強磁性体層と、を有する磁気トンネル接合構造であって、前記ＭｇＯ（１００）層の伝導帯下端と前記アモルファス磁性合金からなる第１又は第２の強磁性体層とのフェルミ準位の間の不連続値（トンネル障壁の高さ）を単結晶における理想的な値よりも低くしたことを特徴とする磁気抵抗素子が提供される。
【発明の効果】
【００１３】
本発明によれば、従来のＴＭＲ素子に比べて大きな磁気抵抗を得ることができ、ＴＭＲ素子の出力電圧を大きくすることができる。従って、ＴＭＲ素子を用いたＭＲＡＭの高集積化が容易になるという利点がある。
【発明を実施するための最良の形態】
【００１４】
本明細書において用いた単結晶における「理想的な値」との用語は、紫外線光電子分光の実験から推測した値である（参考文献：W. Wulfhekel, et al.: Appl. Phys. Lett. 78（2001）509.）。このような状態では、酸素欠損や格子欠陥がほとんど無い理想的な単結晶ＭｇＯのトンネル障壁の上限値と言うことができるため、理想的な値という用語を用いた。
【００１５】
発明の実施の形態について説明する前に、発明者の行った考察について説明を行う。ＭＴＪの磁気抵抗（ＭＲ）比は、以下の式で表される。
ΔＲ／Ｒｐ＝（Ｒａｐ－Ｒｐ）／Ｒｐ
ここで、Ｒｐ及びＲａｐは、２つの電極の磁化が平行と反平行の場合のトンネル接合抵抗である。Ｊｕｌｌｉｒｅの公式によれば、低バイアス電圧におけるＭＲ比は、以下のように表される。
ＭＲ比＝（Ｒａｐ－Ｒｐ）／Ｒｐ＝$2P_1P_2/(1-P_1P_2)$であり、
$P_\alpha=(D_\alpha\uparrow(E_F)-D_\alpha\downarrow(E_F))/(D_\alpha\uparrow(E_F)+D_\alpha\downarrow(E_F))$、α＝１，２　（１）
と表される。
【００１６】
ここで、Ｐαは、電子のスピン分極率であり、$D_\alpha\uparrow(E_F)$と$D_\alpha\downarrow(E_F)$とは、それぞれ、多数スピンバンドと少数スピンバンドのフェルミエネルギー（E_F）における状態密度（Ｄｅｎｓｉｔｙ　ｏｆ　ｓｔａｔｅ：ＤＯＳ）である。強磁性遷移金属及び合金のスピンの偏極は０．５以下であるため、Ｊｕｌｌｉｒｅの公式によれば、最も高い推定ＭＲ比として７０％が予測される。
ＭＴＪ素子をアモルファスのＡｌ－Ｏのトンネル障壁と多結晶電極とを用いて作成すると、室温でのＭＲ比として約７０％という値が得られているが、ＤＲＡＭ並の出力電圧である２００ｍＶを得るのは難しく、上述のようにＭＲＡＭ実現の対する問題点となっている。
【００１７】
発明者は、酸化マグネシウムの単結晶（１００）あるいは（１００）結晶面が優先配向した多結晶ＭｇＯをトンネル障壁として用いたＭＴＪを成長するアプローチを試みている。従来のアモルファスのアルミナ障壁とは異なり、酸化マグネシウムは結晶（原子が規則正しく配列した物質）であるため、電子が散乱されず、電子のコヒーレント状態がトンネル過程のおいて保存されることが予測される。図１は、本実施の形態によるＭＴＪ素子構造（図１（Ｂ））と、強磁性体金属であるＦｅ（１００）のエネルギーバンド構造を示す図であり、波数空間の［１００］方向に対するＥ－E_Fの関係を示す図（図１（Ａ））である。図１（Ｂ）に示すように、本実施の形態によるＭＴＪ素子構造は、第１のＦｅ（１

００）層１と、第２のＦｅ（１００）層５と、これらの間に挟まれた単結晶MgO_x（１００）層あるいは（１００）結晶面が優先配向した多結晶MgO_x（０＜ｘ＜１）層３と、を有して構成されている。上記Ｊｕｌｌｉｒｅのモデルによれば、伝導電子のモメンタムがトンネルプロセス中において保存されるとすると、ＭｇＯを透過するトンネル電流はトンネル障壁に垂直な方向（接合界面に対する法線方向）の波数ベクトルk_Zを有する電子が支配的になる。図１（Ａ）に示す[１００]（Γ－Ｈ）方向におけるＦｅのエネルギーバンド図によれば、フェルミ準位E_Fにおける状態密度（ＤＯＳ）は、多数スピンと少数スピンのサブバンドがフェルミ準位E_Fにおいて状態を有しているため、それほど高い偏極率を示さない。しかしながら、電子のコヒーレント状態がトンネル過程のおいて保存される場合には、障壁に垂直な軸に関してトータルに対称な波動関数を有する伝導電子のみが障壁領域における状態と関連し、ある一定のトンネル確率を持つことになる。図１（Ａ）に示すように、多数スピンΔ１バンド（実線）がフェルミ準位E_Fに状態を有するが、少数スピンΔ１バンド（破線）はフェルミ準位E_Fに状態を有しない。このようなＦｅΔ１バンドのハーフメタル的な特徴により、非常に高いＭＲ比がコヒーレントなスピン偏極トンネルにおいて得られる可能性がある。エピタキシャル（単結晶あるいは（１００）配向多結晶）のＭＴＪは、トンネル過程中における電子の散乱が抑制されるため、上記のようなコヒーレントなトンネルを実現するためには理想的であると考えられる。

【００１８】

以下、本発明の第１の実施の形態による磁気抵抗素子及びその製造方法について図面を参照しつつ説明を行う。図２（Ａ）から図２（Ｄ）までは、本発明の実施の形態によるＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）構造を有する磁気抵抗素子（以下、「Ｆｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ」と称する。）の製造工程を模式的に示す図である。Ｆｅ（１００）は、ＢＣＣ構造を有する強磁性体である。まず、単結晶ＭｇＯ（１００）基板１１を準備し、ＭＢＥ法（分子線エピタキシー法）により、単結晶ＭｇＯ（１００）基板１１の表面のモフォロジーを改善するため、ＭｇＯ（１００）シード層１５を成長する。連続して、図１（Ｂ）に示すように、５０ｎｍ厚のエピタキシャルＦｅ（１００）下部電極（第１電極）１７をＭｇＯ（１００）シード層１５上に室温で成長し、次いで、超高真空下（２×１０－８Ｐａ）において、３５０℃でアニールを行う。尚、電子線蒸着における条件は、加速電圧が８ｋＶであり、成長速度が０．０２ｎｍ／秒、成長温度が室温（２９３Ｋ）、ソースとしては化学量論的組成のＭｇＯ（ＭｇとＯとの比が１：１）を用い、ソースと基板との距離を４０ｃｍとし、バックグラウンドの真空度が１×１０－８Ｐａ、O_2分圧が１×１０－６Ｐａである。尚、化学量論的組成のＭｇＯ（ＭｇとＯとの比が１：１）の代わりに、Ｏ欠損を有するソースを使用することも可能である。

【００１９】

図３（Ａ）は、この際のＦｅ（１００）下部電極（第１電極）１７のＲＨＥＥＤイメージを示す図である。図３（Ａ）に示すように、Ｆｅ（１００）下部電極（第１電極）１７は良好な結晶性と平坦性を有していることを示している。次いで、図２（Ｃ）に示すように、２ｎｍ厚のＭｇＯ（１００）バリア層２１をＦｅ（１００）下部電極（第１電極）１７上に室温でエピタキシャル成長する。この際も、ＭｇＯの電子ビーム蒸着法を用いた。図３（Ｂ）は、この際のＭｇＯ（１００）バリア層２１のＲＨＥＥＤイメージを示す図である。図３（Ｂ）に示すように、ＭｇＯ（１００）バリア層２１も良好な結晶性と平坦性を有していることを示している。

【００２０】

図２（Ｄ）に示すように、ＭｇＯ（１００）バリア層２１上に、室温で厚さ１０ｎｍのＦｅ（１００）上部電極（第２電極）２３を形成した。連続して、１０ｎｍ厚さのＣｏ層２５をＦｅ（１００）上部電極（第２電極）２３上に堆積した。Ｃｏ層２５は、上部電極２３の保持力を高めることによって反平行磁化配置を実現するためのものである。次いで、上記の作成試料を微細加工してＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ素子を形成する。

【００２１】
上記ＥＢによるＭｇＯ蒸着は、１０－９Ｔｏｒｒの超高真空状態で成膜を行った。この方法では、例えばガラス基板上に３００ｎｍの成膜を行った場合でも、無色透明であり、良好な単結晶膜が形成されていることがわかる。図４は、ＭｇＯ成長時における四重極Ｍａｓｓスペクトルの観測結果を示す図である。図４に示すように、ＯのスペクトルＰ１とO_2のスペクトルＰ２とに関する分圧が高いことがわかる。図５は、ＭｇＯ蒸着中の酸素分圧の膜堆積速度依存を示す図である。図５に示すように、酸素分圧自体がかなり高いこと、堆積速度とともに酸素分圧も高くなること、などは、ＭｇＯの堆積時におけるＭｇＯ単結晶からの酸素の離脱を示唆するものであり、MgO_x（０．９＜ｘ＜１）のように酸素欠損が生じている可能性がある。酸素欠損が生じるとＭｇＯトンネル障壁の高さが低くなると考えられ（例えば、0.10～0.85ｅＶ、より詳細には0.2～0.5ｅＶの範囲内）、これにより、トンネル電流が増加するものと考えられる。尚、一般的なＡｌ－Ｏトンネル障壁の場合、Ｆｅ（１００）との間のトンネル障壁の高さは、０．７～２．５ｅＶと考えられる。これに対して、ＭｇＯ結晶は理想的なトンネル障壁の高さは３．６ｅＶであり、実験値としては０．９～３．７ｅＶの値が得られている。本実施の形態による方法を用いると、０．３ｅＶ程度のトンネル障壁の高さが推定され、トンネル障壁の低抵抗化が可能であることがわかる。但し、その他の要因、例えば前述のコヒーレントなトンネルの影響も関連している可能性がある。尚、酸素欠損に基づくMgO_xのｘの値としては、０．９８＜ｘ＜１、より好ましくは０．９９＜ｘ＜１程度であり、Ｍｇ単体のようなものは含まれず、ＭｇＯの特性が基本的には維持される範囲である。
【００２２】
図６は、上記の方法により製造したＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ素子の典型的な磁気抵抗曲線を示す図である。測定温度２０ＫにおいてＭＲ比１４６％であり、測定温度２９３ＫにおいてＭＲ比は８８％であった。この値は、現在までに室温において得られた最も高いＭＲ比である。このような高いＭＲ比は、Ｆｅ（１００）電極のスピン分極率によって説明することはできず、むしろ、コヒーレントなスピン偏極トンネリングに関連すると考えられる。１６０のＭＴＪ素子を試作した結果、ＭＲ比とトンネル抵抗値とに関するばらつきは、２０％以内であった。ＭＴＪの歩留まりも実験室段階で９０％以上であった。このような高い値は、本アプローチの有効性を示唆している。ＭＴＪの抵抗―エリア積（ＲＡ）は、数$k\Omega\mu m^2$であり、この値は、ＭＲＡＭに適した値である。
【００２３】
図７（ａ）は、室温におけるＭＲ比のバイアス電圧依存性を示す図である。図７（ａ）に示すように、ＭＲ比のバイアス電圧依存性はかなり低いことがわかる。非対称な特性を示すが、ＭＲ比が半減する電圧V_{half}は１２５０ｍＶという非常に高い値が得られている。尚、従来のＡｌ－Ｏ系におけるＭＲ比の半減する電圧V_{half}は３００～６００ｍＶである。図７（ｂ）に、ＭＴＪの出力電圧V_{out}は（＝バイアス電圧×（Ｒａｐ－Ｒｐ）／Ｒａｐ）を示す。出力電圧V_{out}の最大値は順バイアスにおいて３８０ｍＶの値が得られている。この値は、Ａｌ－Ｏバリアの場合の値（２００ｍＶ）の約２倍の値である。このように、ＭＲ比と出力電圧との両方で高い値が得られたことは、本実施の形態による技術の有効性を示している。
【００２４】
尚、上記実施の形態においては、ＢＣＣのＦｅ（１００）を用いたが、代わりにＢＣＣのＦｅ系合金、例えば、Ｆｅ－Ｃｏ合金、Ｆｅ－Ｎｉ合金、Ｆｅ－Ｐｔ合金を用いることもできる。或いはＦｅ（１００）層とＭｇＯ（１００）層との間に、１原子層又は数原子層程度の厚さのＣｏ、Ｎｉなどを挿入しても良い。
【００２５】
次に、本発明の第２の実施の形態による磁気抵抗素子及びその製造方法について説明を行う。本実施の形態によるＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＴＭＲ素子の製造方法では、まずスパッタリング法などによりＭｇＯ（１００）を多結晶またはア

モルファス状態で堆積し、その後にアニール処理を行うことにより（１００）結晶面が配向した多結晶または単結晶化する点を特徴とする。スパッタリング条件は、例えば。温度が室温（２９３Ｋ）であり、ターゲットとしては２インチφのＭｇＯを用い、Ａｒ雰囲気中でスパッタリングを行った。加速電力は２００Ｗであり、成長速度は０．００８ｎｍ／ｓである。この条件で堆積したＭｇＯはアモルファス状態であるため、室温から３００℃まで温度を上昇させ、３００℃において一定時間保持をすることにより、結晶化されたＭｇＯを得ることが出来る。

【００２６】

尚、Ｏ欠損の導入方法としては、成長時にＯ欠損が生じる条件で成長を行う方法、Ｏ欠損を後から導入する方法、Ｏ欠損のある状態から例えば酸素プラズマ処理又は自然酸化などにより酸化を行ってある程度のＯ欠陥まで調整する方法のいずれを用いても良い。

【００２７】

以上、本実施の形態による磁気抵抗素子技術によれば、スパッタリング法を用いてアモルファスＭｇＯを堆積した後にアニール処理により結晶化するため、それほど大がかりな装置が必要ないという利点がある。

【００２８】

次に、本発明の実施の形態の変形例による磁気抵抗素子について図面を参照しつつ説明を行う。図１１は、本発明の実施の形態の変形例によるＭＴＪの素子構造を示す図であり、図１（Ｂ）に対応する図である。図１１に示すように、本実施の形態による磁気抵抗素子は、上記実施の形態による磁気抵抗素子と同様に、単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した酸素欠損多結晶MgO_x（０＜ｘ＜１）層５０３に対して設けられる電極として、アモルファス強磁性合金、例えばＣｏＦｅＢ層５０１、５０５を用いた点に特徴がある。アモルファス強磁性合金は、例えば蒸着法或いはスパッタリング法を用いて形成可能である。得られた特性等は第１の実施の形態の場合とほぼ同様である。

【００２９】

尚、アモルファス磁性合金については、例えば、FeCoB、FeCoBSi、FeCoBP、FeZr、CoZrなどを用いることもできる。

【００３０】

以上、本実施の形態による磁気抵抗素子について説明したが、本発明はこれらに制限されるものではない。その他、種々の変更、改良、組み合わせが可能なことは当業者に自明であろう。例えば、ＭｇＯ層に酸素欠陥を導入する代わりに、例えばＣａやＳｒをドーピングすることでトンネル障壁の高さを調整する方法を用いても良い。また、ＭｇＯ層の堆積方法として、電子ビーム蒸着法又はスパッタリング法を例にして説明したが、その他の堆積法も適用可能であることは言うまでもない。また、高真空との用語は、例えば酸素を導入しない場合において、概ね10^{-6}Ｐａ以下の値を指し、一方、酸素を積極的に導入する場合でも、10^{-4}Ｐａ程度の値を指す。

【産業上の利用可能性】

【００３１】

ＭＲＡＭの出力電圧値が従来の約２倍に向上し、ギガビット級の超高集積ＭＲＡＭに適した構造となっている。

【図面の簡単な説明】

【００３２】

【図１】本発明の第１の実施の形態によるＭＴＪ素子構造（図１（Ｂ））と、強磁性体金属であるＦｅ（１００）のエネルギーバンド構造を示す図であり、波数空間の［１００］方向に対する$E-E_F$の関係を示す図（図１（Ａ））である。

【図２】図２（Ａ）から図２（Ｄ）までは、本発明の実施の形態によるＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）構造を有する磁気抵抗素子（以下、「Ｆｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ」と称する。）の製造工程を模式的に示す図である。

【図３】図３（Ａ）は、Ｆｅ（１００）下部電極（第１電極）のＲＨＥＥＤイメージを示す図であり、図３（Ｂ）は、この際のＭｇＯ（１００）バリア層のＲＨＥＥＤイメージを示す図である。

【図４】ＭｇＯ成長時における四重極Ｍａｓｓスペクトルの観測結果を示す図である。

【図５】ＭｇＯ蒸着中の酸素分圧の膜堆積速度依存を示す図である。

【図６】Ｆｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ素子の典型的な磁気抵抗曲線を示す図である。

【図７】図７（Ａ）は、室温におけるＭＲ比のバイアス電圧依存性を示す図である。図７（Ｂ）は、ＭＴＪの出力電圧V_{out}は（＝バイアス電圧×（Ｒａｐ－Ｒｐ）／Ｒａｐ）を示す図である。

【図８】ＴＭＲ素子の構造と、その動作原理を示す図である。

【図９】ＭＲＡＭの基本構造例を示す図であり、図９（Ａ）はＭＲＡＭの斜視図であり、図９（Ｂ）は模式的な回路構成図であり、図９（Ｃ）は、構造例を示す断面図である。

【図１０】アモルファスＡｌ－Ｏをトンネル障壁とした従来型ＴＭＲ素子の磁気抵抗の印加電圧による変化を示す図である。

【図１１】本発明の実施の形態の変形例によるＭＴＪの素子構造を示す図であり、図１（Ｂ）に対応する図である。

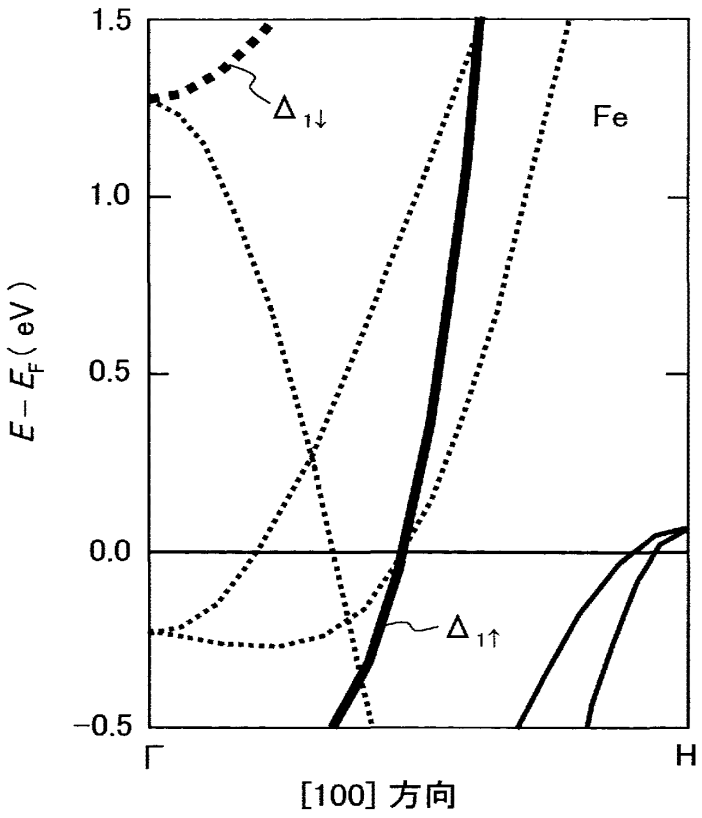
【符号の説明】

【００３３】

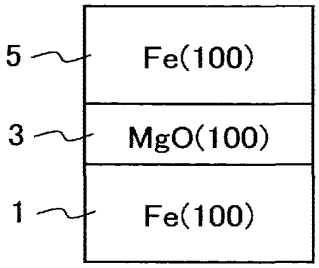
１…第１のＦｅ（１００）層、３…単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x層（０＜ｘ＜１）、５…第２のＦｅ（１００）層、１１…単結晶MgO_x（１００）あるいは（１００）結晶面が優先配向した多結晶MgO_x基板（０＜ｘ＜１）、１５…ＭｇＯ（１００）シード層、１７…エピタキシャルＦｅ（１００）下部電極（第１電極）、２１…ＭｇＯバリア層（１００）、２３…エピタキシャルＦｅ（１００）上部電極（第２電極）、５０３…単結晶MgO_x（００１）あるいは（００１）結晶面が優先配向した多結晶MgO_x層（０＜ｘ＜１）、５０１…アモルファス強磁性体による下部電極（第１電極）、５０３…ＭｇＯバリア層、５０５…アモルファス強磁性体による上部電極（第２電極）。

【書類名】図面
【図１】

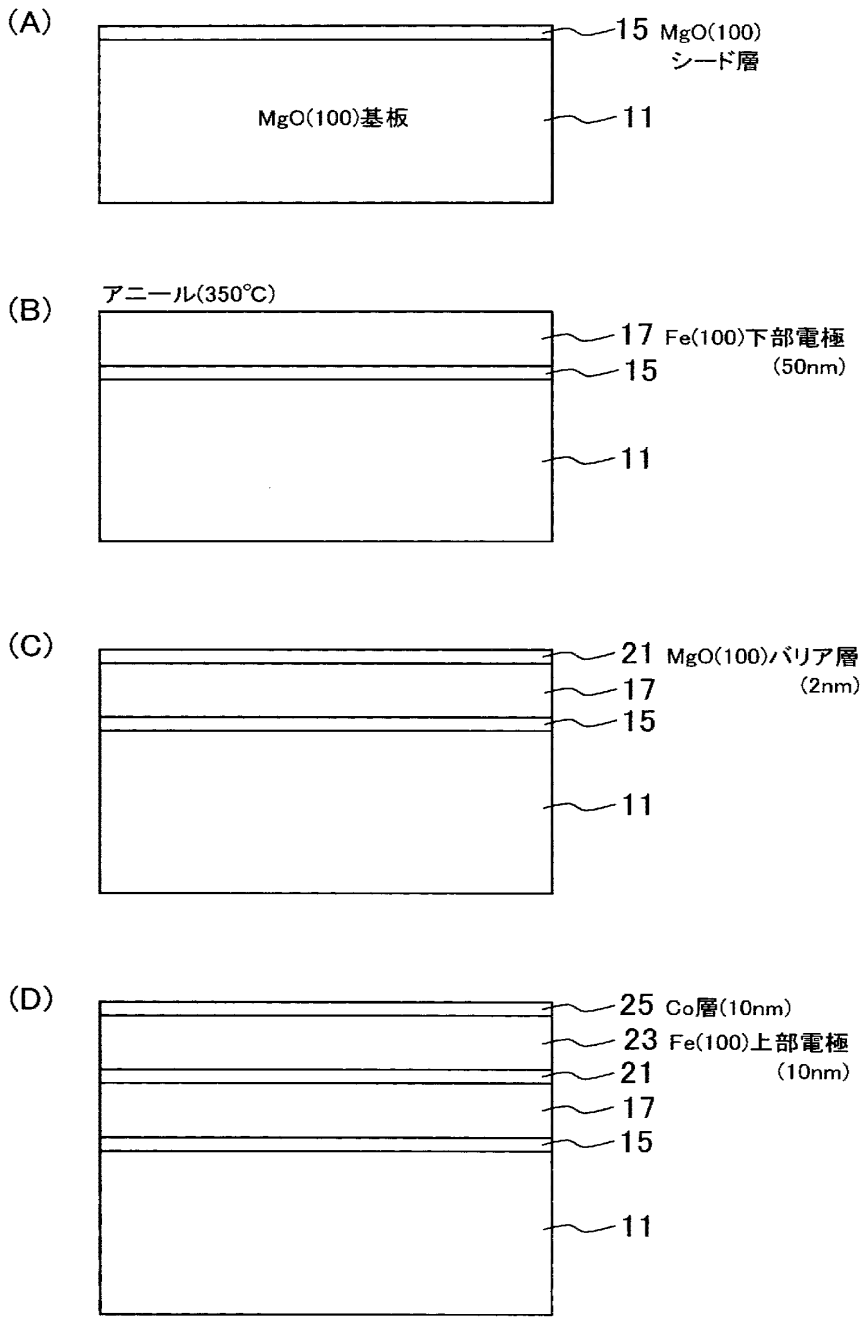
(A)


1.5
1.0
0.5
0.0
−0.5
$E - E_F$ (eV)
$\Delta_{1\downarrow}$
$\Delta_{1\uparrow}$
Fe
Γ
H
[100] 方向

(B)

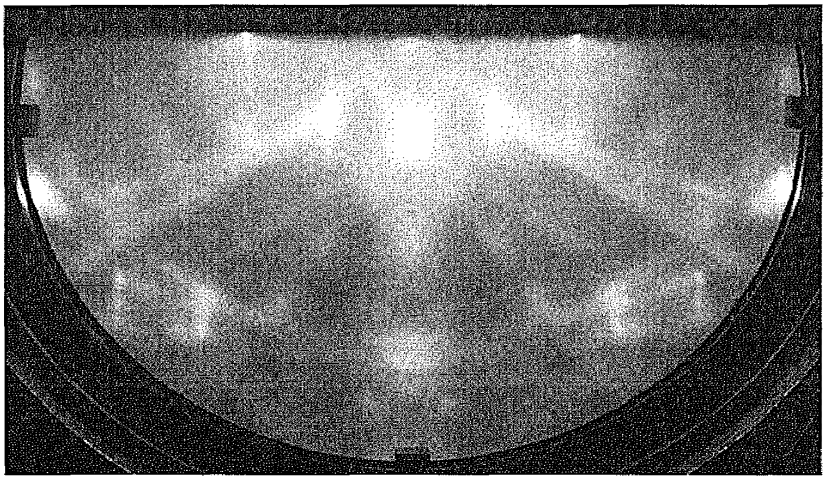

5
Fe(100)
3
MgO(100)
1
Fe(100)

【図２】

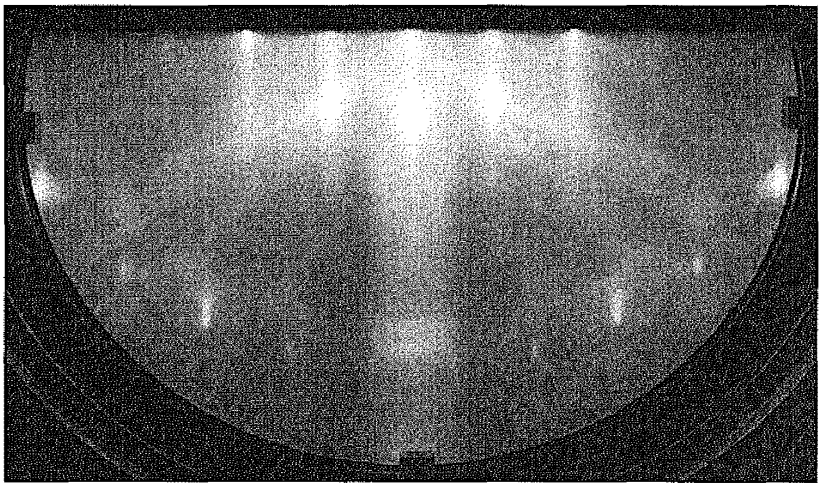

(A)
15 MgO(100)
シード層
MgO(100)基板
11
(B)
アニール(350℃)
17 Fe(100)下部電極
(50nm)
15
11
(C)
21 MgO(100)バリア層
(2nm)
17
15
11
(D)
25 Co層(10nm)
23 Fe(100)上部電極
(10nm)
21
17
15
11

【図３】

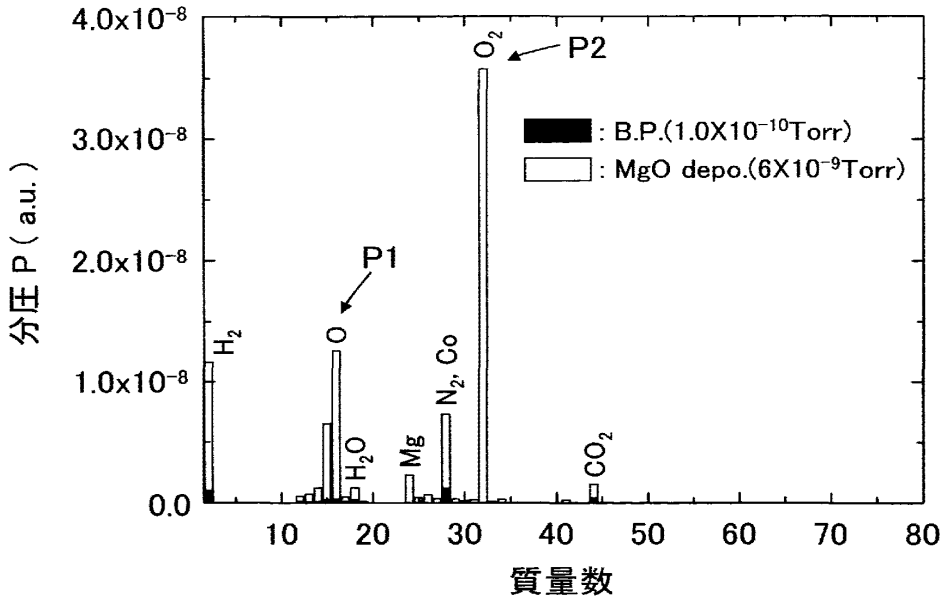
(a)



(b)

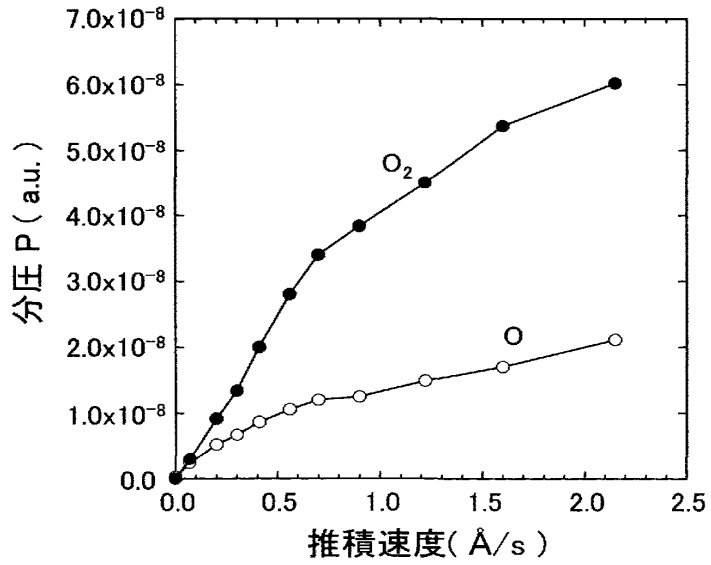


【図４】



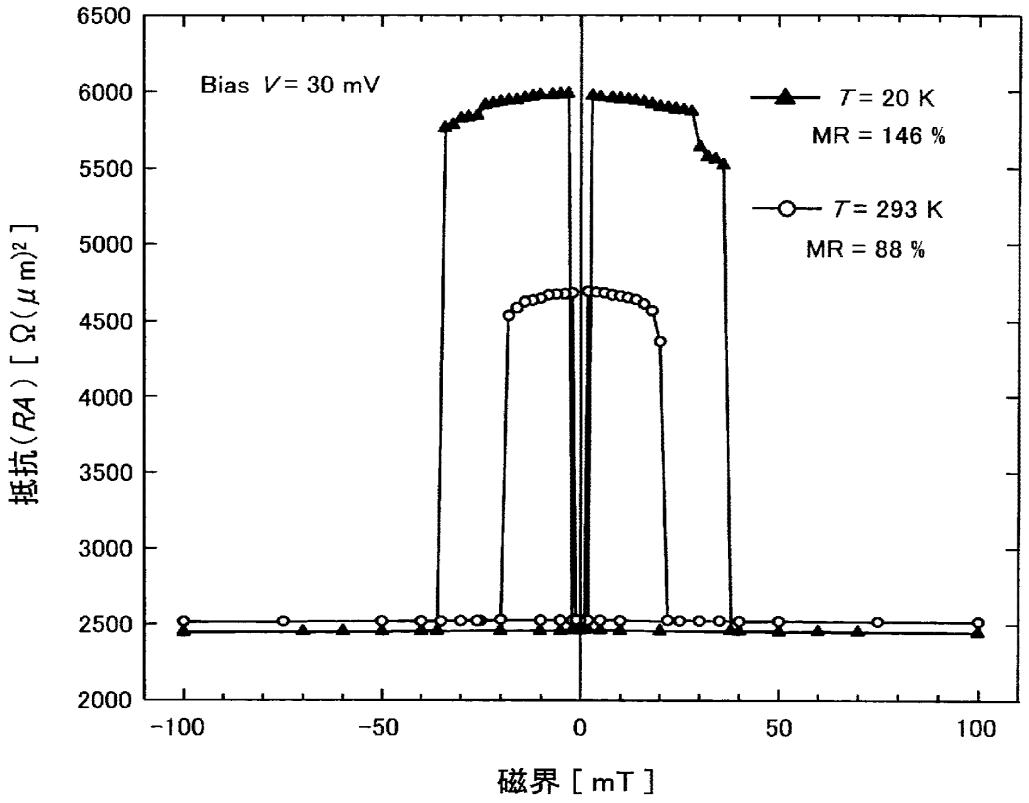
Massスペクトル

【図５】

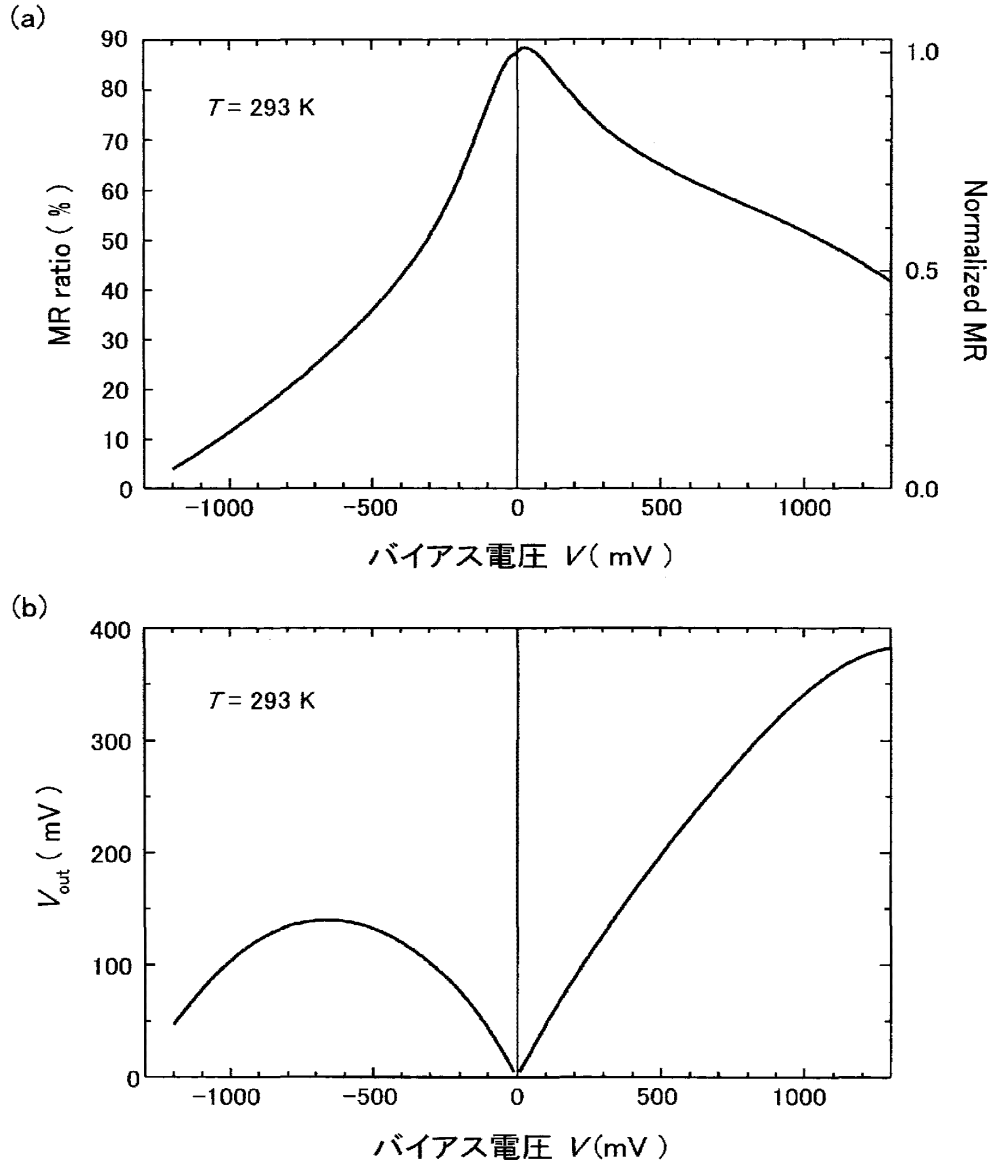


MgO蒸着中の酸素分圧

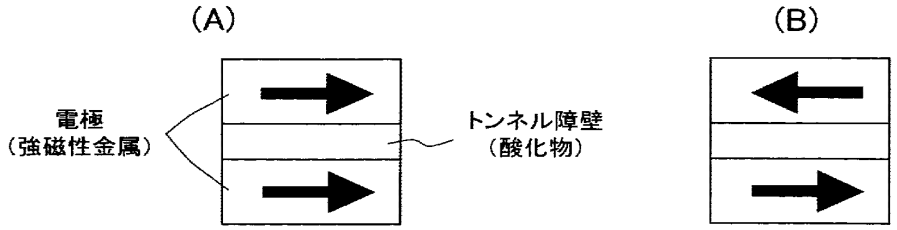
【図６】


Bias V = 30 mV
T = 20 K
MR = 146 %
T = 293 K
MR = 88 %
抵抗(RA)[Ω(μm)²]
磁界[mT]
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
-100
-50
0
50
100

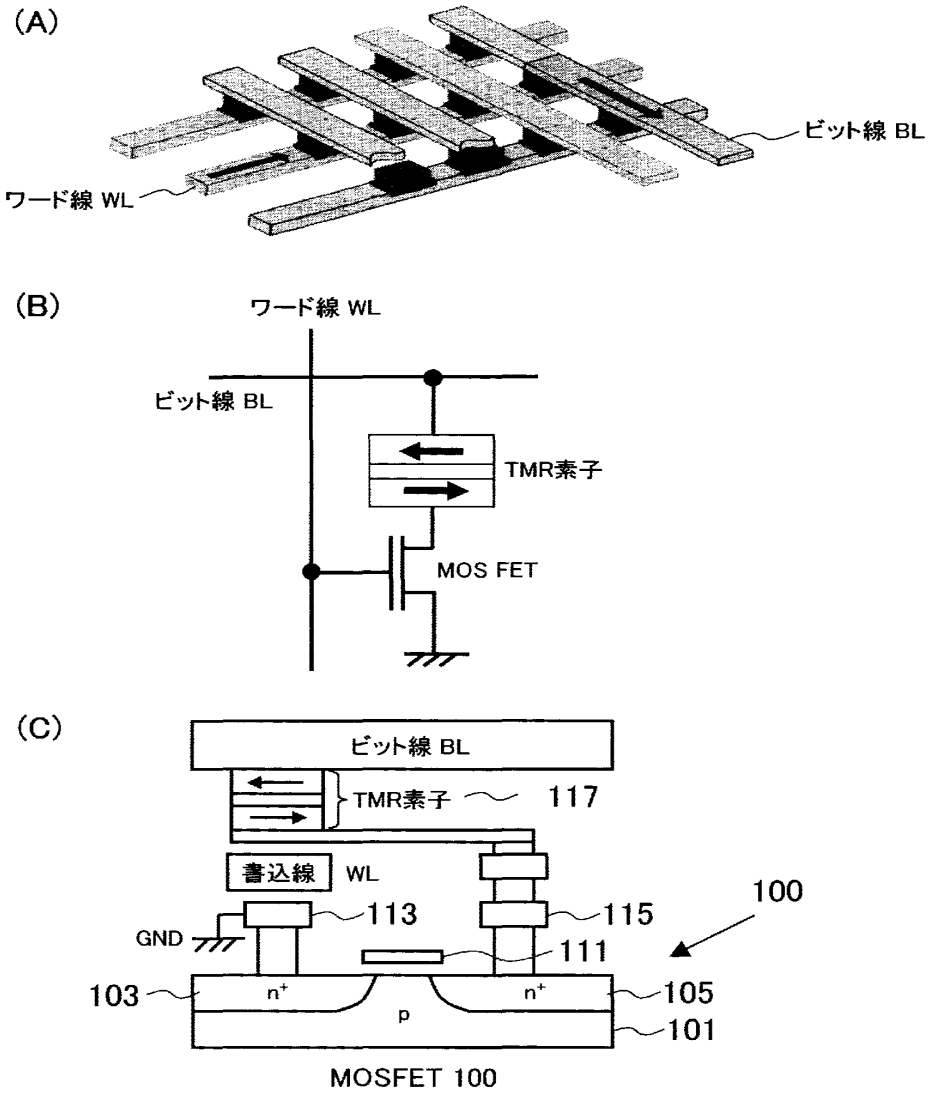
【図７】


(a)
T = 293 K
MR ratio (%)
Normalized MR
90
80
70
60
50
40
30
20
10
0
1.0
0.5
0.0
−1000
−500
0
500
1000
バイアス電圧 V(mV)
(b)
T = 293 K
V_{out} (mV)
400
300
200
100
0
−1000
−500
0
500
1000
バイアス電圧 V(mV)

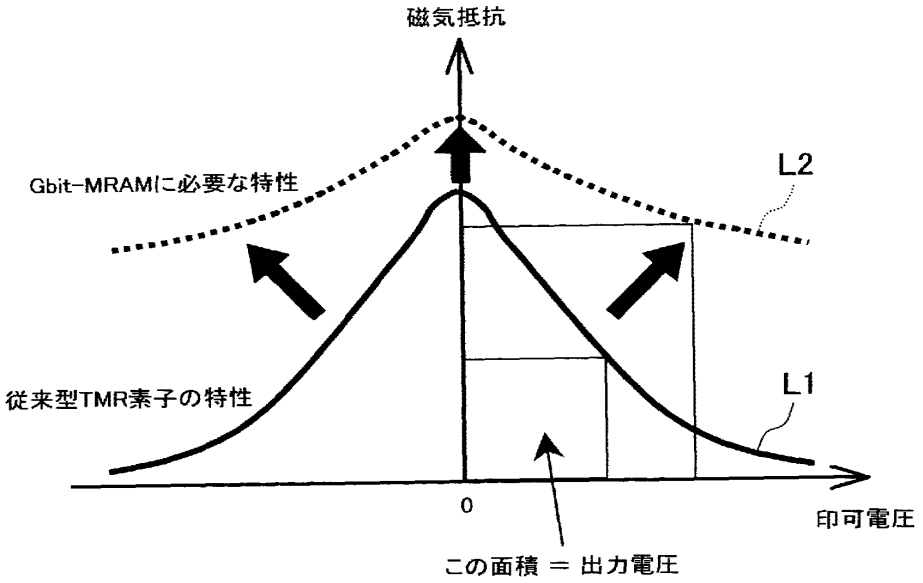
【図８】



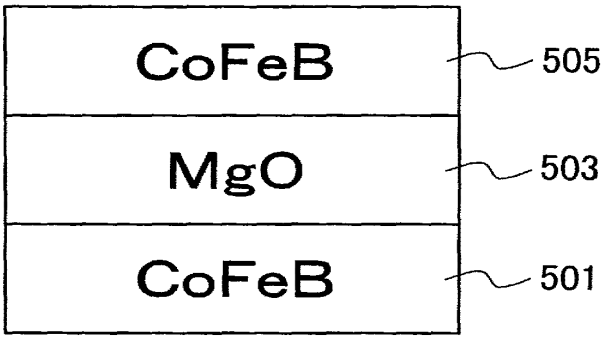
【図９】


(A)
ビット線 BL
ワード線 WL
(B)
ワード線 WL
ビット線 BL
TMR素子
MOS FET
(C)
ビット線 BL
TMR素子
117
書込線
WL
100
113
115
GND
111
103
n+
n+
105
p
101
MOSFET 100

【図１０】


磁気抵抗
Gbit-MRAMに必要な特性
L2
従来型TMR素子の特性
L1
0
印可電圧
この面積 ＝ 出力電圧

【図１１】


CoFeB
505
MgO
503
CoFeB
501

【書類名】要約書
【要約】
【課題】　ＭＲＡＭの出力電圧値を高める。
【解決手段】単結晶ＭｇＯ（１００）基板１１を準備し、５０ｎｍ厚のエピタキシャルＦｅ（１００）下部電極（第１電極）１７をＭｇＯ（１００）シード層１５上に室温で成長し、次いで、超高真空（２×１０－８Ｐａ）において、３５０℃でアニールを行う。２ｎｍ厚のＭｇＯ（１００）バリア層２１をＦｅ（１００）下部電極（第１電極）１７上に室温でエピタキシャル成長する。この際、ＭｇＯの電子ビーム蒸着を用いた。ＭｇＯ（１００）バリア層２１上に室温で、厚さ１０ｎｍのＦｅ（１００）上部電極（第２電極）２３を形成した。連続して、１０ｎｍ厚さのＣｏ層２１をＦｅ（１００）上部電極（第２電極）２３上に堆積した。Ｃｏ層２１は、上部電極２３の強制的な磁界をエンハンスするための反平行磁化配置を実現するためのものである。次いで、上記の作成試料を微細加工してＦｅ（１００）／ＭｇＯ（１００）／Ｆｅ（１００）ＭＴＪ素子を形成する。
【選択図】　図２

【書類名】　手続補正書
【整理番号】　P04-1160
【提出日】　平成16年11月11日
【あて先】　特許庁長官　殿
【事件の表示】
　【出願番号】　特願2004-313350
【補正をする者】
　【識別番号】　503360115
　【氏名又は名称】　独立行政法人科学技術振興機構
【補正をする者】
　【識別番号】　301021533
　【氏名又は名称】　独立行政法人産業技術総合研究所
【代理人】
　【識別番号】　100091096
　【弁理士】
　【氏名又は名称】　平木　祐輔
【発送番号】　115102
【手続補正1】
　【補正対象書類名】　特許願
　【補正対象項目名】　提出物件の目録
　【補正方法】　追加
　【補正の内容】
　　【提出物件の目録】
　　【物件名】　委任状　2

【物件名】　委任状

【添付書類】

委　任　状

平成 16 年 10 月 28 日

私は、識別番号　100091096　100105463　100102576　100108394　弁理士　平木　祐輔　関谷　三男　渡辺　敏章　今村　健一　氏を以って

代理人として下記事項を委任します。

記

1．特　許　出　願

に関する一切の件並びに本件に関する出願の放棄、若しくは取下げ、出願変更、拒絶査定不服及び補正却下の決定に対する審判の請求及びその取下げ

1．特願２００４－０７１１８６に基づく特許法第４１条第１項又は実用新案法第８条第１項の規定による優先権の主張及びその取下げ

1．上記出願に基づく特許法第４１条第１項又は実用新案法第８条第１項の規定による優先権の主張及びその取下げ

1．　に関する出願の変更

1．上記出願に係る特許権、実用新案権、意匠権、商標権又は防護標章登録に基づく権利及びこれらの権利に関する手続き並びにこれらの権利の放棄

1．上記出願に関する特許法第６４条の２第１項の規定による出願公開の請求

1．上記出願に係る特許に対する特許異議の申立て又は商標（防護標章）登録に対する登録異議の申立てに関する手続

1．上記出願に係る特許、特許権の存続期間の延長登録、意匠登録、商標登録、防護標章登録又は商標（防護標章）更新登録に対する無効審判の請求に関する手続

1．上記出願に係る特許権に関する訂正の審判の請求及びその取下げ

1．上記出願に係る商標登録に対する取消しの審判の請求に関する手続

1．上記各項の手続に関する請求の取下げ、申請の取下げ又は申立ての取下げ

1．上記各項に関し行政不服審査法に基づく諸手続をなすこと

1．上記各項の手続を処理するため、復代理人を選任及び解任すること

住　所　埼玉県川口市本町四丁目１番８号
名　称　独立行政法人科学技術振興機構
代表者
理事長　沖　村　憲　樹

委　任　状

平成16年10月28日

私は、識別番号 100091096 100105463 100102576 100108394 弁理士 平木 祐輔 関谷 三男 渡辺 敏章 今村 健一 氏を以って代理人として下記事項を委任します。

記

1．特　許　出　願

に関する一切の件並びに本件に関する出願の放棄、若しくは取下げ、出願変更、拒絶査定不服及び補正却下の決定に対する審判の請求及びその取下げ

1．特願２００４－０７１１８６に基づく特許法第４１条第１項又は実用新案法第８条第１項の規定による優先権の主張及びその取下げ

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1．上記出願に係る特許権に関する訂正の審判の請求及びその取下げ

1．上記出願に係る商標登録に対する取消しの審判の請求に関する手続

1．上記各項の手続に関する請求の取下げ、申請の取下げ又は申立ての取下げ

1．上記各項に関し行政不服審査法に基づく諸手続をなすこと

1．上記各項の手続を処理するため、復代理人を選任及び解任すること

住　所　東京都千代田区霞が関1丁目3番1号
名　称　独立行政法人 産業技術総合研究所
代表者　理事長　吉　川　弘　之

WD EX1008
Western Digital v IP Bridge
Page 187

出願人履歴

５０３３６０１１５

20040401

名称変更

埼玉県川口市本町４丁目１番８号

独立行政法人科学技術振興機構

５０３３６０１１５

20090820

住所変更

東京都千代田区四番町５－３　サイエンスプラザ５Ｆ

独立行政法人科学技術振興機構

５０３３６０１１５

20091008

住所変更

埼玉県川口市本町四丁目１番８号

独立行政法人科学技術振興機構

３０１０２１５３３

20010402

新規登録

５０３０６３７６６

東京都千代田区霞が関１－３－１

独立行政法人産業技術総合研究所

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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
13/767,290	02/14/2013	2811	1650	NAGI-0005	11	4

CONFIRMATION NO. 2082

CORRECTED FILING RECEIPT

38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

OC000000062078061

Date Mailed: 06/26/2013

Receipt is acknowledged of this non-provisional 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 APPLICANT, 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 Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections 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**

Inventor(s)

Shinji YUASA, Ibaraki, JAPAN;

Applicant(s)

Japan Science and Technology Agency, Kawaguchi-shi, JAPAN
National Institute of Advanced Industrial Science and Technology, Tokyo, JAPAN

Assignment For Published Patent Application

Japan Science and Technology Agency, Kawaguchi-shi, JAPAN
National Institute of Advanced Industrial Science and Technology, Tokyo, JAPAN

Power of Attorney: None

Domestic Priority data as claimed by applicant

This application is a CON of 13/400,340 02/20/2012 PAT 8405134
which is a CON of 12/923,643 09/30/2010 PAT 8319263
which is a CON of 10/591,947 09/08/2006 PAT 7884403
which is a 371 of PCT/JP2005/004720 03/10/2005

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)
JAPAN 2004-313350 10/28/2004
JAPAN 2004-071186 03/12/2004

Request to Retrieve - This application either claims priority to one or more applications filed in an intellectual property Office that participates in the Priority Document Exchange (PDX) program or contains a proper **Request to**

Retrieve Electronic Priority Application(s) (PTO/SB/38 or its equivalent). Consequently, the USPTO will attempt to electronically retrieve these priority documents.

If Required, Foreign Filing License Granted: 03/05/2013

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/767,290**

Projected Publication Date: 09/05/2013

Non-Publication Request: No

Early Publication Request: No

Title

Magnetic Tunnel Junction Device

Preliminary Class

257

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications:

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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.

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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005	2082

38327 7590 07/10/2013

Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
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Alexandria, VA 22314-1437

EXAMINER	
CHAMBLISS, ALONZO	
ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
07/10/2013	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):

iplaw@stites.com

Office Action Summary	Application No. 13/767,290	Applicant(s) YUASA ET AL.	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	AIA (First Inventor to File) Status No

-- 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* MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, 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 *2/14/13*.

☐ 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) *1-11* 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) *1-11* is/are rejected.

8)☐ Claim(s) _____ 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 *14 February 2013* 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. 10/591,947.

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/08) Paper No(s)/Mail Date *2/14/13*.

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

4) ☐ Other: _____.

DETAILED ACTION

Priority

1. Acknowledgment is made of applicant's claim for foreign priority under 35 U.S.C. 119 (a)-(d). The certified copy has been filed in parent Application No. 10/591,947 filed on 3/10/05.

Information Disclosure Statement

2. The information disclosure statement (IDS) submitted on 2/14/13 was filed before the mailing date of the non-final rejection on 7/2/13. The submission is in compliance with the provisions of 37 CFR 1.97. Accordingly, the information disclosure statement is being considered by the examiner.

Drawings

3. The drawings are objected to as failing to comply with 37 CFR 1.84(p)(5) because they include the following reference character(s) not mentioned in the description: **113**. Corrected drawing sheets in compliance with 37 CFR 1.121(d), or amendment to the specification to add the reference character(s) in the description in compliance with 37 CFR 1.121(b) 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. 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 § 102

4. The following is a quotation of the appropriate paragraphs of pre-AIA 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 –
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

5. Claims 1 and 8-11 are rejected under pre-AIA 35 U.S.C. 102b as being clearly anticipated by "Large magnetoresistance in Fe/MgO/FeCo(001) epitaxial tunnel junctions of GaAs(001) " journal.

With respect to Claims 1 and 8-11, the journal teaches a tunnel barrier layer located between a first ferromagnetic material layer and a second ferromagnetic material layer, wherein the tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented. The first and second ferromagnetic material layer comprises an iron-based alloy (i.e. made of FeO) and is entirely crystallized (see pages 1655 and 1656).

Double Patenting

6. The nonstatutory double patenting rejection is based on a judicially created doctrine grounded in public policy (a policy reflected in the statute) so as to prevent the unjustified or improper timewise extension of the "right to exclude" granted by a patent

and to prevent possible harassment by multiple assignees. A nonstatutory double patenting rejection is appropriate where the claims at issue are not identical, but at least one examined application claim is not patentably distinct from the reference claim(s) because the examined application claim is either anticipated by, or would have been obvious over, the reference claim(s). See, e.g., *In re Berg*, 140 F.3d 1428, 46 USPQ2d 1226 (Fed. Cir. 1998); *In re Goodman*, 11 F.3d 1046, 29 USPQ2d 2010 (Fed. Cir. 1993); *In re Longi*, 759 F.2d 887, 225 USPQ 645 (Fed. Cir. 1985); *In re Van Ornum*, 686 F.2d 937, 214 USPQ 761 (CCPA 1982); *In re Vogel*, 422 F.2d 438, 164 USPQ 619 (CCPA 1970); and *In re Thorington*, 418 F.2d 528, 163 USPQ 644 (CCPA 1969).

A timely filed terminal disclaimer in compliance with 37 CFR 1.321(c) or 1.321(d) may be used to overcome an actual or provisional rejection based on a nonstatutory double patenting ground provided the reference application or patent either is shown to be commonly owned with this application, or claims an invention made as a result of activities undertaken within the scope of a joint research agreement. A terminal disclaimer must be signed in compliance with 37 CFR 1.321(b).

The USPTO internet Web site contains terminal disclaimer forms which may be used. Please visit http://www.uspto.gov/forms/. The filing date of the application will determine what form should be used. A web-based eTerminal Disclaimer may be filled out completely online using web-screens. An eTerminal Disclaimer that meets all requirements is auto-processed and approved immediately upon submission. For more information about eTerminal Disclaimers, refer to http://www.uspto.gov/patents/process/file/efs/guidance/eTD-info-I.jsp.

7. Claims 1-3 are rejected on the ground of nonstatutory double patenting as being unpatentable over claim 1 of U.S. Patent No. 7,884,403. Although the claims at issue are not identical, they are not patentably distinct from each other because the instant application and the patent recite a first and second ferromagnetic material layers with a tunnel barrier layer made of poly-crystalline magnesium oxide layer between the ferromagnetic materials.

8. **It is inherent that the magnesium oxide layer has some level of oxygen vacancy defects.** A rejection based on double patenting of the "same invention" type finds its support in the language of 35 U.S.C. 101 which states that "whoever invents or discovers any new and useful process... may obtain a patent therefor..." (Emphasis added). Thus, the term "same invention," in this context, means an invention drawn to identical subject matter. See *Miller v. Eagle Mfg. Co.*, 151 U.S. 186 (1894); *In re Vogel*, 422 F.2d 438, 164 USPQ 619 (CCPA 1970); and *In re Ockert*, 245 F.2d 467, 114 USPQ 330 (CCPA 1957).

A statutory type (35 U.S.C. 101) double patenting rejection can be overcome by canceling or amending the claims that are directed to the same invention so they are no longer coextensive in scope. The filing of a terminal disclaimer cannot overcome a double patenting rejection based upon 35 U.S.C. 101.

9. Claims 4 -7 are rejected under 35 U.S.C. 101 as claiming the same invention as that of claim 5 of prior U.S. Patent No. 7,884,403. This is a statutory double patenting rejection.

10. Claims 10 and 11 are rejected on the ground of nonstatutory double patenting as being unpatentable over claim 4 of U.S. Patent No. 7,884,403. Although the claims at issue are not identical, they are not patentably distinct from each other because the instant application and the patent recite a first and second ferromagnetic material layers with a tunnel barrier layer made of poly-crystalline magnesium oxide layer between the ferromagnetic materials. The first ferromagnetic material layer comprises an iron based alloy.

Allowable Subject Matter

11. Claims 2 and 3 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.

12. The following is a statement of reasons for the indication of allowance subject matter: the prior art of record does not teach or suggest the combination of a wherein the tunnel barrier layer has a barrier height q~ in a range of 0.2 to 0.5 electron volts (eV) in claims 2 and 4.

The prior art made of record and not relied upon is cited primarily to show the product of the instant invention.

Conclusion

13. Any inquiry concerning the communication or earlier communications from the examiner should be directed to Alonzo Chambliss whose telephone number is (571) 272-1927.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Fernado L. Toledo can be reached on (571) 272-1867. 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 PMR or Public PMR. Status information for unpublished applications is available through Private PMR only. For more information about the PMR system see http://pair-dkect.uspto.gov. Should you have questions on access to the Private PMR system contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free) or EBC_Support@uspto.gov.

AC/July 3, 2013 /Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Notice of References Cited	Application/Control No. 13/767,290	Applicant(s)/Patent Under Reexamination YUASA ET AL.	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-8,319,263	11-2012	Yuasa, Shinji	257/295
*	B	US-7,884,403	02-2011	Yuasa, Shinji	257/295
*	C	US-8,405,134	03-2013	Yuasa, Shinji	257/295
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	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 MM-YYYY format are publication dates. Classifications may be US or foreign.

Customized PTO/SB/08a+b (07-09)

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	To Be Determined
	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
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U.S. PATENT DOCUMENTS

Exam. Initial*	Document No. Number – Kind Code	Publ. Date MM/DD/YYYY	Name Patentee or Applicant	Relevance Passages/Figs.
	US-2007/0128470 X	06/07/2007	Nagahama et al.	
	US-2004/0144995 X	07/29/2004	Nagahama et al.	
	US-2004/0245553 X	12/09/2004	Hosomi et al.	
	US-2006/0056115 X	03/16/2006	Djayaprawira et al.	
	US-2002/0159203 A1 X	10/31/2002	Saito et al.	
	US-2005/0207071 A1 X	09/22/2005	Sato et al.	
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	US-2008/0055793 8, Z	03/06/2008	Djayaprawira et al.	

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	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 the applicant.*

** Corresponds to U.S. Patent 2007/0128470, U.S. Patent 2004/0144995, WO2002/099905, and EP1 391 942, listed above.

*** Corresponds to U.S. Patent 2004/0245553, WO 2003/085750, and EP 1 494 295, listed above.

**** Corresponds to U.S. Patent 2006/0056115, listed above.

Corresponds to U.S. Document No. 2007-0195592 A1 listed above.

3 Corresponds to US 2004-0144995, (the U.S. Pat. of '995 was previously filed in an IDS on 02-20-2012

8 Corresponds to JP 2006-080116 and US 2006-0056115, which were filed in an IDS on 02-20-2012

10 Corresponds to US 2006-0056115 (previously filed in IDS on 02-20-2012) and EP 1633007 listed above

X = Filed in Great Grandparent Application 10/591,947
Y = Filed in grandparent Application 12/923,643
YY = Cited by Examiner in grandparent Application 12/923,643
Z = Filed in Parent Application 13/400,340

Customized PTO/SB/08a+b (07-09)

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /AC/

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Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	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 the applicant.*

[4] Corresponds to JP 2004-12805 listed above
[5] Corresponds to JP 2004-153258 listed above
[6] Corresponds to KR 2002-0042448 listed above
[9] Corresponds to JP 2002-270790 listed above

Z = Filed in Parent Application 13/400,340

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /AC/

Substitute for Form 1449/PTO	Application #	To Be Determined
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U.S. PATENT DOCUMENTS				
Exam. Initial*	**Document No.** Number – Kind Code	**Publ. Date** MM/DD/YYYY	**Name** Patentee or Applicant	**Relevance** Passages/Figs.
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	JP 2003-318465** [,X]	11/7/2003			Abstract
	JP 2002-204004 [X]	7/19/2002			Abstract
	JP 2002-289943 [X]	10/4/2002			
	JP 2003-304010*** [,X]	10/24/2003	Sony Corp		Abstract

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	Date Considered	

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*** Corresponds to U.S. Patent 2004/0245553, WO 2003/085750, and EP 1 494 295, listed above.

[7] Corresponds to US 2006-0003185 listed above

X = Filed in Great Grandparent Application 10/591,947
Z = Filed in Parent Application 13/400,340

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /AC/

Substitute for Form 1449/PTO		
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	First Inventor	Yuasa
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	WO 2002/099905 X	5/24/2002	National Institute of Advanced Industrial Science and Technology		Abstract
	EP 1 391 942 X	5/24/2002	National Institute of Advanced Industrial Science and Technology; Japan Science and Technology Agency		Yes
	WO 2003/085750 X	10/16/2003	Sony Corp		Abstract
	EP 1 494 295 X	1/5/2005	Sony Corp		Yes
	JP 2006-080116 ****,X	3/23/2006			Abstract
	EP 1 633 007 A2 X	3/8/2006	Anelva Corporation		Yes
	EP 1 633 007 A3 X	3/8/2006	Anelva Corporation		Yes
	EP 1 085 586 A2 X	3/21/2001	Kabushiki Kaisha Toshiba		Yes
	JP 2000-030236 X	1/28/2000	Hitachi Ltd.		Yes
	JP 2001-101645 X	4/13/2001	Akita Prefecture		Yes
	JP 2004-022599 X, Z	1/22/2004	Sony Corp		Yes
	JP 2002-270921 X	9/20/2002	Toshiba Corp		Abstract
	JP 2002-319722 X	10/31/2002	Matsushita Electric Ind Co Ltd		Abstract
	WO 2004/025744 A1 X	3/25/2004	Fujitsu Limited		Abstract
	JP 2003-283001 X	10/3/2003	Toshiba Corp		Yes
	JP 2002-246567 X	8/30/2002	Toshiba Corp		Abstract

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	Date Considered	

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**** Corresponds to U.S. Patent 2006/0056115, listed above.

10 Corresponds to US 2006-0056115 (previously filed in IDS on 02-20-2012) and EP 1633007 listed above

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FOREIGN PATENT DOCUMENTS					
Exam. Initial *	**Country-Number-Kind Code** if known	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Relev.** Psg/Figs.	**Trans-lation**
	WO 2005/088745 A1 X	9/22/2005	Japan Science and Technology Agency; National Institute of Advanced Industrial Science and Technology		Abstract
	JP 11-097766 X	4/9/1999	Res Inst Electric Magnetic Alloys		Abstract & ¶22 & 23
	JP 2008-004956 #,Y	01/10/2008	Japan Science & Technology Agency; National Institute of Advanced Industrial & Technology		Abstract
	JP 2002-270790 A Z	09/20/2002	Toshiba Corp.		Abstract
	JP 2003-304012 A Z	10/24/2003	Matsushita Electric Ind Co. Ltd.		Partial
	JP H05-144729 A Z	06/11/1993	Hitachi Ltd.		Partial
	EP 0 145 403 A2 Z	06/19/1985	Energy Conversion Devices, Inc.		Yes
	EP 1 061 592 A Z	12/20/2000	Odagawa et al.		Yes
	EP 1 793 434 A1 Z	06/06/2007	Japan Science and Technology Agency		Yes
	JP 2002-359413 A Z	12/13/2002	Nat. Inst. Of Adv. Ind. & Technol.; Japan Science & Tech Corp.		Abstract

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	Date Considered	

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Corresponds to U.S. Document No. 2007-0195592 A1 listed above.
9 Corresponds to JP 2002-270790 listed above

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Substitute for Form 1449/PTO	Application #	To Be Determined
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FOREIGN PATENT DOCUMENTS					
Exam. Initial *	**Country-Number-Kind Code** if known	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Relev.** Psg/Figs.	**Trans-lation**
	JP 2003-86863 A	03/20/2003	Nat. Inst. Of Adv. Ind. & Technol; Japan Science & Tech Corp.		Abstract
	JP 2004-063592 A	02/26/2004	Sony Corp.		Abstract
	JP 2004-128015 A	04/22/2004	Sony Corp.		
	JP 2004-153258 A	05/27/2004	Hewlett Packard Development Co.		Abstract
	KR 2002-0042448 A	06/05/2002	Anelva Corp.		Abstract
	KR 2003-0097904 [3]	12/31/2003	Nagahama et al.		Partial
	WO 01/056090 A1	08/02/2001	Takahashi		Abstract

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	International Search Report of PCT/JP2005/004720 mailed June 21, 2005 [X]	Yes
	WOLF, S.A. et al., "Spintronics: A Spin-Based Electronics Vision for the Future", Science, Vol. 294, November 16, 2001, pp. 1488-1495. [X]	Yes
	WULFHEKEL, W. et al., "Single-Crystal Magnetotunnel Junctions", Applied Physics Letters, Vol. 78, No. 4, January 22, 2001, pp. 509-511 [X]	Yes
	JULLIERE, M., "Tunneling Between Ferromagnetic Films", Physics Letters, Vol. 54A, No. 3, September 8, 1975, pp.225-226. [X]	Yes

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	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 the applicant.*

[3] Corresponds to US 2004-0144995, (the U.S. Pat. of '995 was previously filed in an IDS on 02-20-2012
[4] Corresponds to JP 2004-12805 listed above
[5] Corresponds to JP 2004-153258 listed above
[6] Corresponds to KR 2002-0042448 listed above

X = Filed in Great Grandparent Application 10/591,947
Z = Filed in Parent Application 13/400,340

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /AC/

Substitute for Form 1449/PTO	Application #	To Be Determined
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 7 of 12	Docket #	NAGI.0005

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	SOULEN, R.J.., Jr. et al., "Measuring the Spin Polarization of a Metal with a Superconducting Point Contact", Science, Vol. 282, October 2, 1998, pp. 85-88. X	Yes
	SAITO, Y. et al., "Correlation between Barrier Width, Barrier Height, and DC Bias Voltage Dependences on the Magnetoresistance Ratio in Ir-Mn Exchange Biased Single and Double Tunnel Junctions", Jpn. J. Appl. Phys., Vol. 39 (2000), pp. L1035-L1-38. X	Yes
	IURA, S. et al., "Enhancement of Thermal Stability in Ferromagnetic Tunnel Junctions Prepared by the Radical Oxidation Method", Journal of the Magnetics Society of Japan, Vol. 26, No. 6 (2002), pp. 839-842, abstract only in English. X	Yes
	BOWEN, M. et al., "Large Magnetoresistance in Fe/MgO/FeCo(001) Epitaxial Tunnel Junctions on GaAs(001)", Applied Physics Letters, Vol. 79, No. 11, September 10, 2001, pp. 1655-1657. X	Yes
	SIMMONS, JOHN G., "Generalized Formula for the Electric Tunnel Effect between Similar Electrodes Separated by a Thin Insulating Film", Journal of Applied Physics, Vol. 34, NO. 6, June 1963, pp. 1793-1803. X	Yes
	VASSENT, J.L. et al., "A Study of Growth and the Relaxation of Elastic Strain in MgO on Fe(001)", J. Appl. Phys. Vol. 80, No. 10, November 15, 1996, pp. 5727-5735. X	Yes
	FAURE-VINCENT, J. et al., "High Tunnel Magnetoresistance in Expitaxial Fe/MgO/Fe Tunnel Junctions", Applied Physics Letters, Vol. 82, No. 25, June 23, 2003, pp. 4507-4509. X	Yes
	MEYERHEIM, H.L. et al., "Geometrical and Compositional Structure at Metal-Oxide Interfaces: MgO on Fe(001)", Physical Review Letters, Vol. 18, No. 7, August 13, 2001, pp. 076102-1 – 076102-4. X	Yes
	BUTLER, W.H. et al., "Spin-dependent Tunneling Conductance of Fe[MgO]Fe Sandwiches", Physical Review B., Vol. 63, 054416, 2001, pp. 054416-1 – 054416-12. X	Yes

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	Date Considered	

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Substitute for Form 1449/PTO	Application #	To Be Determined
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	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 8 of 12	Docket #	NAGI.0005

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial *	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	MATHON, J. et al., "Theory of Tunneling Magnetoresistance of an Epitaxial Fe/MgO/Fe(001) Junction", Physical Review B., Vol. 63, 220403(R), 2001, pp. 220403-1 – 220403-4. X	Yes
	ZHANG, X.-G. et al., "Effects of the Iron-Oxide Layer in Fe-FeO-MgO-Fe Tunneling Junctions", Physical Review B, Vol. 68, 092402, 2003, pp. 092402-1 – 092402-4. X	Yes
	ZHANG, X.-G. et al., "Large Magnetoresistance in bcc Co/MgO/Co and FeCo/MgO/FeCo Tunnel Junctions", Physical Review B., Vol. 70, 172407, 2004, pp. 172407-1 – 172407-4. X	Yes
	GIBSON, A. et al., "Stability of Vacancy Defects in MgO: The Role of Charge Neutrality", Physical Review B., Vol. 50, No. 4, July 15, 1994-II, pp. 2582-2592. X	Yes
	YUASA, S. et al., "High Tunnel Magnetoresistance at Room Temperature in Fully Expitaxial Fe/MgO/Fe Tunnel Junctions Due to Coherent Spin-Polarized Tunneling", Japanese Journal of Applied Physics, Vol. 43, No. 4B, 2004, pp. L588-L590. X	Yes
	MITANI, S., *et al*., "Fe/MgO/FeCo (100) Epitaxial Magnetic Tunnel Junctions Prepared by Using *in situ* Plasma Oxidation", Journal of Applied Physics, Vol. 93, No. 10, Parts 2 and 3, May 15, 2003, pp. 8041-8043. X	Yes
	POPOVA, E., *et al*., "Epitaxial MgO Layer for Low-Resistance and Coupling-Free Magnetic Tunnel Junctions", Applied Physics Letters, Vol. 81, No. 6, August 5, 2002, pp.1035-1037. X	Yes
	BOUBETA, C. MARTINEZ, et al., "Magnetic Coupling in Epitaxial TM/MgO/Fe(001) (TM=FeCo, Fe/Co, Fe) Macroscopic and MicroscopicTrilayers", Journal of Applied Physics, Vo. 94, No. 6, September 15, 2003, pp. 4006-4012. X	Yes
	Supplementary European Search Report from European Patent Office for Application No. 05720955.3 2222, Patent No. 1737055, PCT/JP2005004720 dated July 2, 2008. X	

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	Date Considered	

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	First Inventor	Yuasa
	Art Unit	
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Sheet 9 of 12	Docket #	NAGI.0005

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial *	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	Office Action from European Patent Office dated November 6, 2009 X	
	F. ERNULT et al., "Preparation of Nanometer-Scale Iron Dots on Insulating Layer", Science and Technology of Advanced Materials, Vol. 4, (2003), pp. 383-389 X	Yes
	DAVID J. SMITH et al., "Structural Characterization of Thin Film Ferromagnetic Tunnel Junctions", Journal of Applied Physics, Vol. 83, No. 10, 15 May 1998, pp. 5154-5158 X	Yes
	X. W. LI et al., "Fabrication and Properties of Heteroepitaxial Magnetite (Fe_3O_4) Tunnel Junctions", Applied Physics Letters, Vol. 73, No. 22, 30 November 1998, pp.3282-3284 X	Yes
	C. L. PLATT, et al., "Spin Polarized Tunneling in Reactively Sputtered Tunnel Junctions", Journal of Applied Physics, Vol. 81, No. 8, 15 April 1997, pp. 5523-5525 X	Yes
	P. TURBAN et al., "Growth and Characterization of Single Crystalline NiMnSb Thin Films and Epitaxial NiMnSb/MgO/NiMnSb(001) Trilayers", 2002 The American Physical Society, Physical Review B., Vol. 65, pp. 134417-1 to 134417-13 X	Yes
	T. MORIYAMA et al., "Preparation and Magnetoresistance in Single-Crystal and Polycrystal Fe/MgO/FeCo Tunnel Junctions", The Physical Society of Japan, 2003 Spring meeting, Abstracts Book 58(1-3), 460, (2003-03-06) X	Yes
	JAGADEESH S. MOODERA et al., "Ferromagnetic-Insulator-Ferromagnetic Tunneling: Spin-Dependent Tunneling and Large Magnetoresistance in Trilayer Junctions (Invited), Journal of Applied Physics, Vol. 79, No. 8, 15 April 1996, pp. 4724-4729 X	Yes
	MASAYOSHI TONOUCHI et al., "Epitaxial Growth of NbN on an Ultrathin MgO/Semiconductor System", Journal of Applied Physics, Vol. 62, No. 3, 1 August 1987, pp. 961-966 X	Yes

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	Date Considered	

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Sheet 10 of 12	Docket #	NAGI.0005

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Exam. Initial *	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	"Giant tunnel magnetoresistance in magnetic tunnel junctions with a crystalline $M_gO(001)$ barrier," S. Yuasa and D.D. Djayaprawira, Journal of Applied Physics D: Applied Physics, 1 Phys, D: Appl. Phys. 40 (2007) R337-R354 [Y]	Yes
	Office Action issued from Japanese Patent Office, in corresponding Japanese Patent Application No. 2011-226907, dated January 31, 2012, pp. 1-3. [Z]	Yes
	ARAKI et al., "Fabrication and Electric Properties of Lapped Type of TMR Heads for ~50 Gb/In^2 and Beyond," IEEE Transactions on Magnetics, Vol. 38, No. 1, pp. 72-77, January 2002. [Z]	Yes
	David D. DJAYAPRAWIRA et al., "230% Room-Temperature Magnetoresistance in CoFeB/MgO/CoFeB, Magnetic Tunnel Junctions," IEICE Technical Report, Vol. 104, No. 713, March 4, 2005 [Z]	Yes
	David D. DJAYAPRAWIRA et al., "Novel Sputtering Technology of Magnetic Tunnel Junctions for MRAM Application," Papers 01 the 66th Symposium on Semiconductors and Integrated Circuits Technology, Vol. 66, pp. 58-61, 2004 [Z]	Yes
	H. DOMON et al., "Effect of Ge Addition on Postannealed CoCrGePt Thin Film Media," Journal of Applied Physics, Vol. 91, No. 10, pp, 8632-8634, May 15, 2002. [Z]	Yes
	H. DOMON et al. "Reduction of Magnetic Interaction in CoB/Pd Multilayer Perpendicular Media Using a Phase-Separated Pd-SiO Underlayer," Journal of Applied Physics, Vol. 93, No. 10, pp. 8164-8166, May 15, 2003. [Z]	Yes
	Extended European Search Report, issued from European Patent Office, of European Application No. 08159511.8, dated June 5, 2009. [10, Z]	Yes

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	Date Considered	

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[10] Corresponds to US 2006-0056115 (previously filed in IDS on 02-20-2012) and EP 1633007 listed above

Y = Filed in grandparent Application 12/923,643
Z = Filed in Parent Application 13/400,340

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /AC/

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	To Be Determined
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	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 11 of 12	Docket #	NAGI.0005

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	T. KAKUTA et al., " Novel PVD Tool for Magnetoresistive Random Access Memory (MRAM) Mass Production," Anelva Technical Report, Vol. 10, pp, 27-33, January 25, 2004. Z	Abstract
	A. KOBAYASHI et al., "TMR Devices Fabricated with RIE Etching Using Co+ NH_3," Journal of the Magnetics Society of Japan, Vol. 28, No. 2, February 1, 2004. Z	Abstract
	J.S. MOODERA et al., "Large Magnetoresistance at Room Temperature in Ferromagnetic Thin Film Tunnel Junctions," Physical Review Letters, Vol. 74, No. 16, pp. 3273-3276, April 17, 1995. Z	Yes
	J.S. MOODERA, "Interface Magnetism and Spin Wave Scattering in Ferromagnet-Insulator-Ferromagnet Tunnel Junctions," Physical Review Letters, Vol. 80, No. 13, pp. 2941-2944, March 30, 1998. Z	Yes
	J. MURAI et al., "Direct Observation of Magnon Excitation in a Ferromagnetic Tunnel Junction Using Inelastic-Electron-Tunneling Spectroscopy," Japanese Journal of Applied Physics, Vol. 38, pp. L1106-L1108, October 1, 1999. Z	Yes
	K. NAGASAKA et al., "CPP Operational Mode of GMR Head," Fujitsu Sci. Tech. J., Vol. 37, No. 2, pp. 192-200, December 2001. Z	Yes
	T. OSADA et al., "Dry Etching of Magnetic Thin Film Stacks Using CO/NH_3 and CH_3OH Gases for Tunneling Magneto-Resistance Devices," 2004 Dry Process International Symposium, Vol. 4, pp. 127-131, 2004. Z	Yes
	Stuart S.P. PARKIN et al." Giant Tunnelling Magnetoresistance At Room Temperature with MgO (100) Tunnel Barriers," Nature Materials, Vol, 3, pp. 862-867, December 2004. Z	Yes
	M. TAKAGISHI et al., "The Applicability of CPP-GMR Heads for Magnetic Recording," IEEE Transactions on Magnetics, Vol. 38, No. 5, pp. 2277-2282, September 2002. Z	Yes
	A. TANAKA et al., "Spin-Valve Heads in the Current-Perpendicular-to-Plane Mode for Ultrahigh-Density Recording," IEEE Transactions on Magnetics, Vol. 38, No. 1, January 2002. Z	Yes
	K. TSUNEKAWA et al., "Surface Treatment Techniques in Fabrication of GMR and TMR Films, "Journal of the Magnetics Society of Japan, Vol. 28, No. 11, pp. 1074-1080, November 1, 2004. Z	Yes

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	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 the applicant.*

Z = Filed in Parent Application 13/400,340

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Substitute for Form 1449/PTO	Application #	To Be Determined
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 12 of 12	Docket #	NAGI.0005

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Translation**
	D. WANG et al., "70% TMR at Room Temperature for SDT Sandwich Junctions With CoFeB as Free and Reference Layers," IEEE Transactions on Magnetics, Vol. 40, No. 4, pp. 2270-2271, July 2004. Z	Yes
	S. YOSHIMURA et al., " Magnetic Grain Size Reduction by Using Oxygen Exposure Process Onto Very Thin Islandlike WCr Seedlayer in Longitudinal Recording Media," Journal of Applied Physics, Vol. 91, No. 10, pp. 8629-8631, May 15, 2002. Z	Yes
	S. YOSHIMURA et al. "Grain Size Reduction by Utilizing A Very Thin, High-Melting-Point WCr Seedlayer in Longitudinal Media: Media Noise Reduction in High H_k^{grain} Media, Vol. 25, No. 4-2, pp. 627-630 (2001). Z	Abstract
	YU et al., "Electron Transport Properties in Magnetic Tunnel Junctions with Epitaxial NiFe (111) Ferromagnetic Bottom Electrodes," Applied Physics Letters, Vol. 82, No. 26, pp. 4735-4737, June 30, 2003. Z	Yes
	S. YUASA et al. "Magnetic Tunnel Junctions With Single-Crystal Electrodes: A Crystal Anisotropy of Tunnel Magneto-Resistance," Europhysics Letters, Vol. 52, No. 3, pp. 344-350 November 1, 2000. Z	Yes
	S. YUASA et al., "Giant Room-Temperature Magnetoresistance in Single-Crystal Fe/MgO/Fe Magnetic Tunnel Junctions," Nature Materials Vol. 3, pp. 868-871, October 31, 2004 Z	Yes
	S. YUASA et al., "Spin-Polarized Resonant Tunneling In Magnetic Tunnel Junctions," Science, Vol. 297, pp. 234-237, July 12, 2002. Z	Yes
	S. Zhang et al. "Quenching of Magnetoresistance by Hot Electrons in Magnetic Tunnel Junctions," Physical Review Letters, Vol. 79, No. 19, pp. 3744-3747, November 10, 1997. Z	Yes

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	Date Considered	

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Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

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

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

CLAIM		DATE								
Final	Original	07/03/2013								
	1	✓								
	2	✓								
	3	✓								
	4	✓								
	5	✓								
	6	✓								
	7	✓								
	8	✓								
	9	✓								
	10	✓								
	11	✓								

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Western Digital v IP Bridge
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Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC- SEARCHED		
Symbol	Date	Examiner

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner

SEARCH NOTES		
Search Notes	Date	Examiner
East text search only - see attached printout	7/3/13	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner

UNITED STATES PATENT AND TRADEMARK OFFICE

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BIB DATA SHEET

CONFIRMATION NO. 2082

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
13/767,290	02/14/2013 RULE	257	2897	NAGI-0005

APPLICANTS

Shinji YUASA, Ibaraki, JAPAN;
Japan Science and Technology Agency, Residence Not Provided
National Institute of Advanced Industrial Science and Technology, Tokyo, JAPAN

**** CONTINUING DATA ***************************

This application is a CON of 13/400,340 02/20/2012 PAT 8405134
which is a CON of 12/923,643 09/30/2010 PAT 8319263
which is a CON of 10/591,947 09/08/2006 PAT 7884403
which is a 371 of PCT/JP2005/004720 03/10/2005

**** FOREIGN APPLICATIONS ***************************

JAPAN 2004-313350 10/28/2004
JAPAN 2004-071186 03/12/2004

**** IF REQUIRED, FOREIGN FILING LICENSE GRANTED ****

03/05/2013

Foreign Priority claimed ☑ Yes ☐ No 35 USC 119(a-d) conditions met ☑ Yes ☐ No Verified and Acknowledged /ALONZO CHAMBLISS/ Examiner's Signature	☐ Met after Allowance Initials	STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
		JAPAN	10	11	4

ADDRESS

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Alexandria, VA 22314-1437
UNITED STATES

TITLE

Magnetic Tunnel Junction Device

FILING FEE RECEIVED		
1650	FEES: Authority has been given in Paper No._____ to charge/credit DEPOSIT ACCOUNT No._____ for following:	☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other _____ ☐ Credit

BIB (Rev. 05/07).

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	40367	"257"/$.ccls. and poly adj2 crystalline adj3 magnesium adj2 oxide nad (MTJ magnetic adj3 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2013/07/02 22:30
L2	6	"257"/$.ccls. and poly adj2 crystalline adj3 magnesium adj2 oxide and (MTJ magnetic adj3 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2013/07/02 22:31
L3	6	poly adj2 crystalline adj3 magnesium adj2 oxide and (MTJ magnetic adj3 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2013/07/02 22:33
L4	6	poly adj2 crystalline adj3 magnesium adj2 oxide same tunnel adj3 barrier	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2013/07/02 23:04

EAST Search History (Interference)

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7/3/2013 12:50:32 AM
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WD EX1008
Western Digital v IP Bridge
Page 217

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005

CONFIRMATION NO. 2082

38327
Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
1199 North Fairfax Street
Suite 900
Alexandria, VA 22314-1437

PUBLICATION NOTICE

OC000000063594945

Title: Magnetic Tunnel Junction Device

Publication No.US-2013-0228883-A1
Publication Date:09/05/2013

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 Office of Public Records. The Office of Public Records can be reached by telephone at (703) 308-9726 or (800) 972-6382, by facsimile at (703) 305-8759, by mail addressed to the United States Patent and Trademark Office, Office of Public Records, 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 http://pair.uspto.gov/. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

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Office of Data Managment, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	
YUASA	)	**Confirmation No. 2082**
	)	
U.S. Application No.: 13/767,290	)	**Art Unit 2686**
	)	
Filed: February 14, 2013	)	**Examiner**
	)	**Alonzo Chambliss**
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
Attorney Docket No.: NAGI-0005	)	

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

RESPONSE AND AMENDMENT UNDER 37 C.F.R. § 1.111

Sir:

This is in response to the Office Action mailed on July 10, 2013, the period of response to which is set to expire on November 10, 2013, with the payment of the requisite fee for an extension of time of one month. This response is being timely filed on November 12, 2013, in accordance with 37 C.F.R. §1.7(a). Please amend the above-referenced application as follows:

IN THE CLAIMS:

Claims 1-3, 5 and 10-11 stand for consideration in this application, wherein claims 5 and 10-11 are being amended to more particularly point out and distinctly claim the subject invention; claims 4 and 6-9 are being canceled without prejudice or disclaimer, all as follows:

1. (Previously Presented) A tunnel barrier layer located between a first ferromagnetic material layer and a second ferromagnetic material layer,

wherein the tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented.

2. (Previously Presented) A tunnel bather layer according to claim 1,

wherein the tunnel barrier layer has a barrier height in a range of 0.2 to 0.5 e V.

3. (Previously Presented) A tunnel barrier layer according to claim 2, wherein the tunnel barrier layer height ϕ is obtained by fitting J-V characteristics of a tunnel barrier junction structure to an equation (1):

$$J = [(2m\,\phi)^{1/2}/\Delta\, s]\,(e/h)^2 \times \exp[-(4\,\pi\,\Delta\, s/h) \times (2m\,\phi)^{1/2}] \times V \qquad (1)$$

where J is a tunnel current density flowing through the tunnel barrier layer, V is an applied bias voltage that is 100 mV or smaller, m is the free electron mass, e is the elementary electric charge, h is the Plank's constant, Δ s is an effective thickness of the tunnel barrier layer that is approximately equivalent to ($t_{Mg}o$ —0.5 nm), and $t_{Mg}o$ is an actual thickness of the tunnel barrier layer determined using a cross-sectional transmission electron microscope image.

4. (Canceled).

5. (Currently Amended) The ~~magnetoresistive device~~ tunnel barrier layer according to claim [[4]] 1, wherein ~~at least one of~~ the tunnel barrier layer is on the first ~~and second~~ ferromagnetic material ~~layers~~ layer which comprises CoFeB alloy.

6-9. (Canceled).

10. (Currently Amended) The tunnel barrier layer according to claim 5, ~~A magnetoresistive device having a tunnel barrier junction structure, the magnetoresistive device comprising:~~

~~a first ferromagnetic material layer deposited on a substrate;~~

~~a second ferromagnetic material layer; and~~

~~a tunnel barrier layer located between the first and second ferromagnetic material layers, and~~

~~wherein the tunnel barrier layer comprises a single crystalline magnesium oxide in which a (001) crystal plane is preferentially oriented or a poly crystalline magnesium oxide in which a (001) crystal plane is preferentially oriented, and~~

wherein ~~at least~~ the first ferromagnetic material layer CoFeB ~~comprises an iron based alloy and~~ is entirely crystallized.

11. (Currently Amended) The ~~magnetoresistive device~~ tunnel barrier layer according to claim 10, wherein the second ferromagnetic material layer comprises an iron-based alloy and is entirely crystallized.

REMARKS

The above amendments to the above-captioned application along with the following remarks are being submitted as a full and complete response to the Office Action dated July 10, 2013 (USPTO Paper No. 20130702). In view of the above amendments and the following remarks, the Examiner is respectfully requested to give due reconsideration to this application, to indicate the allowability of the claims, and to pass this case to issue.

Status of the Claims

As outlined above, claims 1-3, 5 and 10-11 stand for consideration in this application, wherein claims 5 and 10-11 are being amended to more particularly point out and distinctly claim the subject invention; claims 4 and 6-9 are being canceled without prejudice or disclaimer. Any and all amendments to the specification and/or to the claims are fully supported throughout the disclosure of the invention. Applicants submit that no new matter is being introduced into this application through the submission of this response.

Double Patenting Rejections

Claims 4-7 were rejected under 35 U.S.C. §101 for statutory double patenting as being unpatentable over claim 5 of U.S. Patent No. 7,884,403. Further, the Examiner rejected claims 1-3 and 10-11 under the judicially-created doctrine of obviousness-type double patenting in view of claims 1 of U.S. Patent No. 7,884,403, which was the predecessor of this application.

As outlined above, the claims are being amended to more particularly point out and distinctly claim the subject invention. In addition, a Terminal Disclaimer is being submitted concurrently herewith. As such, Applicants will submit that the Examiner's double patenting rejections have been obviated and/or rendered moot.

Formality Objection

The Examiner objected to the drawings for a minor formality and has requested correction thereof. The Examiner objected to the drawings due to the inclusion of reference character **113** which was not mentioned in the description. However, Applicants did not locate

reference character **113** in the drawings. Applicants will respectfully make any such formality corrections to the drawings upon clarification by the Examiner. The Examiner's kind consideration is respectfully requested.

Prior Art Rejections

The Examiner rejected claims 1 and 8-11 under 35 U.S.C. §102(b) as being anticipated by Bowen ("Large magnetoresistance in Fe/MgO/FeCo(001) epitaxial tunnel junctions on GaAs(001)". Appl. Phys. Lett. 79 (11): 1655. (2001)). Applicants have reviewed the above-noted rejection and hereby respectfully traverse.

For anticipation to be present under 35 U.S.C. §102, "[t]he identical invention must be shown in as complete detail as is contained in the...claim." *Richardson v. Suzuki Motor Co.*, 868 F.2d 1226, 1236 (Fed. Cir. 1989). More particularly, under 35 U.S.C. §102, "[a] claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." *Verdegaal Bros. v. Union Oil Co. of Cal.,* 814 F.2d 628, 631 (Fed. Cir. 1987). That is, to anticipate a claim under §102, a single source must contain all of the elements of the claim. *Lewmar Marine Inc. v. Burient, Inc.*, 827 F.2d 744, 747 (Fed. Cir. 1987).

The present invention as now recited in claim 1 is directed to a tunnel barrier layer located between a first ferromagnetic material layer and a second ferromagnetic material layer, wherein the tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented.

Contrary to the Examiner's assertions in citing Bowen, this reference merely discloses a tunnel barrier that is single-crystalline, whereas the tunnel barrier layer of the present invention comprises a **poly-crystalline** magnesium oxide layer. Therefore, the reference of Bowen does not show each and every element of the present invention as claimed. As such, Bowen cannot and does not anticipate the claimed invention.

Further, Applicants will contend that the structural and chemical characteristics of a single-crystalline tunnel barrier are distinctly different from those of a tunnel barrier layer having a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented of disclosed in the journal is distinctly different from that of the present invention. Thus, Bowen

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also cannot be cited for showing or suggesting every feature of the claimed invention. Rather, one of ordinary skill in the art would not have turned to the single-crystalline tunnel barrier structure of Bowen to achieve, much less teach, the tunnel barrier having a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented, as in the claimed invention. The present invention would not be rendered obvious in view of Bowen. Consequently, the present invention as recited in independent claim 1 and all of its dependent claims is distinguishable and thereby allowable over the reference of Bowen.

Allowable Subject Matter

In the Office Action, the Examiner only objected to claims 2 and 3 as being dependent on a rejected base claim, but would allow the claims if they are amended to add all the limitations of its base claim and any intervening claims, and to address the above-noted informality objection. As outlined above, the claims are distinguishable and thereby allowable over the prior art of record. In view of all the above, Applicants will submit that all the claims remaining of record are now in condition for allowance.

Conclusion

In view of all the above, Applicants respectfully submit that certain clear and distinct differences as discussed exist between the present invention as now claimed and the prior art as a whole. These differences are more than sufficient that the present invention as now claimed would not have been anticipated nor rendered obvious given the prior art. Rather, the present invention as a whole is distinguishable, and thereby allowable over the prior art.

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Favorable reconsideration of this application as amended is respectfully solicited. Should there be any outstanding issues requiring discussion that would further the prosecution and allowance of the above-captioned application, the Examiner is invited to contact the Applicants' undersigned representative at the address and phone number indicated below.

Respectfully submitted,

Douglas E. Jackson FOR #28,578

Juan Carlos A. Marquez
Registration Number 34,072

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November 12, 2013

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	
YUASA	)	**Confirmation No. 2082**
	)	
U.S. Application No.: 13/767,290	)	**Art Unit 2686**
	)	
Filed: February 14, 2013	)	**Examiner**
	)	**Alonzo Chambliss**
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
Attorney Docket No.: NAGI-0005	)	

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

TERMINAL DISCLAIMER

Sir:

I, Juan Carlos A. Marquez, represent that I am the attorney of record for the above-identified application.

The invention has been assigned to Japan Science and Technology Agency and National Institute of Advanced Industrial Science and Technology, who are the owners by assignment of 100 percent of the right, title and interest in the above-captioned patent application.

Japan Science and Technology Agency and National Institute of Advanced Industrial Science and Technology are also the owners of 100 percent of the right, title and interest to U.S. Patent No. 7,884,403 by assignment and hereby disclaims, except as otherwise provided hereinbelow, the terminal part of any patent granted on the above-captioned patent application, which would extend beyond the expiration date of the full statutory term of the **prior patent** U.S. Patent No. 7,884,403, the term of said **prior patent** is defined in 35 U.S.C. §§154 and 173, and as the term of said **prior patent** is presently shortened by any terminal disclaimer. Japan Science and Technology Agency and National Institute of Advanced Industrial Science and Technology hereby agree that any patent so granted on the instant application shall be enforceable only for and during such period that it and the **prior patent** are commonly owned.

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This agreement runs with any patent granted on the instant application and is binding upon the grantee, its successors or assigns.

In making the above disclaimer, Japan Science and Technology Agency and National Institute of Advanced Industrial Science and Technology do not disclaim the terminal part of the term of any patent granted on the instant application that would extend to the expiration date of the full statutory term as defined in 35 U.S.C. §§154 and 173 of the **prior patent**, "as the term of said **prior patent** is presently shortened by any terminal disclaimer," in the event that said **prior patent** later: (a) expires for failure to pay a maintenance fee; (b) is held unenforceable; (c) is found invalid by a court of competent jurisdiction; (d) is statutorily disclaimed in whole or terminally disclaimed under 37 CFR 1.321; (e) has all claims canceled by a reexamination certificate; (f) is reissued; or (g) is in any manner terminated prior to the expiration of its full statutory term as presently shortened by any terminal disclaimer.

Respectfully submitted,

/Juan Carlos A. Marquez/

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November 12, 2013

310289:1:ALEXANDRIA

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Electronic Patent Application Fee Transmittal

Application Number:	13767290
Filing Date:	14-Feb-2013
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Juan Carlos A. Marquez/Nancy DeSanti
Attorney Docket Number:	NAGI-0005

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Extension - 1 month with $0 paid	1251	1	200	200

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
Statutory or Terminal Disclaimer	1814	1	160	160
		Total in USD ($)		**360**

Electronic Acknowledgement Receipt	
EFS ID:	17377230
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	38327
Filer:	Juan Carlos A. Marquez/Nancy DeSanti
Filer Authorized By:	Juan Carlos A. Marquez
Attorney Docket Number:	NAGI-0005
Receipt Date:	12-NOV-2013
Filing Date:	14-FEB-2013
Time Stamp:	14:34:58
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$360
RAM confirmation Number	1095
Deposit Account	120555
Authorized User	STITES & HARBISON PLLC
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees) Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)	

Charge any Additional Fees required under 37 C.F.R. Section 1.19 (Document supply fees) Charge any Additional Fees required under 37 C.F.R. Section 1.20 (Post Issuance fees) Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		NAGI-5-amd-11-12-13.pdf	426280 419470299a78500abaf13259480a3ba36b26e869	yes	11

Multipart Description/PDF files in .zip description

Document Description	Start	End
Transmittal Letter	1	2
Amendment/Req. Reconsideration-After Non-Final Reject	3	3
Claims	4	5
Applicant Arguments/Remarks Made in an Amendment	6	9
Terminal Disclaimer Filed	10	11

Warnings:

Information:

2	Fee Worksheet (SB06)	fee-info.pdf	32252 bcd2b3fea169db2557b578347b646b0508dfd6be	no	2

Warnings:

Information:

Total Files Size (in bytes):	458532

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.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	
YUASA	)	**Confirmation No. 2082**
	)	
U.S. Application No.: 13/767,290	)	**Art Unit 2686**
	)	
Filed: February 14, 2013	)	**Examiner**
	)	**Alonzo Chambliss**
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
Attorney Docket No.: NAGI-0005	)	

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

COVER LETTER

Sir:

[x] The fee for submission of claims is calculated as shown below:

FOR	TOTAL WITH NEW CLAIMS ADDED	TOTAL CURRENTLY ON FILE	CLAIMS ALREADY PAID	RATE	CALCULATION
Total Claims	6	11	(Over 20)	x $80	0
Independent Claims	1	4	1 (Over 3)	x $420	0
MULTIPLE DEPENDENT CLAIM(S)				+ $780	0
REDUCTION FOR FILING BY SMALL ENTITY (note 37 C.F.R. §§ 1.9, 1.27, 1.28).				x ½	
			TOTAL		$0

In addition, the below-identified communications are submitted in the above-captioned application or proceeding:

[x] Response and Amendment to Office Action (with claim amendments)
[ ] Substitute Abstract
[ ] Terminal Disclaimer
[ ] Information Disclosure Statement
[ ] __ sheets of drawings
[ ] RCE
[ ] Other: _____

[x] Applicant(s) hereby request and petition that the time for taking action in this case be extended pursuant to 37 C.F.R. § 1.136(a) for:
[x] **one (1) month** [ ] **two (2) months** [ ] **three (3) months**

The fee set in 37 C.F.R. § 1.17 for the extension of time is **$200.00** for a large entity.

[x] Credit card information for **$200.00** to cover the 1-month extension fee and **$160.00** to cover the Terminal Disclaimer fee associated with this filing is enclosed.

[ ] Please charge my **Deposit Account Number** _____ in the amount of _____ to cover the fees for _____.

[x] The Commissioner is hereby authorized to charge any additional fees associated with this communication, including fees under 37 C.F.R. § 1.16 and 1.17, or credit any overpayment to **Deposit Account Number 12-0555**.

Respectfully submitted,

Douglas E. Jackson FOR #28,518

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November 12, 2013

310226:1:ALEXANDRIA

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 13/767,290	Filing Date 02/14/2013	☐ 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 $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ 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

AMENDMENT	11/12/2013	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 6	Minus	** 20	= 0	X $80 =	0
	Independent (37 CFR 1.16(h))	* 1	Minus	***4	= 0	X $420 =	0
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	0

AMENDMENT		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
	☐ 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.
** 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 number found in the appropriate box in column 1.

LIE
/PARTHENIA D. MERRILL/

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.

Application Number	Application/Control No.	Applicant(s)/Patent under Reexamination	
	13/767,290	YUASA, SHINJI	

Document Code - DISQ	Internal Document – DO NOT MAIL

TERMINAL DISCLAIMER	☐ APPROVED	☒ DISAPPROVED
Date Filed : 11/12/13	This patent is subject to a Terminal Disclaimer	

Approved/Disapproved by:

The person who signed the terminal disclaimer (only for applicati ns filed on or after September 16,2012 is not the applicant, patentee or an attorney or agent of record. 37 CFR 1.321 (a) and (b). (See FP 14.26.08)

Jean Proctor

U.S. Patent and Trademark Office

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.
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005	2082

38327 7590 12/31/2013

Juan Carlos A. Marquez
c/o Stites & Harbison PLLC
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Alexandria, VA 22314-1437

EXAMINER	
CHAMBLISS, ALONZO	
ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
12/31/2013	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):

iplaw@stites.com

Office Action Summary	Application No. 13/767,290	Applicant(s) YUASA, SHINJI	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	AIA (First Inventor to File) Status No

-- 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 *11/12/13*.

☐ 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) *1-3,5,10 and 11* 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) *1-3,5,10, and 11* is/are rejected.

8)☐ Claim(s) _____ 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 *2/14/13* 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. 10/591,947.

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: *see Detailed Action*.

DETAILED ACTION

1. The present application is being examined under the pre-AIA first to invent provisions.

2. The amendment filed on 11/12/13 has been fully considered and made of record in this application.

Oath/Declaration

3. An Oath/Declaration has not been filed along with this application.

Terminal Disclaimer

4. The terminal disclaimer filed on 11/12/13 disclaiming the terminal portion of any patent granted on this application which would extend beyond the expiration date of US 7,884,403 has been reviewed and is NOT accepted.

5. The terminal disclaimer does not comply with 37 CFR 1.321 because:
Juan Carlos A. Marquez is not the applicant, patentee, or an attorney or agent of record.

Response to Arguments

6. Applicant's arguments filed 11/12/13 have been fully considered but they are not persuasive. In regards to Bowen failing to disclose a poly-crystalline magnesium oxide layer. However, Bowen discloses a poly-crystalline magnesium oxide layer (see page 1656 first full paragraph). Therefore, this action is made **final**.

Claim Rejections - 35 USC § 102

7. The following is a quotation of the appropriate paragraphs of pre-AIA 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 –
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

8. Claim 1 is rejected under pre-AIA 35 U.S.C. 102b as being clearly anticipated by "Large magnetoresistance in Fe/MgO/FeCo(001) epitaxial tunnel junctions of GaAs(001) " journal.

With respect to Claim 1, the journal teaches a tunnel barrier layer located between a first ferromagnetic material layer and a second ferromagnetic material layer, wherein the tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented. The first and second ferromagnetic material layer comprises an iron-based alloy (i.e. made of FeO) and is entirely crystallized (see pages 1655 and 1656).

Double Patenting

9. The nonstatutory double patenting rejection is based on a judicially created doctrine grounded in public policy (a policy reflected in the statute) so as to prevent the unjustified or improper timewise extension of the "right to exclude" granted by a patent and to prevent possible harassment by multiple assignees. A nonstatutory double patenting rejection is appropriate where the claims at issue are not identical, but at least one examined application claim is not patentably distinct from the reference claim(s) because the examined application claim is either anticipated by, or would have been

obvious over, the reference claim(s). See, e.g., *In re Berg*, 140 F.3d 1428, 46 USPQ2d 1226 (Fed. Cir. 1998); *In re Goodman*, 11 F.3d 1046, 29 USPQ2d 2010 (Fed. Cir. 1993); *In re Longi*, 759 F.2d 887, 225 USPQ 645 (Fed. Cir. 1985); *In re Van Ornum*, 686 F.2d 937, 214 USPQ 761 (CCPA 1982); *In re Vogel*, 422 F.2d 438, 164 USPQ 619 (CCPA 1970); and *In re Thorington*, 418 F.2d 528, 163 USPQ 644 (CCPA 1969).

A timely filed terminal disclaimer in compliance with 37 CFR 1.321(c) or 1.321(d) may be used to overcome an actual or provisional rejection based on a nonstatutory double patenting ground provided the reference application or patent either is shown to be commonly owned with this application, or claims an invention made as a result of activities undertaken within the scope of a joint research agreement. A terminal disclaimer must be signed in compliance with 37 CFR 1.321(b).

The USPTO internet Web site contains terminal disclaimer forms which may be used. Please visit http://www.uspto.gov/forms/. The filing date of the application will determine what form should be used. A web-based eTerminal Disclaimer may be filled out completely online using web-screens. An eTerminal Disclaimer that meets all requirements is auto-processed and approved immediately upon submission. For more information about eTerminal Disclaimers, refer to http://www.uspto.gov/patents/process/file/efs/guidance/eTD-info-I.jsp.

10. Claims 1-3, 5, 10, and 11 are rejected on the ground of nonstatutory double patenting as being unpatentable over claim 1 of U.S. Patent No. 7,884,403. Although the claims at issue are not identical, they are not patentably distinct from each other because the instant application and the patent recite a first and second ferromagnetic

material layers with a tunnel barrier layer made of poly-crystalline magnesium oxide layer between the ferromagnetic materials.

Allowable Subject Matter

11. Claims 2 and 3 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.

12. The following is a statement of reasons for the indication of allowance subject matter: the prior art of record does not teach or suggest the combination of a wherein the tunnel barrier layer has a barrier height in a range of 0.2 to 0.5 electron volts (eV) in claims 2 and 4.

The prior art made of record and not relied upon is cited primarily to show the product of the instant invention.

Conclusion

13. **THIS ACTION IS MADE FINAL.** Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire THREE MONTHS from the mailing date of this action. In the event a first reply is filed within TWO MONTHS of the mailing date of this final action and the advisory action is not mailed until after the end of the THREE-MONTH shortened statutory period, then the

shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the mailing date of this final action.

Any inquiry concerning the communication or earlier communications from the examiner should be directed to Alonzo Chambliss whose telephone number is (571) 272-1927.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Fernando L. Toledo can be reached on (571) 272-1867. 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 PMR or Public PMR. Status information for unpublished applications is available through Private PMR only. For more information about the PMR system see http://pair-dkect.uspto.gov. Should you have questions on access to the Private PMR system contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free) or EBC_Support@uspto.gov.

AC/December 19, 2013 /Alonzo Chambliss/

Primary Examiner, Art Unit 2897

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L2	10	poly adj3 crystalline near5 (magnesium adj3 oxide MgO) and (MTJ magnetic adj3 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2013/12/18 22:57

EAST Search History (Interference)

< This search history is empty>

12/ 18/ 2013 10:58:02 PM
C:\ Users\ achambliss\ Documents\ EAST\ Workspaces\ 12652379.wsp

WD EX1008
Western Digital v IP Bridge
Page 244

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC- SEARCHED		
Symbol	Date	Examiner

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner

SEARCH NOTES		
Search Notes	Date	Examiner
East text search only - see attached printout	7/3/13	AC
Updated previous East text search only - see attached printout	12/18/13	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

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

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

CLAIM		DATE								
Final	Original	07/03/2013	12/18/2013							
	1	✓	✓							
	2	✓	✓							
	3	✓	✓							
	4	✓								
	5	✓	✓							
	6	✓								
	7	✓								
	8	✓								
	9	✓								
	10	✓	✓							
	11	✓	✓							

Doc Code: PA..
Document Description: Power of Attorney

PTO/AIA/82B (07-13)
Approved for use through 11/30/2014. OMB 0651-0031
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

POWER OF ATTORNEY BY APPLICANT

I hereby revoke all previous powers of attorney given in the application identified in either the attached transmittal letter or the boxes below.

Application Number	Filing Date

(Note: The boxes above may be left blank if information is provided on form PTO/AIA/82A.)

☑ I hereby appoint the Patent Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above: 00881

OR

☐ I hereby appoint Practitioner(s) named in the attached list (form PTO/AIA/82C) as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the patent application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above. (Note: Complete form PTO/AIA/82C.)

Please recognize or change the correspondence address for the application identified in the attached transmittal letter or the boxes above to:

☑ The address associated with the above-mentioned Customer Number

OR

☐ The address associated with Customer Number: 00881

OR

Firm or Individual Name					
Address					
City		State		Zip	
Country					
Telephone		Email			

I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

Japan Science and Technology Agency

☐ Inventor or Joint Inventor (title not required below)

☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)

☑ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)

☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature	A. Saito	Date (Optional)	
Name	Hitoshi SAITO		
Title	Senior Director		

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☐ Total of forms are submitted.

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. 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 1.11 and 1.14. This collection is estimated to take 3 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.

Doc Code: PA..
Document Description: Power of Attorney

PTO/AIA/82B (07-13)
Approved for use through 11/30/2014. OMB 0651-0031
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

POWER OF ATTORNEY BY APPLICANT

I hereby revoke all previous powers of attorney given in the application identified in either the attached transmittal letter or the boxes below.

Application Number	Filing Date

(Note: The boxes above may be left blank if information is provided on form PTO/AIA/82A.)

☑ I hereby appoint the Patent Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above: 00881

OR

☐ I hereby appoint Practitioner(s) named in the attached list (form PTO/AIA/82C) as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the patent application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above. (Note: Complete form PTO/AIA/82C.)

Please recognize or change the correspondence address for the application identified in the attached transmittal letter or the boxes above to:

☑ The address associated with the above-mentioned Customer Number

OR

☐ The address associated with Customer Number: 00881

OR

Firm or Individual Name					
Address					
City		State		Zip	
Country					
Telephone		Email			

I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

National Institute of Advanced Industrial Science and Technology

☐ Inventor or Joint Inventor (title not required below)

☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)

☑ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)

☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature	Shigeki Kamiyama	Date (Optional)	12.03.2014
Name	Shigeki KAMIYAMA		
Title	Director, Intellectual Property Division		

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☐ Total of forms are submitted.

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. 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 1.11 and 1.14. This collection is estimated to take 3 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.

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Electronic Acknowledgement Receipt

EFS ID:	18745216
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	38327
Filer:	Billy Aaron Schulman/Stacy Johnson
Filer Authorized By:	Billy Aaron Schulman
Attorney Docket Number:	NAGI-0005
Receipt Date:	11-APR-2014
Filing Date:	14-FEB-2013
Time Stamp:	17:40:03
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	Power of Attorney	NAGI_0005POAs.pdf	340226 7e7a70c5e8cd27643aedbeb972f8f75a492dafcc	no	2
Warnings:					
Information:					

Total Files Size (in bytes):	340226

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.

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
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005

CONFIRMATION NO. 2082

881
STITES & HARBISON PLLC
1199 NORTH FAIRFAX STREET
SUITE 900
ALEXANDRIA, VA 22314

POA ACCEPTANCE LETTER

OC000000067911396

Date Mailed: 04/28/2014

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 04/11/2014.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

/ttkim/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

Customized PTO/SB/30 (07-09)

REQUEST FOR CONTINUED EXAMINATION (RCE) Transmittal Mail Stop RCE		
	Application #	13/767,290
	Confirmation #	2082
	Filing Date	February 14, 2013
	First Inventor	YUASA, et al.
	Art Unit	2897
	Examiner	Chambliss, Alonzo
	Docket #	NAGI-0005

This is a Request for Continued Examination (RCE) under 37 CFR § 1.114 of the above application.
RCE practice does not apply to any utility application filed prior to June 8, 1995, or to any design application. Prosecution must be closed.

Submission **required** under 37 CFR § 1.114

Note: If the RCE is proper, any previously filed unentered amendments and amendments enclosed with the RCE will be entered in the order in which they were filed unless applicant instructs otherwise (with a separate request for non-entry).

☐ **Previously submitted.** *If a final Office action is outstanding, any amendments filed after the final Office action may be considered by the PTO as a submission even if the box for the following line is not checked.*
- ☐ Consider the arguments in the Appeal Brief or Reply Brief previously filed on
- ☐ Other:

☒ **Enclosed**
- ☒ Amendment/Reply
- ☐ Affidavit(s)/Declaration(s)
- ☐ Information Disclosure Citation
- ☒ Other: Terminal Disclaimer

Miscellaneous

☐ **Suspension of action** on the above-identified application is requested under 37 CFR § 1.103(c) for a period of months *(Period of suspension shall not exceed 3 months; Fee under 37 CFR§ 1.17(i) required).*
☐ Other:

FEES calculated below (after reduction for an amendment if noted above).

	STATUS of Applicant is:			☐ MICRO	☐ SMALL	☒ LARGE	
	NOW	*Prev.*	*Extra*	$	$	$	$
☒ TOTAL Claims	6	- 20	0	X 20 =	X 40 =	X 80 =	0
☒ INDEP. Claims	1	- 3	0	X 105 =	X 210 =	X 420 =	0
☒ *FIRST* RCE				300	600	1200	1200
☐ *SECOND/FURTHER* RCE				425	850	1700	
☒ Extension of Time for ONE month(s) (serving as a constructive EOT Petition)							200
☐ Other fee for							
TOTAL OF ALL FEES =							**1400**

☒ Payment of **$1400** is made by:
- ☒ **ELECTRONIC FUNDS TRANSFER** submitted herewith.
- ☐ **CREDIT CARD** (Form PTO-2038 is enclosed).

☒ The Director is authorized to charge any fee, additional fee or extension fee due in connection herewith to Deposit Account No. 12-0555:
(1) **if** no payment or an insufficient payment is enclosed and a fee is due in connection herewith; or
(2) **if** no petition for extension of time is enclosed but an EOT is required - and in this event, applicant hereby petitions under 37 CFR 1.136(a) for an extension of time of as many months as are required to render this submission timely.

Date: April 30, 2014

Nicholas B. Trenkle

Signed By Name: Nicholas B. Trenkle
Attorney of Record Registration No.: 54,500

STITES & HARBISON PLLC • 1199 North Fairfax St. • Suite 900 • Alexandria, VA 22314
TEL: 703-739-4900 ◆ FAX: 703-739-9577 ◆ CUSTOMER NO. 881

2355LT:00005:327000:1:ALEXANDRIA

PTO/SB/26 (08-11)
Approved for use through 07/31/2012. OMB 0651-0031
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.

TERMINAL DISCLAIMER TO OBVIATE A DOUBLE PATENTING REJECTION OVER A "PRIOR" PATENT

Docket Number (Optional)
NAGI-0005

In re Application of: YUASA, Shinji

Application No.: 13/767,290

Filed: February 14, 2013

For: MAGNETIC TUNNEL JUNCTION DEVICE
Japan Science and Technology Agency and
National Institute of Advanced Industrial Science

The owner*, and Technology, of 100 percent interest in the instant application hereby disclaims, except as provided below, the terminal part of the statutory term of any patent granted on the instant application which would extend beyond the expiration date of the full statutory term of **prior patent** No. 7,884,403 as the term of said **prior patent** is presently shortened by any terminal disclaimer. The owner hereby agrees that any patent so granted on the instant application shall be enforceable only for and during such period that it and the **prior patent** are commonly owned. This agreement runs with any patent granted on the instant application and is binding upon the grantee, its successors or assigns.

In making the above disclaimer, the owner does not disclaim the terminal part of the term of any patent granted on the instant application that would extend to the expiration date of the full statutory term of the **prior patent**, "as the term of said **prior patent** is presently shortened by any terminal disclaimer," in the event that said **prior patent** later:

expires for failure to pay a maintenance fee;
is held unenforceable;
is found invalid by a court of competent jurisdiction;
is statutorily disclaimed in whole or terminally disclaimed under 37 CFR 1.321;
has all claims canceled by a reexamination certificate;
is reissued; or
is in any manner terminated prior to the expiration of its full statutory term as presently shortened by any terminal disclaimer.

Check either box 1 or 2 below, if appropriate.

1. ☐ For submissions on behalf of a business/organization (e.g., corporation, partnership, university, government agency, etc.), the undersigned is empowered to act on behalf of the business/organization.

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 Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

2. ☑ The undersigned is an attorney or agent of record. Reg. No. 00881

Nicholas B. Trenkle — April 25, 2014
Signature — Date

Nicholas B. Trenkle
Typed or printed name

703-739-4900
Telephone Number

☐ Terminal disclaimer fee under 37 CFR 1.20(d) included.

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.

*Statement under 37 CFR 3.73(b) is required if terminal disclaimer is signed by the assignee (owner).
Form PTO/SB/96 may be used for making this certification. See MPEP § 324.

This collection of information is required by 37 CFR 1.321. 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 1.11 and 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.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	
YUASA	**Confirmation No. 2082**
U.S. Application No.: 13/767,290	**Art Unit 2897**
Filed: February 14, 2013	**Examiner Alonzo Chambliss**
For: MAGNETIC TUNNEL JUNCTION DEVICE	
Attorney Docket No.: NAGI-0005	

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

RESPONSE AND AMENDMENT UNDER 37 C.F.R. § 1.114

Sir:

This is in response to the Final Office Action mailed on December 31, 2013, the period of response to which is set to expire on April 30, 2014, with the payment of the appropriate extension fees for an extension of time of one month. A Request for Continued Examination (RCE) and a replacement terminal disclaimer in compliance with 37 C.F.R. 1.321 are being submitted herewith. Because the replacement terminal disclaimer is being submitted to replace the terminal disclaimer that was previously filed on November 12, 2013, Applicants submit that, in accordance with section 1490 of the MPEP, the terminal disclaimer fee for the previously filed terminal disclaimer should be applied to the replacement terminal disclaimer submitted herewith, and, therefore, a second terminal disclaimer fee should not be assessed/charged. Please amend the above-referenced application as follows:

IN THE CLAIMS

Claims 1-3, 5, 10, and 11 stand for consideration in this application, wherein claims 1, 5, 10, and 11 are being amended to improve form, as follows:

1. (Currently Amended) A tunnel barrier layer located between a first ferromagnetic material layer and a second ferromagnetic material layer,

wherein the tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented, and

wherein the first ferromagnetic material layer comprises CoFeB alloy that is at least partially crystallized.

2. (Previously Presented) A tunnel bather layer according to claim 1, wherein the tunnel barrier layer has a barrier height in a range of 0.2 to 0.5 e V.

3. (Previously Presented) A tunnel barrier layer according to claim 2, wherein the tunnel barrier layer height ϕ is obtained by fitting J-V characteristics of a tunnel barrier junction structure to an equation (1):

$$J = [(2m\phi)^{1/2}/\Delta s]\,(e/h)^2 \times \exp[-(4\pi\Delta s/h) \times (2m\phi)^{1/2}] \times V \qquad (1)$$

where J is a tunnel current density flowing through the tunnel barrier layer, V is an applied bias voltage that is 100 mV or smaller, m is the free electron mass, e is the elementary electric charge, h is the Plank's constant, Δ s is an effective thickness of the tunnel barrier layer that is approximately equivalent to ($t_{Mg}o$ − 0.5 nm), and $t_{Mg}o$ is an actual thickness of the tunnel barrier layer determined using a cross-sectional transmission electron microscope image.

4. (Canceled).

5. (Currently Amended) The tunnel barrier layer according to claim 1, wherein ~~the tunnel barrier layer is on~~ the first ferromagnetic material layer is entirely crystallized~~which comprises CoFeB alloy~~.

6-9. (Canceled).

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10. (Currently Amended) The tunnel barrier layer according to claim 2[[5]], wherein the first ferromagnetic material layer ~~CoFeB~~ is entirely crystallized.

11. (Currently Amended) The tunnel barrier layer according to claim 1[[0]], wherein the second ferromagnetic material layer comprises an iron-based alloy and is entirely crystallized.

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REMARKS

The above amendments to the above-captioned application along with the following remarks are being submitted as a full and complete response to the Final Office Action dated December 31, 2013 (U.S. Patent Office Paper No. 20131218). In view of the above amendments and the following remarks, the Examiner is respectfully requested to give due reconsideration to this application, to indicate the allowability of the claims, and to pass this case to issue.

Status of the Claims

As outlined above, claims 1-3, 5, 10, and 11 stand for consideration in this application, wherein claims 1, 5, 10, and 11 are being amended to improve form.

All amendments to the application are fully supported therein. For example, the amendments to the claims are supported by paragraphs [0052-53] of the present application as originally filed, as well as by Figure 11. Applicants hereby submit that no new matter is being introduced into the application through the submission of this response.

Allowable Subject Matter

The Examiner stated that claims 2 and 3 would each be allowable if rewritten in independent form to include all the limitations of the base claim and any intervening claims from which it depends.

Double Patenting Rejections

The Examiner rejected claims 1-3, 5, 10, and 11 as being unpatentable over claim 1 of U.S. Patent No. 7,884,403 ("the '403 application") on grounds of nonstatutory obviousness-type double patenting. In response, Applicants respectfully submit that the present application and the '403 application were commonly owned pursuant to 35 U.S.C. §103(c)(1) at the time the claimed invention of the present application was made. Accordingly, as set forth above, Applicants are submitting a replacement terminal disclaimer in compliance with 37 C.F.R. 1.321 herewith that replaces the terminal disclaimer that was previously filed on November 12, 2013 and not accepted, thereby rendering moot and/or obviating the non-statutory obviousness-type double patenting rejections.

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Prior Art Rejections

The Examiner rejected claim 1 under 35 U.S.C. §102(b) as being anticipated by Bowen ("Large magnetoresistance in Fe/MgO/FeCo(001) epitaxial tunnel junctions on GaAs(001)". Appl. Phys. Lett. 79 (11): 1655. (2001)). Applicants have reviewed the above-noted rejection, and hereby respectfully traverse.

For anticipation to be present under 35 U.S.C. §102, "[t]he identical invention must be shown in as complete detail as is contained in the...claim." *Richardson v. Suzuki Motor Co.*, 868 F.2d 1226, 1236 (Fed. Cir. 1989). More particularly, under 35 U.S.C. §102, "[a] claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." *Verdegaal Bros. v. Union Oil Co. of Cal.*, 814 F.2d 628, 631 (Fed. Cir. 1987). That is, to anticipate a claim under §102, a single source must contain all of the elements of the claim. *Lewmar Marine Inc. v. Burient, Inc.*, 827 F.2d 744, 747 (Fed. Cir. 1987).

As outlined above, claims 1-3, 5, 10 and 11 remain of record. Applicants respectfully submit that Bowen fails to show each and every limitation of claim 1. For example, Bowen fails to teach or disclose that "the tunnel barrier layer comprises a **poly-crystalline magnesium oxide layer** **in which a (001) crystal plane is preferentially oriented**" as required by independent claim 1. Rather, Bowen contrastingly describes "tunneling experiments on Fe(001)MgO (20 A)/FeCo(001) **single-crystal** epitaxial junctions." (Abstract) (emphasis added).

To this point, as explained in the Response submitted on November 12, 2013, it is clear that Bowen merely discloses a tunnel barrier that is single-crystalline, and the structural and chemical characteristics of a single-crystalline tunnel barrier are distinctly different from those of a tunnel barrier layer having a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented, as required by claim 1.

In reply to these arguments, the Examiner, on page 2 of the Final Office Action, now asserts that the first full paragraph on page 1656 of Bowen discloses a poly-crystalline magnesium oxide layer. The portion of Bowen being cited here by the Examiner, however, simply references a disclosure of "previous transport studies using...polycrystalline MgO by Moodera et al." ("Ferromagnetic-insulator-ferromagnetic tunneling: Spin-dependent tunneling and large magnetoresistance in trilayer junctions", J. Appl. Phys. 79, 4724 (1996)).

In this regard, Applicants note that not only is a simple reference to studies using "polycrystalline MgO" clearly not a description of a poly-crystalline magnesium oxide layer

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"in which a (001) crystal plane is preferentially oriented" as specifically required by claim 1, the Moodera article that is cited in Bowen fails to actually include any disclosure of polycrystalline MgO at all. Rather, while Moodera describes "[t]unneling between ferromagnet-insulator-ferromagnet (FM-I-FM) trilayer thin-film planar junction...with Al_2O_3 or MgO as the barrier layers" (Abstract), Moodera fails to include any mention or suggestion of even whether such MgO is crystal or amorphous. While references to such MgO as the barrier layer can be found in Moodera at columns 1 and 2 of page 4725, column 1 of page 4726, column 1 of page 4727, column 2 of page 4728, and column 1 of page 4729, none of the references to MgO in the entire Moodera include any further description of such a barrier layer beyond simply "MgO."

Accordingly, it is clear that the reference in Bowen to a disclosure of "polycrystalline MgO by Moodera et al." cited by the Examiner is clearly a misstatement by the author that should not be taken literally, not an actual disclosure of a poly-crystalline magnesium oxide layer, much less a disclosure of "a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented" as specifically required by claim 1. In other words, the simple description of an MgO layer, as described in Moodera and referenced by Bowen, is clearly not a description of a poly-crystalline magnesium oxide layer as required by claim 1, much less a description of "a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented" as more specifically required by claim 1. For this reason alone, claim 1 is clearly patentable over Bowen.

As another example, Bowen fails to teach or disclose that "the first ferromagnetic material layer comprises CoFeB alloy that is at least partially crystallized" as required by claim 1. Rather, in contrast to claim 1, Bowen merely describes Fe and FeCo layers and fails to include any mention or suggestion of any ferromagnetic material layer comprising CoFeB alloy. For this reason alone, claim 1 is patentable over Bowen.

For at least these reasons, Applicants respectfully submit that Bowen fails to teach or disclose each and every limitation of claim 1 and, therefore, that claim 1 is now in condition for allowance. Applicants therefore respectfully request reconsideration and withdrawal of the rejection based on Bowen and submit that the present invention as claimed is distinguishable and thereby allowable over the prior art of record.

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Conclusion

In view of all the above, Applicants respectfully submit that certain clear and distinct differences as discussed exist between the present invention as now claimed and the prior art references upon which the rejections in the Final Office Action rely. These differences are more than sufficient to establish that the present invention as now claimed would not have been anticipated nor rendered obvious given the prior art. Rather, the present invention as a whole is distinguishable, and thereby allowable over the prior art.

Favorable reconsideration of this application as amended is respectfully solicited. Should there be any outstanding issues requiring discussion that would further the prosecution and allowance of the above-captioned application, the Examiner is invited to contact the Applicants' undersigned representative at the address and phone number indicated below.

Respectfully submitted,

Nicholas B. Trenkle

Nicholas B. Trenkle
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April 30, 2014

325216:1:ALEXANDRIA

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Electronic Patent Application Fee Transmittal

Application Number:	13767290
Filing Date:	14-Feb-2013
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Billy Aaron Schulman/Stacy Johnson
Attorney Docket Number:	NAGI-0005

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Extension - 1 month with $0 paid	1251	1	200	200

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
Request for Continued Examination	1801	1	1200	1200
		Total in USD ($)		**1400**

Electronic Acknowledgement Receipt

EFS ID:	18908400
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Billy Aaron Schulman/Stacy Johnson
Filer Authorized By:	Billy Aaron Schulman
Attorney Docket Number:	NAGI-0005
Receipt Date:	30-APR-2014
Filing Date:	14-FEB-2013
Time Stamp:	16:53:07
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$1400
RAM confirmation Number	4209
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1		NAGI_0005RCE_Amdt_TerminalDisclaimer.pdf	453097 6a3db48961ad74f997a04c3136ee3f1c03c81b77	yes	9

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Request for Continued Examination (RCE)	1	1
	Terminal Disclaimer Filed	2	2
	Amendment Submitted/Entered with Filing of CPA/RCE	3	9

Warnings:

Information:

2	Fee Worksheet (SB06)	fee-info.pdf	32413 f16dedd3cc0a2bbac1d78dd73413d07231a3544e	no	2

Warnings:

Information:

Total Files Size (in bytes):	485510

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.

Application Number	Application/Control No.	Applicant(s)/Patent under Reexamination	
	13/767,290	YUASA, SHINJI	

Document Code - DISQ	Internal Document – DO NOT MAIL

TERMINAL DISCLAIMER	☒ APPROVED	☐ DISAPPROVED
Date Filed : 4/30/14	This patent is subject to a Terminal Disclaimer	

Approved/Disapproved by:
jean proctor

U.S. Patent and Trademark Office

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www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005	2082

881 7590 05/08/2014

STITES & HARBISON PLLC
1199 NORTH FAIRFAX STREET
SUITE 900
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	
ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
05/08/2014	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):

iplaw@stites.com

Office Action Summary	Application No. 13/767,290	Applicant(s) YUASA, SHINJI	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	AIA (First Inventor to File) Status No

-- 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 *4/30/14*.

☐ 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) *1-3,5,10 and 11* 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) *1-3,5,10 and 11* is/are rejected.

8)☐ Claim(s) _____ 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 *2/14/13* 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. 10/591,947.

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

1. The present application is being examined under the pre-AIA first to invent provisions.

Continued Examination Under 37 CFR 1.114

2. A request for continued examination under 37 CFR 1.114, including the fee set forth in 37 CFR 1.17(e), was filed in this application after final rejection. Since this application is eligible for continued examination under 37 CFR 1.114, and the fee set forth in 37 CFR 1.17(e) has been timely paid, the finality of the previous Office action has been withdrawn pursuant to 37 CFR 1.114. Applicant's submission filed on 4/30/14 has been entered.

Response to Arguments

3. Applicant's arguments with respect to claims 1-3, 5, 10, and 11 have been considered but are moot because the arguments do not apply to any of the references being used in the current rejection.

Double Patenting

4. **It is inherent the first ferromagnetic material layer would be deposited on a substrate.** Therefore, a rejection based on double patenting of the "same invention" type finds its support in the language of 35 U.S.C. 101 which states that "whoever invents or discovers any new and useful process... may obtain a patent therefor..."

(Emphasis added). Thus, the term "same invention," in this context, means an invention drawn to identical subject matter. See *Miller v. Eagle Mfg. Co.*, 151 U.S. 186 (1894); *In re Vogel*, 422 F.2d 438, 164 USPQ 619 (CCPA 1970); and *In re Ockert*, 245 F.2d 467, 114 USPQ 330 (CCPA 1957).

A statutory type (35 U.S.C. 101) double patenting rejection can be overcome by canceling or amending the claims that are directed to the same invention so they are no longer coextensive in scope. The filing of a terminal disclaimer cannot overcome a double patenting rejection based upon 35 U.S.C. 101.

5. Claims 1-3, 5, 10, and 11 are rejected under 35 U.S.C. 101 as claiming the same invention as that of claim1 of prior U.S. Patent No. 8,405,134. This is a statutory double patenting rejection.

The prior art made of record and not relied upon is cited primarily to show the process and product of the instant invention.

Conclusion

6. Any inquiry concerning the communication or earlier communications from the examiner should be directed to Alonzo Chambliss whose telephone number is (571) 272-1927.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Fernando L. Toledo can be reached on (571) 272-1867. 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 PMR or Public PMR. Status information for unpublished applications is available through Private PMR only. For more information about the PMR system see http://pair-dkect.uspto.gov. Should you have questions on access to the Private PMR system contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free) or EBC_Support@uspto.gov.

AC/May 4, 2014

/Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Notice of References Cited	Application/Control No. 13/767,290	Applicant(s)/Patent Under Reexamination YUASA, SHINJI	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2006/0049441	03-2006	Janesky et al.	257/295
	B	US-			
	C	US-			
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	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 MM-YYYY format are publication dates. Classifications may be US or foreign.

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	349	"219"/$.ccls. and (cover lid cap) same (shield$3 block$3) and (base food) same container and water	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/05/03 23:32
L2	6	("5277326" | "5387781" | "5558798").PN. OR ("6952000").URPN.	US-PGPUB; USPAT; USOCR	OR	OFF	2014/05/03 23:37
L3	7	backaert.in. and (cover lid cap) same (shield$3 block$3) and (base food) same container and water	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/05/03 23:54
L4	7	demuynck.in. and (cover lid cap) same (shield$3 block$3) and (base food) same container and water	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/05/03 23:55
L6	3	dart adj2 industries.as. and (cover lid cap) same (shield$3 block$3) and (base food) same container and water	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/05/03 23:56
L7	1	("20100163553").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2014/05/04 00:06
L8	3	(("8319263") or ("7884403") or ("8405134")).PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2014/05/04 01:02
L9	208	"257"/$.ccls. and (MTJ magnetic adj3 junction) and tunnel adj3 barrier with CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2014/05/04 01:05
L10	124	"438"/$.ccls. and (MTJ magnetic adj3 junction) and tunnel adj3 barrier with CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2014/05/04 01:23
L11	2	japan adj3 science.as. and (MTJ magnetic adj3 junction) and tunnel adj3 barrier with CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2014/05/04 01:31
L12	1	("8405134").PN.	USPAT; USOCR	OR	OFF	2014/05/04 01:33
L13	1	("7884403").PN.	USPAT; USOCR	OR	OFF	2014/05/04 01:33
L14	127	9 AND ((H01L43/08 OR H01L28/55 OR H01L27/11502 OR H01L27/222).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2014/05/04 01:51

EAST Search History (Interference)

<This search history is empty>

5/4/2014 1:52:35 AM
C:\Users\achambliss\Documents\EAST\Workspaces\13870490.wsp

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

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

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

CLAIM		DATE								
Final	Original	07/03/2013	12/18/2013	05/04/2014						
	1	✓	✓	✓						
	2	✓	✓	✓						
	3	✓	✓	✓						
	4	✓								
	5	✓	✓	✓						
	6	✓								
	7	✓								
	8	✓								
	9	✓								
	10	✓	✓	✓						
	11	✓	✓	✓						

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Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC- SEARCHED		
Symbol	Date	Examiner

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner

SEARCH NOTES		
Search Notes	Date	Examiner
East text search only - see attached printout	7/3/13	AC
Updated previous East text search only - see attached printout	12/18/13	AC
Updated previous East text search only - see attached printout	5/4/14	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	
YUASA	)	**Confirmation No. 2082**
	)	
U.S. Application No.: 13/767,290	)	**Art Unit 2897**
	)	
Filed: February 14, 2013	)	**Examiner**
	)	**Alonzo Chambliss**
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
Attorney Docket No.: NAGI-0005	)	

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

RESPONSE AND AMENDMENT UNDER 37 C.F.R. § 1.111

Sir:

This is in response to the Office Action mailed on May 8, 2014, the period of response to which is set to expire on September 8, 2014, with the payment of the appropriate extension fees for an extension of time of one month. Please amend the above-referenced application as follows:

IN THE CLAIMS

Claims 1-3, 5, and 10 stand for consideration in this application, wherein claim 11 is being canceled without prejudice or disclaimer, and wherein claims 1, 5, and 10 are being amended to improve form, as follows:

1. (Currently Amended) A tunnel barrier layer ~~located between~~disposed on ~~a first~~ ferromagnetic material layer that is disposed on a substrate~~and a second ferromagnetic material layer~~,

wherein the tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented, and

wherein the ~~first~~ ferromagnetic material layer comprises CoFeB alloy that is at least partially crystallized.

2. (Previously Presented) A tunnel bather layer according to claim 1, wherein the tunnel barrier layer has a barrier height in a range of 0.2 to 0.5 e V.

3. (Previously Presented) A tunnel barrier layer according to claim 2, wherein the tunnel barrier layer height ϕ is obtained by fitting J-V characteristics of a tunnel barrier junction structure to an equation (1):

$$J = [(2m\,\phi)^{1/2}/\Delta s]\,(e/h)^2 \times \exp[-(4\,\pi\,\Delta\, s/h) \times (2m\,\phi)^{1/2}] \times V \qquad (1)$$

where J is a tunnel current density flowing through the tunnel barrier layer, V is an applied bias voltage that is 100 mV or smaller, m is the free electron mass, e is the elementary electric charge, h is the Plank's constant, Δ s is an effective thickness of the tunnel barrier layer that is approximately equivalent to ($t_{Mg}o$ – 0.5 nm), and $t_{Mg}o$ is an actual thickness of the tunnel barrier layer determined using a cross-sectional transmission electron microscope image.

4. (Canceled).

5. (Currently Amended) The tunnel barrier layer according to claim 1, wherein the ~~first~~ ferromagnetic material layer is entirely crystallized.

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6-9. (Canceled).

10. (Currently Amended) The tunnel barrier layer according to claim 2, wherein the ~~first~~ ferromagnetic material layer is entirely crystallized.

11. (Canceled).

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REMARKS

The above amendments to the above-captioned application along with the following remarks are being submitted as a full and complete response to the Office Action dated May 8, 2014 (U.S. Patent Office Paper No. 20140504). In view of the above amendments and the following remarks, the Examiner is respectfully requested to give due reconsideration to this application, to indicate the allowability of the claims, and to pass this case to issue.

Status of the Claims

As outlined above, claims 1-3, 5, and 10 stand for consideration in this application, wherein claim 11 is being canceled without prejudice or disclaimer, and wherein claims 1, 5, and 10 are being amended to improve form.

All amendments to the application are fully supported therein. For example, the amendments to the claims are supported by paragraphs [0014] and [0036] of the present application as originally filed, as well as by Figures 2A-2D. Applicants hereby submit that no new matter is being introduced into the application through the submission of this response.

Double Patenting Rejections

The Examiner rejected claims 1-3, 5, 10, and 11 under 35 U.S.C. §101 as being unpatentable over U.S. Patent Application No. 13/400,340 (U.S. Patent No. 8,405,134; "the '134 patent") on grounds of double patenting. Applicant has reviewed the above-noted rejections, and hereby respectfully traverse.

Claims 1-3, 5, and 10 stand for consideration in the present application. "In determining whether a statutory basis for a double patenting rejection exists, the question to be asked is: Is the same invention being claimed twice? 35 U.S.C. 101 prevents two patents from issuing on the same invention. **'Same invention' means identical subject matter.** *Miller v. Eagle Mfg. Co.*, 151 U.S. 186 (1984)....A reliable test for double patenting under 35 U.S.C. 101 is whether a claim in the application could be literally infringed without literally infringing a corresponding claim in the patent. *In re Vogel*, 422 F.2d 438, 164 USPQ 619 (CCPA 1970). **Is there an embodiment of the invention that falls within the scope of one claim, but not the other? If there is such an embodiment, then identical subject matter is not defined by both claims and statutory double patenting would not exist.**" MPEP 804(II.A) (emphasis added).

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Accordingly, Applicants respectfully submit that claims 1, 3, 5, and 10 of the present application are substantively different from and not identical to claim 1 of the '134 patent. In particular, Applicants first note that the claims of the present application is directed to a tunnel barrier layer, while claim 1 of the '134 patent is contrastingly directed to a magnetoresistive device that specifically requires, in addition to a tunnel barrier layer, further components that are not required by the tunnel barrier layer of the claims of the present application. Thus, a tunnel barrier layer, as recited by the claims of the present application, is clearly not a magnetoresistive device, as recited by claim 1 of the '134.

For example, claim 1 of the '134 patent requires each of the limitations of "a second ferromagnetic material layer" and that the tunnel barrier layer be "located between the first and second ferromagnetic material layers." Neither of these limitations are required by the claims of the present application. Thus, it would clearly be possible to literally infringe the claims of the present application without also literally infringing claim 1 of the '134 patent.

Moreover, there are also embodiments of a magnetoresistive device in which a tunnel barrier layer that is included therein comprises a single-crystalline magnesium oxide in which (001) crystal plane is preferentially oriented that would fall within the scope of claim 1 of the '134 patent but not within the scope of the claims of the present application, which are directed to a tunnel barrier layer that, in contrast to the tunnel barrier layer in such embodiments a magnetoresistive device, comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented. Thus, it would also clearly be possible to literally infringe claim 1 of the '134 patent without also literally infringing the claims of the present application.

For at least these reasons, Applicants respectively submit that the present invention as claimed is distinguishable from claim 1 of the '134 application. Accordingly, Applicants respectively request reconsideration and withdrawal of the rejections to claims 1, 3, 5, and 10 issued under 35 U.S.C. §101 and submit that the present invention as claimed is distinguishable and thereby allowable over the prior art of record.

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Conclusion

In view of all the above, Applicants respectfully submit that certain clear and distinct differences as discussed exist between the present invention as now claimed and the prior art references upon which the rejections in the Office Action rely. These differences are more than sufficient to establish that the present invention as now claimed would not have been anticipated nor rendered obvious given the prior art. Rather, the present invention as a whole is distinguishable, and thereby allowable over the prior art.

Favorable reconsideration of this application as amended is respectfully solicited. Should there be any outstanding issues requiring discussion that would further the prosecution and allowance of the above-captioned application, the Examiner is invited to contact the Applicants' undersigned representative at the address and phone number indicated below.

Respectfully submitted,

Nicholas B. Trenkle

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September 3, 2014

336157:1:ALEXANDRIA

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Page 281

Electronic Acknowledgement Receipt

EFS ID:	20038752
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Billy Aaron Schulman/Stacy Johnson
Filer Authorized By:	Billy Aaron Schulman
Attorney Docket Number:	NAGI-0005
Receipt Date:	03-SEP-2014
Filing Date:	14-FEB-2013
Time Stamp:	18:23:52
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		NAGI_0005Trans_AfterFinalRequestForm_AmdtAfterFinal.pdf	291736 94dbca50fe03195a89d904582a5395ed62a00e24	yes	7

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Miscellaneous Incoming Letter	1	1
	After Final Consideration Program Request	2	2
	Response After Final Action	3	7
Warnings:			
Information:			
	Total Files Size (in bytes):	291736	

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

Customized PTO/SB/21 (07-09)

TRANSMITTAL FORM *(for all correspondence after initial filing)*		
	Application #	13/767,290
	Confirmation #	2082
	Filing Date	February 14, 2013
	First Inventor	YUASA
	Art Unit	2897
	Examiner	Alonzo Chambliss
Total number of pages in this submission =	Docket #	NAGI-0005

ENCLOSURES *(check all that apply)*

- ☐ **Fees** calculated below
  - ☐ including **Extension of Time Fee**
- ☒ **Amendment/Reply**
  - ☒ including **Attachment**(s)
- ☐ **After Final** Amendment/Reply
  - ☐ including **Attachment**(s)
- ☐ Reply to **Missing Parts**/Incomplete Application
- ☐ **I**nformation **D**isclosure **S**tatement
- ☐
- ☐.
- ☐

FEES CALCULATION: For claims if required and/or other fees as shown below:

STATUS of Applicant is: ☐ MICRO ☐ SMALL ☐ LARGE

FEE FOR	CALCULATION	$	$	$	FEE DUE $
☐ TOTAL CLAIMS	- 20 = 0 (extra)	× 20 =	× 40 =	× 80 =	0
☐ INDEP. CLAIMS	- 3 = 0 (extra)	× 105 =	× 210 =	× 420 =	0
☐ Extension of Time for months *(serving as constructive EOT Petition)* =					
☐ Other fee for					
				TOTAL	**0**

☐ **Payment** of **$** is made by:

- ☐ **ELECTRONIC FUNDS TRANSFER** - submitted concurrently herewith.
- ☐ **CREDIT CARD PAYMENT FORM** - PTO-2038 submitted concurrently herewith.

☒ The Director is authorized to charge any fee, additional fee or extension fee due in connection herewith to Deposit Account No. 12-0555:
(1) **if** no payment or an insufficient payment is enclosed and a fee is due in connection herewith; or
(2) **if** no petition for extension of time is enclosed but an EOT is required - and in this event, applicant hereby petitions under 37 CFR 1.136(a) for an extension of time of as many months as are required to render this submission timely.

Date: September 3, 2014

Nicholas B. Trenkle

Signed By Name: Nicholas Trenkle
Attorney of Record Registration No.: 54,500

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2355LT:00005:336823:1:ALEXANDRIA

PTO/SB/06 (09-11)
Approved for use through 1/31/2014. OMB 0651-0032
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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 13/767,290	Filing Date 02/14/2013	☐ 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 $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ 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

AMENDMENT	09/03/2014	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 5	Minus	** 20	= 0	X $80 =	0
	Independent (37 CFR 1.16(h))	* 1	Minus	***3	= 0	X $420 =	0
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	0

AMENDMENT		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
	☐ 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.
** 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 number found in the appropriate box in column 1.

LIE
/PAULA BRITTON/

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.
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005	2082

881 7590 10/30/2014

STITES & HARBISON PLLC
1199 NORTH FAIRFAX STREET
SUITE 900
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	
ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
10/30/2014	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):

iplaw@stites.com

Office Action Summary	Application No. 13/767,290	Applicant(s) YUASA, SHINJI	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	AIA (First Inventor to File) Status No

-- 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 *9/3/14*.

☐ 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) *1-3,5 and 10* 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) *1-3,5 and 10* is/are rejected.

8)☐ Claim(s) _____ 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 *2/14/13* 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. 10/591,947.

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

1. The present application is being examined under the pre-AIA first to invent provisions.

2. The amendment filed on 9/3/14 has been fully considered and made of record in this application.

Response to Arguments

3. Applicant's arguments with respect to claims 1-3, 5, and 10 have been considered but are moot because the arguments do not apply to any of the references being used in the current rejection.

Claim Rejections - 35 USC § 103

4. The following is a quotation of pre-AIA 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

5. 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 pre-AIA 35 U.S.C. 103(a) 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.

6. Claims 1, 2, 5, and 10 rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over Applied Physics Letters (Large magnetoresistance in Fe/MgO/FeCo (001) epitaxial tunnel junctions on GaAs (001)and Collins et al. (US 5,800,635) in view of Collins et al. (US 5,800,635).

With respect to Claims 1, 2, 5, and 10, the Applied Physics Letters discloses a tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented. A ferromagnetic material layer comprises FeCo alloy (see pages 1655 and 1656). The Applied Physics Letters fails to disclose the ferromagnetic material layer comprises CoFeB alloy that is at least partially crystallized and entirely crystallized. However, Collins discloses a ferromagnetic material layer comprises CoFeB alloy that is at least partially crystallized and entirely crystallized during the anneal process at a temperature range between 400 – 430 (see col. 4 lines 65-67 and col. 5 lines 1-10). Thus, the Applied Physics Letters and Collins have substantially the same environment of tunnel barrier layer on a ferromagnetic layer. Therefore, one skilled in the art at the time of invention would readily recognize substituting the CoFeB layer for the CoFe layer of the Applied Physics Letters, since the CoFeB layer would provide a reliable material for the tunnel barrier layer in magnetic optical data storage system as taught by Collins.

With respect to Claim 2, the Applied Physics Letters discloses wherein the tunnel barrier layer has a barrier height in a range of 0 - .9eV (i.e. between .2 - .5eV) (see page 1656).

Double Patenting

7. The nonstatutory double patenting rejection is based on a judicially created doctrine grounded in public policy (a policy reflected in the statute) so as to prevent the unjustified or improper timewise extension of the "right to exclude" granted by a patent and to prevent possible harassment by multiple assignees. A nonstatutory double patenting rejection is appropriate where the claims at issue are not identical, but at least one examined application claim is not patentably distinct from the reference claim(s) because the examined application claim is either anticipated by, or would have been obvious over, the reference claim(s). See, e.g., *In re Berg*, 140 F.3d 1428, 46 USPQ2d 1226 (Fed. Cir. 1998); *In re Goodman*, 11 F.3d 1046, 29 USPQ2d 2010 (Fed. Cir. 1993); *In re Longi*, 759 F.2d 887, 225 USPQ 645 (Fed. Cir. 1985); *In re Van Ornum*, 686 F.2d 937, 214 USPQ 761 (CCPA 1982); *In re Vogel*, 422 F.2d 438, 164 USPQ 619 (CCPA 1970); and *In re Thorington*, 418 F.2d 528, 163 USPQ 644 (CCPA 1969).

A timely filed terminal disclaimer in compliance with 37 CFR 1.321(c) or 1.321(d) may be used to overcome an actual or provisional rejection based on a nonstatutory double patenting ground provided the reference application or patent either is shown to be commonly owned with this application, or claims an invention made as a result of

activities undertaken within the scope of a joint research agreement. A terminal disclaimer must be signed in compliance with 37 CFR 1.321(b).

The USPTO internet Web site contains terminal disclaimer forms which may be used. Please visit http://www.uspto.gov/forms/. The filing date of the application will determine what form should be used. A web-based eTerminal Disclaimer may be filled out completely online using web-screens. An eTerminal Disclaimer that meets all requirements is auto-processed and approved immediately upon submission. For more information about eTerminal Disclaimers, refer to http://www.uspto.gov/patents/process/file/efs/guidance/eTD-info-I.jsp.

8. Claims 1-3, 5, and 10 are rejected on the ground of nonstatutory double patenting as being unpatentable over claim 4 of U.S. Patent No. 7,884,403. Although the claims at issue are not identical, they are not patentably distinct from each other because the application and the patent both recite a tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented. A ferromagnetic material layer comprises CoFeB alloy.

Allowable Subject Matter

9. Claim 3 is 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.

The following is a statement of reasons for the indication of allowance subject matter: the prior art of record does not teach or suggest the combination of the tunnel

barrier layer height qb is obtained by fitting J-V characteristics of a tunnel barrier junction structure to an equation (1):J = [(2m qb)m/A s] (e/h)2 x exp [-(4 ~ A s/h) x (2m qb) 1/2] xV (1) where J is a tunnel current density flowing through the tunnel barrier layer, V, is an applied bias voltage that is 100 mV or smaller, m is the free electron mass, e is the elementary electric charge, h is the Plank's constant, A s is an effective thickness of the tunnel barrier layer that is approximately equivalent to (tMgO = 0.5 nm), and tMgO is an actual thickness of the tunnel barrier layer determined using a cross-sectional transmission electron microscope image in claim 3.

The prior art made of record and not relied upon is cited primarily to show the product of the instant invention.

Conclusion

10. Applicant's amendment necessitated the new ground(s) of rejection presented in this Office action. Accordingly, **THIS ACTION IS MADE FINAL**. See MPEP § 706.07(a). Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire THREE MONTHS from the mailing date of this action. In the event a first reply is filed within TWO MONTHS of the mailing date of this final action and the advisory action is not mailed until after the end of the THREE-MONTH shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of

the advisory action. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the date of this final action.

Any inquiry concerning the communication or earlier communications from the examiner should be directed to Alonzo Chambliss whose telephone number is (571) 272-1927.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Fernando L. Toledo can be reached on (571) 272-1867. 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 PMR or Public PMR. Status information for unpublished applications is available through Private PMR only. For more information about the PMR system see http://pair-dkect.uspto.gov. Should you have questions on access to the Private PMR system contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free) or EBC_Support@uspto.gov.

AC/October 27, 2014 /Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Notice of References Cited	Application/Control No. 13/767,290	Applicant(s)/Patent Under Reexamination YUASA, SHINJI	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-5,800,635	09-1998	Collins et al.	148/304
*	B	US-5,239,504	08-1993	Brady et al.	365/157
	C	US-			
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	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 MM-YYYY format are publication dates. Classifications may be US or foreign.

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC- SEARCHED		
Symbol	Date	Examiner
H01L43/12,43/10, 27/222; H01F10/132, 10/3254, 10/16; B82Y25/00, 10/00	10/26/14	AC

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner

SEARCH NOTES		
Search Notes	Date	Examiner
East text search only - see attached printout	7/3/13	AC
Updated previous East text search only - see attached printout	12/18/13	AC
Updated previous East text search only - see attached printout	5/4/14	AC
Updated previous East text search only - see attached printout	10/26/14	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	300	ferromagnetic with crystalliz$5 same (heat$3 anneal$3)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/10/26 22:19
L2	1	("20130228883").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2014/10/26 22:22
L3	117	1 AND ((H01L43/12 OR H01L43/10 OR H01L27/222 OR B82Y25/00 OR B82Y10/00 OR H01F10/3254 OR H01F10/16 OR H01F10/132).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/10/26 22:29

EAST Search History (Interference)

< This search history is empty>

10/26/2014 10:32:44 PM
C:\Users\achambliss\Documents\EAST\Workspaces\13870490.wsp

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

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

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

CLAIM		DATE								
Final	Original	07/03/2013	12/18/2013	05/04/2014	10/27/2014					
	1	✓	✓	✓	✓					
	2	✓	✓	✓	✓					
	3	✓	✓	✓	✓					
	4	✓								
	5	✓	✓	✓	✓					
	6	✓								
	7	✓								
	8	✓								
	9	✓								
	10	✓	✓	✓	✓					
	11	✓	✓	✓						

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REQUEST FOR CONTINUED EXAMINATION (RCE) Transmittal Mail Stop RCE		
	Application #	13/767,290
	Confirmation #	2082
	Filing Date	February 14, 2013
	First Inventor	YUASA
	Art Unit	2897
	Examiner	Chamblis, Alonzo
	Docket #	NAGI-0005

This is a Request for Continued Examination (RCE) under 37 CFR § 1.114 of the above application.
RCE practice does not apply to any utility application filed prior to June 8, 1995, or to any design application. Prosecution must be closed.

Submission **required** under 37 CFR § 1.114

Note: If the RCE is proper, any previously filed unentered amendments and amendments enclosed with the RCE will be entered in the order in which they were filed unless applicant instructs otherwise (with a separate request for non-entry).

☐ **Previously submitted.** *If a final Office action is outstanding, any amendments filed after the final Office action may be considered by the PTO as a submission even if the box for the following line is not checked.*
- ☐ Consider the arguments in the Appeal Brief or Reply Brief previously filed on
- ☐ Other:

☒ **Enclosed**
- ☒ Amendment/Reply
- ☐ Affidavit(s)/Declaration(s)
- ☒ Information Disclosure Citation
- ☐ Other:

Miscellaneous

☐ **Suspension of action** on the above-identified application is requested under 37 CFR § 1.103(c) for a period of months *(Period of suspension shall not exceed 3 months; Fee under 37 CFR§ 1.17(i) required).*
☐ Other:

FEES calculated below (after reduction for an amendment if noted above).

STATUS of Applicant is: ☐ MICRO ☒ SMALL ☐ LARGE

	NOW	*Prev.*	*Extra*	$	$	$	$
☒ TOTAL Claims	2	- 20	0	X 20 =	X 40 =	X 80 =	0
☒ INDEP. Claims	1	- 3	0	X 105 =	X 210 =	X 420 =	0
☐ *FIRST* RCE				300	600	1200	
☒ *SECOND/FURTHER* RCE				425	850	1700	1700
☒ Extension of Time for TWO month(s) (serving as a constructive EOT Petition)							600
☐ Other fee for							
TOTAL OF ALL FEES =							**2300**

☒ Payment of **$ 2300** is made by:
- ☒ **ELECTRONIC FUNDS TRANSFER** submitted herewith.
- ☐ **CREDIT CARD** (Form PTO-2038 is enclosed).

☒ The Director is authorized to charge any fee, additional fee or extension fee due in connection herewith to Deposit Account No. 12-0555:
(1) **if** no payment or an insufficient payment is enclosed and a fee is due in connection herewith; or
(2) **if** no petition for extension of time is enclosed but an EOT is required - and in this event, applicant hereby petitions under 37 CFR 1.136(a) for an extension of time of as many months as are required to render this submission timely.

Date: March 25, 2015

Nicholas Trenkle

Signed By Name: Nicholas Trenkle
Attorney of Record Registration No.: 54,500

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2355LT:00005:353104:1:ALEXANDRIA

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	
YUASA	)	**Confirmation No. 2082**
	)	
U.S. Application No.: 13/767,290	)	**Art Unit 2897**
	)	
Filed: February 14, 2013	)	**Examiner**
	)	**Alonzo Chambliss**
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
Attorney Docket No.: NAGI-0005	)	

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

RESPONSE AND AMENDMENT UNDER 37 C.F.R. § 1.114

Sir:

This is in response to the Final Office Action mailed on October 30, 2014, the period of response to which is set to expire on March 30, 2015, with the payment of the appropriate extension fees for an extension of time of two months. A Request for Continued Examination (RCE) is being filed concurrently herewith. Please amend the above-referenced application as follows:

IN THE CLAIMS

Claims 1 and 5 are pending in this application, wherein claims 2, 3, and 10 are being canceled without prejudice or disclaimer, and wherein claim 1 is being amended to improve form, as follows:

1. (Currently Amended) A tunnel barrier layer disposed on a ferromagnetic material layer that is disposed on a substrate,

wherein the tunnel barrier layer comprises a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented,

wherein the tunnel barrier layer has a barrier height ϕ in a range of 0.2 to 0.5 e V, where the barrier height ϕ is obtained by fitting J-V characteristics of a tunnel barrier junction structure to an equation (1):

$$J = [(2m\,\phi)^{1/2}/\Delta s]\,(e/h)^2 \times \exp[-(4\,\pi\,\Delta\,s/h) \times (2m\,\phi)^{1/2}] \times V \qquad (1)$$

where J is a tunnel current density flowing through the tunnel barrier layer, V is an applied bias voltage that is 100 mV or smaller, m is the free electron mass, e is the elementary electric charge, h is the Plank's constant, Δs is an effective thickness of the tunnel barrier layer that is approximately equivalent to (t_{MgO} − 0.5 nm), and t_{MgO} is an actual thickness of the tunnel barrier layer determined using a cross-sectional transmission electron microscope image, and

wherein the ferromagnetic material layer comprises CoFeB alloy that is at least partially crystallized.

2-4. (Canceled).

5. (Previously Presented) The tunnel barrier layer according to claim 1, wherein the ferromagnetic material layer is entirely crystallized.

6-11. (Canceled).

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REMARKS

The above amendments to the above-captioned application along with the following remarks are being submitted as a full and complete response to the Final Office Action dated October 30, 2014 (U.S. Patent Office Paper No. 20141026). In view of the above amendments and the following remarks, the Examiner is respectfully requested to give due reconsideration to this application, to indicate the allowability of the claims, and to pass this case to issue.

Status of the Claims

As outlined above, claims 1 and 5 stand for consideration in this application, wherein claims 2, 3, and 10 are being canceled without prejudice or disclaimer, and wherein claim 1 is being amended to improve form.

All amendments to the application are fully supported therein. Applicants hereby submit that no new matter is being introduced into the application through the submission of this response.

Allowable Subject Matter

The Examiner stated that claim 3 would be allowable if rewritten in independent form to include all the limitations of the base claim and any intervening claims from which it depends.

Double Patenting Rejections

The Examiner rejected claims 1-3, 5, and 10 as being unpatentable over claim 4 of U.S. Patent No. 7,884,403 ("the '403 application") on grounds of nonstatutory double patenting. Applicants have reviewed the above-noted rejections, and hereby respectfully traverse.

In particular, Applicants note a terminal disclaimer was already in the present application with respect to the '403 application on April 30, 2014, and this terminal disclaimer was reviewed and accepted by the USPTO on May 2, 2014. Accordingly, Applicants respectfully note that the nonstatutory double patenting rejections appear to have been issued in error.

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Prior Art Rejections

The Examiner rejected claims 1, 2, 5, and 10 under 35 U.S.C. §103(a) as being unpatentable over Bowen ("Large magnetoresistance in Fe/MgO/FeCo(001) epitaxial tunnel junctions on GaAs(001)". Appl. Phys. Lett. 79 (11): 1655. (2001)) in view of Collins (U.S. Patent No. 5,800,635). Applicants have reviewed the above-noted rejections, and hereby respectfully traverse.

As outlined above, claims 2, 3, and 10 are being canceled without prejudice or disclaimer, and, therefore, claims 1 and 5 are presently of record in the present application. Independent claim 1 is being amended to further include all of the limitations of claims 2 and 3 of the present application as previously presented in the Response submitted on September 3, 2014. Accordingly, claim 1 is now presented in a form that the Examiner stated would be allowable. Moreover, because claim 5 depends directly from claim 1, Applicants respectfully submit that claim 5 is also now in condition for allowance. Accordingly, Applicants respectfully submit that the present invention as claimed is distinguishable and thereby allowable over the prior art of record.

Conclusion

In view of all the above, Applicants respectfully submit that certain clear and distinct differences as discussed exist between the present invention as now claimed and the prior art references upon which the rejections in the Final Office Action rely. These differences are more than sufficient to establish that the present invention as now claimed would not have been anticipated nor rendered obvious given the prior art. Rather, the present invention as a whole is distinguishable, and thereby allowable over the prior art.

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Favorable reconsideration of this application as amended is respectfully solicited. Should there be any outstanding issues requiring discussion that would further the prosecution and allowance of the above-captioned application, the Examiner is invited to contact the Applicants' undersigned representative at the address and phone number indicated below.

Respectfully submitted,

Nicholas B. Trenkle

Nicholas B. Trenkle
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March 25, 2015

352532:1:ALEXANDRIA

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INFORMATION DISCLOSURE STATEMENT		
	Application #	13/767,290
	Confirmation #	2082
	Filing Date	February 14, 2013
	First Inventor	YUASA
	Art Unit	2897
	Examiner	Chamblis, Alonzo
	Docket #	NAGI-0005

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

This IDS is submitted pursuant to 37 CFR. §1.97-1.98 and includes the following:

☒ A **listing** of the documents on PTO-1449.

☒ A copy of all **non-US** documents which are listed on the PTO-1449.

☐ A copy of a corresponding foreign or PCT **Search Report** which explains the relevance of the documents noted therein (and which is listed on the PTO-1449).

☐ It will be noted that the relevance of some of the listed references is at least as is disclosed in the specification.

☐ A separate **explanation of relevance**.

Please note the following particulars concerning the filing of this IDS:

☒ **1.** This IDS is filed (Rule 1.97(b)) at whichever is the latest of:

- within three months of the filing date of a NATIONAL APPLICATION other than a CPA, or
- within three months of the date of entry into the NATIONAL STAGE as set forth in 37 CFR. §1.491 in an international application, or
- before the mailing date of a first Office Action on the merits (including after filing of an RCE) *(but if a first Office Action is mailed but not yet received and the date on the face of the attached communication makes it evident that this IDS is submitted within three months from the mailing of the search report, then applicant is entitled to have this IDS considered under 2.B. below and such boxes should be considered as having been checked).*

☐ **2.** This IDS is filed (Rule 1.97(c)) **after a first Office Action**, but before a Final Action, Allowance, or any other action which closes prosecution, **and**:

- ☐ **A.** Is accompanied by a payment as required by 37 CFR. §1.17(p) in the amount of:
  - ☐ $180 large entity or
  - ☐ $90 small entity

or (*one of the following*)

- ☐ **B.** I hereby state that each item of information contained in this IDS was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of this IDS.
- ☐ **C.** I hereby state that no item of information in this IDS herewith was cited in a communication from a foreign patent office in a counterpart foreign application, and, to my knowledge after making reasonable inquiry, was known to any individual designated in 37 CFR. §1.56(c) more than 3 months prior to the filing of this IDS.
- ☐ **D.** An appropriate Statement is attached.

2355LT:00005:347412:1:ALEXANDRIA

☐ **3.** This IDS is filed (Rule 1.97(d)) **after** a final action or allowance, but on/before payment of the issue fee, **and**:

- ☐ **A.** is accompanied by a payment as required by 37 CFR. §1.17(p) in the amount of:
  - ☐ $180 large entity or
  - ☐ $90 small entity .

and (*one of the following*)

- ☐ **B.** I hereby state that each item of information contained in this IDS was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of this IDS.
- ☐ **C.** I hereby state that no item of information in this IDS herewith was cited in a communication from a foreign patent office in a counterpart foreign application, and, to my knowledge after making reasonable inquiry, was known to any individual designated in 37 CFR. §1.56(c) more than 3 months prior to the filing of this IDS.
- ☐ **D.** An appropriate Statement is attached.

☐ **4.** This IDS does not comply with 37 CFR 1.97-1.98, and is being filed **for placement in the file** pursuant to 37 CFR. §1.97(i).

☒ **5.** It will also be appreciated that:

- **a.** It is believed that this IDS complies fully with 37 CFR 1.56 and 1.97-98 and with MPEP § 609; but if for some reason it does not and will not be entered, the examiner is requested to telephone the undersigned so that any deficiency can be timely remedied.
- **b.** Some of the documents may have markings thereon, but no significance should be attached to those markings.
- **c.** These documents are not necessarily analogous art.
- **d.** Where an English language translation of any part of a document is provided from a public source, applicant cannot vouch for the accuracy of that translation.

☒ **6.** If no payment is enclosed and a fee is due in connection with this communication or if the payment enclosed is insufficient, the Director is authorized to charge any fee or additional fee due with this communication to Deposit Account No. 12-0555.

Respectfully submitted,

Date: March 25, 2015

Nicholas Trenkle

By: Nicholas Trenkle
Registration No.: 54500

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2355LT:00005:347412:1:ALEXANDRIA

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	13/767,290
	Confirmation #	2082
	Filing Date	February 14, 2013
	First Inventor	YUASA
	Art Unit	2897
	Examiner	Chamblis, Alonzo
Sheet 1 of 1	Docket #	NAGI-0005

U.S. PATENT DOCUMENTS				
Initial (*)	**Document No.** Number – Kind Code	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Corresponds to**
	US-2003/0203189	10-30-2003	FUTAMOTO et al.	JP2001023140
	US-2004/0001372	01-01-2004	HIGO et al.	JP2004031694
	US-6,819,586	11-16-2004	ANTHONY et al.	
	US-2005/0047027	03-03-2005	LIN, et al.	

FOREIGN PATENT DOCUMENTS				
Initial (*)	**Country-Number-Kind Code** if known	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Trans-lation**
	JP2004022599 (A)	01-22-2004	MIZUGUCHI TETSUA et al.	Yes

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Trans-lation**
	SHANG, et al "The First-principles Study of Electronic Structure of Fe/MgO/Fe Magnetic Tunnel Junctions Interface", 2005, pp.2255-2258, vols. 475-479, Materials Science Forum	
	MEYERHEIM, et al "Surface X-Ray Diffraction Analysis of the MGO/FE(001) Interface: Evidence for an FEO Layer", 2002, pp. 144433-1- 144433-7, vol. 65, Physical Review	
	DJAYAPRAWIRA, et al, "230% Room-Temperature Magnetoresistance in COFEB/MGO/COFEB Magnetic Tunnel Junctions" 2005, pp. 092502-1 – 092502-3, vol. 86, Appl. Phys. Lett.	
	MIYOKAWA, et al., "X-Ray Absorption and X-Ray Magnetic Circular Dichroism Studies of a Monatomic FE(001) Layer Facing a Single-Crystalline", 2005, pp. L9-L11, vol. 44, no. 1, Japanese Journal of Applied Physics	
	KLAUA, et al, "Growth, Structure, Electronic, and Magnetic Properties of MGO/FE(001) Bilayers and FE/MGO/FE(001) Trilayers" 2001, vol. 64, pp. 134411-1 – 134411-8, Physical Review B	
	MITANI, et al, "FE/MGO/FECO(100) Expitaxial Magnetic Tunnel Junctions Prepared by Using in situ Plasma Oxidation" May 15, 2003, pp. 8041-8043, vo. 93, no. 10, parts 2 & 3, J. Appl. Phys.	
	YUASA, et al, "Giant Room-Temperature Magnetoresistance in Single-Crystal FE/MGO/FE Magnetic Tunnel Junctions" December 2004, pp. 868-871, vol. 3, Nature materials	
	NOZAKI, et al, "Bias Voltage Effect on Tunnel Magnetoresistance in Fully Epitaxial MGO Double-Barrier Magnetic Tunnel Junctions" 2005, pp. 082501-1-082501-3, vol. 86, Appl. Phys. Lett.	

	BUTLER, et al. "Spin-Dependent Tunneling and Conductance of FE/MGO/FE Sandwiches", 2001, pp. 054416-1 – 054416-11, vol. 63, Physical Review	
	ZHANG, et al, "Large Magnetoresistance in BCC. CO/MGO/CO and FECO/MGO/FECO Tunneling Junctions", November 17, 2012, pp. 1-9	
	BOUBETA, et al "Magnetization Reversal and Magnetic Anisotropies in Epitaxial FE/MGO and Fe/MgO/Fe heterostructures grown on Si(001)", February 15, 2003, pp. 2126-2134, vol. 93, no. 4, J. Appl. Phys.	

Examiner Signature		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 the applicant.*

PATENT ABSTRACTS OF JAPAN

(11)Publication number : **2004-022599**

(43)Date of publication of application : **22.01.2004**

(51)Int.Cl. **H01L 43/08**
G11B 5/39
G11C 11/15
H01F 10/32
H01L 27/105
H01L 43/10
H01L 43/12

(21)Application number : **2002-171806** (71)Applicant : **SONY CORP**

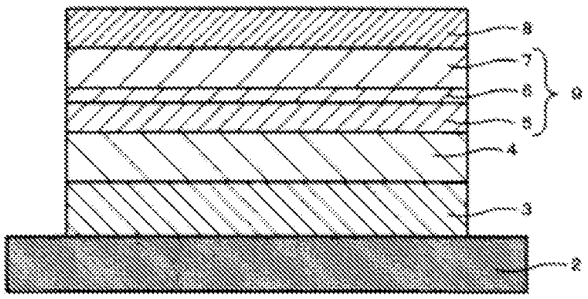
(22)Date of filing : **12.06.2002** (72)Inventor : **MIZUGUCHI TETSUYA**
HOSOMI MASAKATSU
OBA KAZUHIRO
BESSHO KAZUHIRO
HIGO YUTAKA
YAMAMOTO TETSUYA
SONE TAKESHI
KANO HIROSHI

(54) **MAGNETORESISTANCE EFFECT ELEMENT AND MAGNETIC MEMORY, AND THIER FABRICATING PROCESS**

(57)Abstract:

PROBLEM TO BE SOLVED: To provide a magnetoresistance effect element exhibiting good magnetic characteristics by controlling the magnetic anisotropy of a ferromagnetic layer, and to provide a magnetic memory comprising the magnetoresistance effect element and exhibiting excellent writing characteristics, and thier fabricating process.

SOLUTION: The magnetic memory has such a structure as a pair of ferromagnetic layers (a fixed magnetization layer 5 and a free magnetization layer 7) facing each other through an intermediate layer 6, and the magnetic resistance is varied by supplying a current perpendicularly to the film surface. At least the free magnetization layer 7 of the ferromagnetic layers has amorphous or microcrystal texture and comprises a magnetoresistance effect element 1 heat treated in a magnetic field at a temperature between 300° C and the crystallization point of the free magnetization layer 7, and a bit line and a word line sandwiching the magnetoresistance effect element 1 in the direction of thickness. After formation of at least the free magnetization layer 7, the heat treatment process in a magnetic field is carried out thus fabricating the magnetoresistance effect element 1 and the magnetic memory.



[PUBLICATION NUMBER] Japanese Laid-Open Patent Publication No. 2004-22599 (P2004-22599A)

[TITLE OF INVENTION] MAGNETORESISTANCE EFFECT ELEMENT AND MAGNETIC MEMORY, AND THIER FABRICATING PROCESS

[NUMBER OF CLAIMS] 10
[APPLICATION NUMBER] P2002-171806
[FILING DATE] June 12, 2002

[APPLICANT] Sony Corporation

[CLAIMS]

[Claim 1] A magnetoresistance effect element, comprising a pair of ferromagnetic layers facing each other through an intermediate layer and a structure in which the magnetoresistance is varied by supplying a current perpendicularly to the film surface, wherein:

one of the ferromagnetic layers is a fixed magnetization layer and the other is a free magnetization layer;

at least the free magnetization layer of the ferromagnetic layers has amorphous or microcrystal texture; and

the ferromagnetic layer is provided with heat treatment in a magnetic field at a temperature between 300 [deg.] C and the crystallization temperature of the free magnetization layer.

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[Claim 2] A magnetoresistance effect element according to claim 1, wherein:

the free magnetization layer comprises material selected from FeCoB, FeCoNiB, and FeCoSiB.

[Claim 3] A magnetoresistance effect element according to claim 1, wherein:

the magnetoresistance effect element is a tunnel magnetoresistance effect element that uses a tunnel barrier layer comprised of an insulator or a semiconductor as the intermediate layer.

[Claim 9] A method for manufacturing a magnetoresistance effect element, comprising a pair of ferromagnetic layers facing each other through an intermediate layer and a structure in which the magnetoresistance is varied by supplying a current perpendicularly to the film surface, wherein:

the magnetoresistance effect element assumes a structure in which one of the ferromagnetic layers is a fixed magnetization layer and the other is a free magnetization layer and at least the free magnetization layer of the ferromagnetic layers has amorphous or microcrystal texture; and

after formation of at least the free magnetization layer, the heat treatment process in a magnetic field

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is carried out at a temperature between 300 [deg.] C and the crystallization temperature of the free magnetization layer.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field to Which Invention Pertains]

This invention relates to a magnetoresistance effect element that assumes a structure in which the magnetic resistance is varied by supplying a current perpendicularly to the film surface and a magnetic memory that includes the magnetoresistance effect element. In addition, this invention relates to a fabricating process for the magnetoresistance effect element and a method for manufacturing the magnetic memory.

[0007] In a spin valve type TMR element, its resistance value change rate is defined by the following expression (A), letting P1 and P2 stand for the spin polarizability of each ferromagnetic layer.

2P1P2 / (1 - P1P2) (A)

Thus, the greater each spin polarizability is, the greater the resistance change rate becomes.

[0008]

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[TECHNICAL PROBLEM]

As disclosed in, for example, Japanese Laid-Open Patent Publication No. H10-116490, an MRAM has a basic structure in which a plurality of bit write lines (so called bit lines) and a plurality of word write lines (so called word lines), which are perpendicular to the plurality of bit write lines, are provided and TMR elements are disposed at intersections between the bit write lines and the word write lines as magnetic memory elements. Then, at a time of recording with such MRAM, selective writing into TMR elements is carried out using asteroid characteristics.

[0009] There is a problem that in an MRAM, the magnetic property of TMR elements varies according to each element and, if there is a variation when an identical element is used repeatedly, selective writing using asteroid characteristics becomes difficult.

Accordingly, the TMR elements are required to have a magnetic property to make an ideal asteroid curve.

Making an ideal asteroid curve requires that the R-H (resistance - magnetic field) loop in TMR measurement is free from Barkhausen noise and other types of noise, has a good waveform squareness, and a stable magnetization state, thereby giving little

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variation in coercivity Hc.

[0010] Barkhausen noise, deterioration in squareness, and variation in coercivity are caused mainly by the magnetic anisotropy of the material. Magnetic anisotropy direction and intensity that vary in a film surface cause these problems, and hence magnetic anisotropy direction control is very important.

[0011] In order to solve the problem described above, the present invention provides a magnetoresistance effect element exhibiting good magnetic property by controlling the magnetic anisotropy of a ferromagnetic layer, a magnetic memory comprising the magnetoresistance effect element and exhibiting an excellent writing property, and a method for manufacturing the magnetoresistance effect element and the magnetic memory.

[0016] According to the structure of a magnetoresistance effect element of the present invention described above, one of the ferromagnetic layers is a fixed magnetization layer and the other is a free magnetization layer, at least the free magnetization layer of the ferromagnetic layers has amorphous or microcrystal texture, the ferromagnetic

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layer is provided with heat treatment in a magnetic field at a temperature between 300 [deg.] C and the crystallization temperature of the free magnetization layer, and thus the magnetic anisotropy of the ferromagnetic layer is controlled, thereby improving squareness of the resistance - external magnetic field curve of a magnetoresistance effect element and improving variation in coercivity.

[0018] According to the method for manufacturing a magnetoresistance effect element of the present invention described above, after formation of at least the free magnetization layer, the heat treatment process in a magnetic field is carried out at a temperature between 300 [deg.] C and the crystallization temperature of the free magnetization layer, and hence the magnetic anisotropy of at least the free magnetization layer is controlled and it becomes possible to produce a magnetoresistance effect element having improved variation of squareness of the resistance - external magnetic field curve and coercivity of the magnetoresistance effect element.

[0020]

[EMBODIMENTS]

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The present invention is a magnetoresistance effect element, comprising a pair of ferromagnetic layers facing each other through an intermediate layer and a structure in which the magnetic resistance is varied by supplying a current perpendicularly to the film surface, wherein one of the ferromagnetic layers is a fixed magnetization layer and the other is a free magnetization layer; at least the free magnetization layer of the ferromagnetic layers has amorphous or microcrystal texture; and the ferromagnetic layer is provided with heat treatment in a magnetic field at a temperature between 300 [deg.] C and the crystallization temperature of the free magnetization layer.

[0021] In addition, the present invention is the magnetoresistance effect element in which the free magnetization layer comprises material selected from FeCoB, FeCoNiB, and FeCoSiB.

[0022] In addition, the present invention is the magnetoresistance effect element that assumes a structure in which the magnetoresistance effect element is a tunnel magnetoresistance effect element that uses a tunnel barrier layer comprised of an insulator or a semiconductor as the intermediate layer.

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[0028] At first, an outline structure diagram of an embodiment of a magnetoresistance effect element of the present invention is presented in FIG. 1. FIG. 1 presents an embodiment in which the present invention is applied to a tunnel magnetoresistance effect element (hereinafter referred to as a TMR element).

[0029] The TMR element 1 is constituted with an underlayer 3, an antiferromagnetic layer 4, a fixed magnetization layer 5, which is a ferromagnetic layer, a tunnel barrier layer 6, a free magnetization layer 7, which is a ferromagnetic layer, and a top coat layer 8, which are layered in this order on a substrate 2 that comprises silicon and the like. Namely, one of the ferromagnetic layers is the fixed magnetization layer 5 and the other is the free magnetization layer 7, thus constituting a so-called spin valve type TMR element, and the fixed magnetization layer 5 and the free magnetization layer 7, which are a pair of ferromagnetic layers, sandwich the tunnel barrier layer 6, thereby forming a ferromagnetic tunnel junction 9. Then, when the TMR element 1 is applied to a magnetic memory and the like, the free magnetization layer 7 becomes an information recording layer, on which information is recorded.

[0030] The antiferromagnetic layer 4 is a layer

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that, by being antiferromagnetically coupled with the fixed magnetization layer 5, which is one of the ferromagnetic layers, does not invert magnetization of the fixed magnetization layer 5 even by the current magnetic field for writing, and does maintain a constant direction of magnetization of the fixed magnetization layer 5. Namely, in the TMR element 1, presented in FIG. 1, magnetization of only the free magnetization layer 7, which is the other ferromagnetic layers, is inverted by an external magnetic field or the like. Since the free magnetization layer 7 is a layer on which information is recorded when the TMR element 1 is applied to, for example, a magnetic memory or the like, it is referred to as an information recording layer.

The antiferromagnetic layer 4 may be constituted with material such as Mn alloy that include Fe, Ni, Pt, Ir, Rh, and the like, Co oxide, and Ni oxide.

[0031] In the spin valve type TMR element 1 presented in FIG. 1, by being antiferromagnetically coupled with the antiferromagnetic layer 4, a constant direction of magnetization of the fixed magnetization layer 5 is maintained. Due to this, magnetization of the fixed magnetization layer 5 is not inverted even by the current magnetic field at the time of writing.

[0032] The tunnel barrier layer 6 is a layer through

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which the fixed magnetization layer 5 and the free magnetization layer 7 are magnetically isolated and tunnel current flows.

The tunnel barrier layer 6 may be constituted with insulating material such as oxide, nitride, and halide of Al, Mg, Si, Li, Ca, and the like.

[0033] The tunnel barrier layer 6 can be obtained by oxidizing or nitriding a metal film having been formed using the sputtering method, the evaporation method, or the like.

In addition, it can also be obtained with the CVD method that uses organic metal with oxygen, ozone, nitrogen, halogen, halogenated gas, and the like.

[0034] The present embodiment assumes a particular structure in which the ferromagnetic tunnel junction 9 including the fixed magnetization layer 5 and the free magnetization layer 7, which are ferromagnetic layers, have been provided with heat treatment in a magnetic field at a temperature 300 [deg.] C or higher. This structure improves squareness of the R-H curve and reduces variation in coercivity.

[0035] It is preferable that the direction of magnetic field in the heat treatment in a magnetic field is parallel to the magnetic easy axes of the ferromagnetic layers 5 and 7.

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[0036] It is preferable that the ferromagnetic layer, in particular the free magnetization layer 7 comprises amorphous or microcrystal material composed mostly of any of Fe, Co, and Ni or a plurality of them.

[0037] It is to be noted that while an alloy composed mostly of Fe, Co, and Ni such as FeCo is crystalline in normal film thickness, it is in a state close to amorphous if its film thickness is reduced to as very thin as, for example, about 1 nm, and the hence the heat treatment at a temperature 300 [deg.] C gives an effect. However, this alloy has crystal magnetic anisotropy and the crystal magnetic anisotropy is difficult to control by heat treatment, and thus its effect is less than that of amorphous material.

[0038] Here, the spin valve type TMR element assuming a structure in which the free magnetization layer 7 comprises amorphous ferromagnetic material with composition of Co72Fe8B20 (atom %) is actually produced by providing heat treatment in a static magnetic field at a temperature 300 [deg.] C and the same is actually produced by providing heat treatment in a static magnetic field at a temperature 250 [deg.] C. FIG. 2 presents the results of measurement of the resistance - external magnetic field curve (R-H curve) for each of them. As clearly indicated by FIG. 2, the

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TMR element provided with heat treatment at a temperature 300 [deg.] C exhibits improved squareness of R-H curve and reduced Barkhausen noise, compared with the TMR element provided with heat treatment at a temperature 250 [deg.] C. Accordingly, the present invention achieves improvement in the shape of asteroid curve and improvement in writing property and reduction in write errors.

[0039] While it is not clear as to what improves the property in a heat treatment condition at a temperature 300 [deg.] C or higher, suggesting that a temperature close to Curie temperature is related.

[0040] The heat treatment furnace in which heat treatment in a magnetic field is carried out assumes a structure presented in, for instance, FIG. 3. This heat treatment furnace is constituted with a heater 32 disposed outside a vacuum chamber 31 and a magnet 33 disposed further outside.

[0041] In this heat treatment furnace, heat treatment in a magnetic field is carried out as follows.

At first, a wafer 30 where the TMR element is to be formed is placed on a rack 34 in a vacuum chamber 31 such that a main surface 30A of the wafer 30 is parallel to the direction of a magnetic field 35 by the magnet 33.

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Then, it is possible to carry out heat treatment in a magnetic field for the TMR element of the wafer 30 by heating it with the heater 32 and applying the magnetic field with the magnet 33.

[0042] In addition, while the upper limit of temperature of heat treatment in a magnetic field is determined according to the crystallization temperature of the amorphous or microcrystal material used for the ferromagnetic layer, it is determined to be equal to or less than 400 [deg.] C at highest in view of heat resistance of the TMR element.

[0043] Since the heat treatment in a magnetic field is intended to improve the magnetization inversion property of a ferromagnetic layer, the treatment is provided to at least the free magnetization layer 7 and, more preferably, both the free magnetization layer 7 and the fixed magnetization layer 5.

This results in giving a more remarkable effect of improving the magnetic property of the TMR element 1.

[0044] In addition, in order to provide more effective heat treatment described above for instance, it is desirable that the film thickness of amorphous or microcrystal material used for the free magnetization layer 7 is between 1 nm and 15 nm. The

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film thickness being within this range ensures an excellent magnetic property. When the film thickness of the free magnetization layer 7 is less than 1 nm, interdiffusion by heat significantly damages the magnetic property, and meanwhile, when the film thickness of the free magnetization layer 7 exceeds 15 nm, coercivity of the TMR element 1 becomes excessively high, and hence it may be inappropriate in practice.

[0045] In addition, similarly, in order to provide more effective heat treatment described above when amorphous or microcrystal material is also used for the fixed magnetization layer 5, it is desirable that the film thickness of amorphous or microcrystal material used for the fixed magnetization layer 5 is between 0.5 nm and 6 nm. The film thickness being within this range ensures an excellent magnetic property. When the film thickness of the fixed magnetization layer 5 is less than 0.5 nm, interdiffusion by heat significantly damages the magnetic property, and meanwhile, when the film thickness of the fixed magnetization layer 5 exceeds 6 nm, an exchange coupling magnetic field with the antiferromagnetic layer 4 may not be sufficiently obtained.

[0054] It is to be noted that the range of intensity

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of the magnetic field at the heat treatment in magnetic field depends on the structure, film thickness, and property of the fixed magnetization layer 5 because in a structure as the TMR element 1 of the embodiment mentioned above, in which the free magnetization layer 7 is on an upper layer side than the fixed magnetization layer 5 (so-called bottom spin type), heat treatment in a magnetic field at a temperature 300 [deg.] C or higher doubles heat treatment that determines the bias acting on the fixed magnetization layer 5 from the antiferromagnetic layer 4.

For example, if the fixed magnetization layer 5 only comprises a CoFe film (single layer) with the film thickness of 2 nm and the antiferromagnetic layer 4 comprises FeMn, RhMn, IrMn, or the like, a magnetic field of about 1 kOe is sufficient. Also in a structure where the fixed magnetization layer 5 comprises a CoFe film (single layer) with the film thickness 2 nm, if the antiferromagnetic layer 4 comprises PtMn or the like, a magnetic field of about 3 kOe is required.

In addition, if as in the TMR element 10 and the like presented in FIG. 4, a robust antiferromagnetic coupling is formed because of the fixed magnetization layer 5 having a laminated ferrimagnetic structure, all of the plurality of magnetic layers that form this

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antiferromagnetic coupling are required to have magnetization with the same direction. For example, if the fixed magnetization layer 5 has a structure of CoFe (2 nm) / Ru (0.8 nm) / CoFe (2 nm), a magnetic field of about 10 kOe is required.

On the other hand, while there is not any particular upper limit of the magnitude of the magnetic field, it is set to an appropriate size because in order to increase the magnetic field, the magnetic field application means needs to be large in size.

[0063] It is to be noted that in a structure, for instance, in which the arrangement of the fixed magnetization layer and the free magnetization layer is opposite to the structure of the embodiment mentioned above (so-called bottom spin type), i.e., a structure in which the free magnetization layer is formed on the substrate side and the fixed magnetization layer and the antiferromagnetic layer are formed on an upper layer than the free magnetization layer (so-called top spin type), it is considered that after formation of the ferromagnetic film of the free magnetization layer and heat treatment in a magnetic field carried out at a temperature 300 [deg.] C or higher, the fixed magnetization layer and the antiferromagnetic layer

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are formed, and the after that, heat treatment in a magnetic field is carried out at a temperature of less than 300 [deg.] C so as to regularize (determine the bias described above) the antiferromagnetic layer . In this case, heat treatment in a magnetic field is carried out twice. However, compared with the case in which after the fixed magnetization layer and the antiferromagnetic layer have been formed, heat treatment in a magnetic field is carried out at a temperature 300 [deg.] C or higher, there is an advantage that the fixed magnetization layer and the antiferromagnetic layer, which are close to the surface of the TMR film, are free from the effect of the temperature 300 [deg.] C or higher.

[0064] (Embodiment)

<Sample 1>

[0066] More specifically, the TEG presented in FIG. 8 and FIG. 9 was produced as follows.

At first, a substrate 21 comprised of silicon of 0.6 mm thick that is provided with a thermally oxidized film (2 μm thick) formed on its surface was prepared. Next, after a film of material of the word line is formed

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on the substrate 21 and masked by photolithography, a part other than the word line is selectively etched by Ar plasma, thereby forming the word line WL. At this time, the region other than the word line WL is etched to the depth of 5 nm of the substrate 21.

After that, the word line WL is covered by an insulation film 26, and the surface is planarized.

[0067] Subsequently, a TMR element 22 constituted with the layer structure (1) described below is produced by using a publicly known lithography technique and etching. In the layer structure (1), the left hand side of "/" represents the substrate side and inside "()" represents the film thickness.

Ta (3 nm) / Cu (100 nm) / PtMn Film (20 nm) / CoFe (3 nm) / Ru (0.8 nm) / CoFe (2.5 nm) / Al (1 nm)-O_x / Free Magnetization Layer (t nm) / Ta (5 nm) -(1)

[0068] It is to be noted that in the layer structure (1) mentioned above, the composition of the free magnetization layer was Co72Fe8B20 (atom %), and the film thickness t of the free magnetization layer was 4 nm.

In addition, the composition of each CoFe film was Co75Fe25 (atom %).

[0069] The Al-O_x film of the tunnel barrier layer 6 was formed by at first depositing the metal Al film

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by 1 nm using the DC sputtering technique, then determining the flow ratio of oxygen/argon as 1:1 and the chamber gas pressure as 0.1 m Torr, and plasma oxidizing the metal Al film by plasma from ICP (inductively coupled plasma). While oxidizing time depends upon ICP plasma output, it was 30 seconds in the present embodiment.

[0087]

[ADVANTAGEOUS EFFECT OF THE INVENTION]

According to a magnetoresistance effect element and the manufacturing method of the present invention described above, improvement of squareness of R-H curve and improvement of variation of coercivity can be achieved.

Due to this, for instance, when a magnetoresistance effect element is applied to a magnetic memory, write errors can be reduced and thus an excellent writing property can be achieved.

[0088] In addition, according to a magnetic memory and the manufacturing method of the present invention, an excellent writing property can be achieved.

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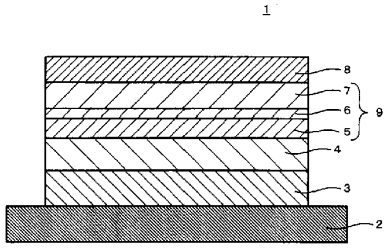
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(54)【発明の名称】磁気抵抗効果素子及び磁気メモリ装置、磁気抵抗効果素子及び磁気メモリ装置の製造方法

(57)【要約】
【課題】強磁性層の磁気異方性を制御することにより良好な磁気特性を有する磁気抵抗効果素子、及びこの磁気抵抗効果素子を備えて優れた書き込み特性を有する磁気メモリ装置、並びにこれら磁気抵抗効果素子及び磁気メモリ装置の製造方法を提供する。
【解決手段】対の強磁性層（磁化固定層5と磁化自由層７）が中間層6を介して対向され、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成であり、強磁性層のうち少なくとも磁化自由層7がアモルファスあるいは微結晶組織を有し、強磁性層が３００℃以上磁化自由層7の結晶化温度以下で磁場中熱処理されている磁気抵抗効果素子1及びこの磁気抵抗効果素子1と磁気抵抗効果素子1を厚み方向に挟むビット線及びワード線とを備えた磁気メモリ装置を構成する。さらに、少なくとも磁化自由層7を形成した後に、上記磁場中熱処理の工程を行って上記磁気抵抗効果素子1及び上記磁気メモリ装置を製造する。
【選択図】　図1



【特許請求の範囲】
【請求項１】
対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子であって、
上記強磁性層のうち一方が磁化固定層であり、他方が磁化自由層であり、
上記強磁性層のうち少なくとも上記磁化自由層は、アモルファスあるいは微結晶組織を有し、
上記強磁性層が、３００℃以上、上記磁化自由層の結晶化温度以下で、磁場中熱処理されている
ことを特徴とする磁気抵抗効果素子。
【請求項２】
上記磁化自由層が、ＦｅＣｏＢ、ＦｅＣｏＮｉＢ、ＦｅＣｏＳｉＢから選ばれる材料から成ることを特徴とする請求項１に記載の磁気抵抗効果素子。
【請求項３】
上記中間層として絶縁体もしくは半導体から成るトンネルバリア層を用いたトンネル磁気抵抗効果素子であることを特徴とする請求項１に記載の磁気抵抗効果素子。
【請求項４】
積層フェリ構造を有することを特徴とする請求項１に記載の磁気抵抗効果素子。
【請求項５】
対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子と、
上記磁気抵抗効果素子を厚み方向に挟むワード線及びビット線とを備え、
上記強磁性層のうち一方が磁化固定層であり、他方が磁化自由層であり、
上記強磁性層のうち少なくとも上記磁化自由層は、アモルファスあるいは微結晶組織を有し、
上記強磁性層が、３００℃以上、上記磁化自由層の結晶化温度以下で、磁場中熱処理されている
ことを特徴とする磁気メモリ装置。
【請求項６】
上記磁化自由層が、ＦｅＣｏＢ、ＦｅＣｏＮｉＢ、ＦｅＣｏＳｉＢから選ばれる材料から成ることを特徴とする請求項５に記載の磁気メモリ装置。
【請求項７】
上記磁気抵抗効果素子が上記中間層として絶縁体もしくは半導体から成るトンネルバリア層を用いたトンネル磁気抵抗効果素子であることを特徴とする請求項５に記載の磁気メモリ装置。
【請求項８】
上記磁気抵抗効果素子が積層フェリ構造を有することを特徴とする請求項５に記載の磁気メモリ装置。
【請求項９】
対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子を製造する方法であって、
上記磁気抵抗効果素子は、上記強磁性層のうち一方が磁化固定層であり、他方が磁化自由層であり、上記強磁性層のうち少なくとも上記磁化自由層は、アモルファスあるいは微結晶組織を有する構成であり、
少なくとも上記磁化自由層を形成した後に、３００℃以上、上記磁化自由層の結晶化温度以下で、磁場中熱処理を施す工程を行う
ことを特徴とする磁気抵抗効果素子の製造方法。
【請求項１０】
対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子と、上記磁気抵抗効果素子を厚み方向に

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挟むワード線及びビット線とを備えた磁気メモリ装置を製造する方法であって、
上記磁気抵抗効果素子は、上記強磁性層のうち一方が磁化固定層であり、他方が磁化自由層であり、上記強磁性層のうち少なくとも上記磁化自由層は、アモルファスあるいは微結晶組織を有する構成であり、
少なくとも上記磁化自由層を形成した後に、３００℃以上、上記磁化自由層の結晶化温度以下で、磁場中熱処理を施す工程を行う
ことを特徴とする磁気メモリ装置の製造方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】

本発明は、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子及び磁気抵抗効果素子を備えて成る磁気メモリ装置に係わる。また、この磁気抵抗効果素子の製造方法及び磁気メモリ装置の製造方法に係わる。

【０００２】

【従来の技術】

情報通信機器、特に携帯端末などの個人用小型機器の飛躍的な普及に伴い、これを構成するメモリやロジック等の素子には、高集積化、高速化、低電力化等、一層の高性能化が要請されている。特に不揮発性メモリの高密度・大容量化は、可動部分の存在により本質的に小型化が不可能なハードディスクや光ディスクを置き換える技術として、ますます重要になってきている。

【０００３】

不揮発性メモリとしては、半導体を用いたフラッシュメモリや、強誘電体を用いたＦＲＡＭ（Ｆｅｒｒｏ ｅｌｅｃｔｒｉｃ Ｒａｎｄｏｍ Ａｃｃｅｓｓ Ｍｅｍｏｒｙ）等が挙げられる。
しかしながら、フラッシュメモリは、書き込み速度がμ秒のオーダーと遅いという欠点がある。一方、ＦＲＡＭにおいては、書き換え可能回数が少ないという問題が指摘されている。

【０００４】

これらの欠点がない不揮発性メモリとして注目されているのが、例えば「Ｗａｎｇｅｔ ａｌ．，ＩＥＥＥ Ｔｒａｎｓ．Ｍａｇｎ．３３（１９９７），４４９８」に記載されているような、ＭＲＡＭ（Ｍａｇｎｅｔｉｃ Ｒａｎｄｏｍ Ａｃｃｅｓｓ Ｍｅｍｏｒｙ）と呼ばれる磁気メモリである。このＭＲＡＭは、構造が単純であるため高集積化が容易であり、また磁気モーメントの回転により記録を行うために書き換え可能回数が大である。またアクセス時間についても非常に高速であることが予想され、既にナノ秒台で動作可能であることが確認されている。

【０００５】

このＭＲＡＭに用いられる、磁気抵抗効果素子、特にトンネル磁気抵抗効果（Ｔｕｎｎｅｌ Ｍａｇｎｅｔｏｒｅｓｉｓｔａｎｃｅ：ＴＭＲ）素子は、基本的に強磁性層／トンネルバリア層／強磁性層の積層から成る強磁性トンネル接合で構成される。この素子では、強磁性層間に一定の電流を流した状態で強磁性層間に外部磁場を印加した場合、両磁性層の磁化の相対角度に応じて磁気抵抗効果が現れる。双方の強磁性層の磁化の向きが反平行の場合は抵抗値が最大となり、平行の場合は抵抗値が最小となる。メモリ素子としての機能は外部磁場により反平行と平行の状態を作り出すことによってもたらされる。

【０００６】

特にスピンバルブ型のＴＭＲ素子においては、一方の強磁性層が隣接する反強磁性層と反強磁性的に結合することによって磁化の向きが常に一定とされた磁化固定層とされる。他方の強磁性層は、外部磁場等によって容易に磁化反転する磁化自由層とされる。そして、この磁化自由層が磁気メモリにおける情報記録層となる。

【０００７】

スピンバルブ型のＴＭＲ素子において、その抵抗値の変化率は、それぞれの強磁性層のス

ピン分極率をＰ１，Ｐ２とすると、下記の式（Ａ）で表される。
２Ｐ１Ｐ２／（１－Ｐ１Ｐ２）　（Ａ）
このように、それぞれのスピン分極率が大きい程、抵抗変化率が大きくなる。
【０００８】
【発明が解決しようとする課題】
ところで、ＭＲＡＭの基本的な構成は、例えば特開平１０－１１６４９０号公報に開示されているように、複数のビット書き込み線（いわゆるビット線）と、これら複数のビット書き込み線に直交する複数のワード書き込み線（いわゆるワード線）とを設け、これらビット書き込み線とワード書き込み線との交点に磁気メモリ素子としてＴＭＲ素子が配されて成る。そして、このようなＭＲＡＭで記録を行う際には、アステロイド特性を利用してＴＭＲ素子に対して選択書き込みを行う。
【０００９】
ＭＲＡＭにおいてＴＭＲ素子の磁気特性が素子毎にばらつくことや、同一素子を繰り返し使用した場合のばらつきが存在すると、アステロイド特性を使用した選択書き込みが困難になるという問題点がある。
従って、ＴＭＲ素子には、理想的なアステロイド曲線を描かせるための磁気特性も求められる。
理想的なアステロイド曲線を描かせるためには、ＴＭＲ測定を行った際のＲ－Ｈ（抵抗－磁場）ループにおいてバルクハウゼンノイズ等のノイズがないこと、波形の角形性がよいこと、磁化状態が安定しており保磁力Ｈｃのばらつきが少ないことが必要である。
【００１０】
バルクハウゼンノイズや角形性の劣化、保磁力のばらつきは、主にその材料の磁気異方性に起因している。膜面内で磁気異方性の方向や強度が分散していると、これらの問題が発生する原因となるため、磁気異方性の方向制御は非常に重要である。
【００１１】
上述した問題の解決のために、本発明においては、強磁性層の磁気異方性を制御することにより良好な磁気特性を有する磁気抵抗効果素子、及びこの磁気抵抗効果素子を備えて優れた書き込み特性を有する磁気メモリ装置、並びにこれら磁気抵抗効果素子及び磁気メモリ装置の製造方法を提供するものである。
【００１２】
【課題を解決するための手段】
本発明の磁気抵抗効果素子は、対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成であって、強磁性層のうち一方が磁化固定層であり他方が磁化自由層であり、強磁性層のうち少なくとも磁化自由層は、アモルファスあるいは微結晶組織を有し、強磁性層が３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理されているものである。
【００１３】
本発明の磁気メモリ装置は、対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子と、磁気抵抗効果素子を厚み方向に挟むワード線及びビット線とを備え、強磁性層のうち一方が磁化固定層であり他方が磁化自由層であり、強磁性層のうち少なくとも磁化自由層は、アモルファスあるいは微結晶組織を有し、強磁性層が３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理されているものである。
【００１４】
本発明の磁気抵抗効果素子の製造方法は、対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成であり、強磁性層のうち一方が磁化固定層であり他方が磁化自由層であり、強磁性層のうち少なくとも磁化自由層はアモルファスあるいは微結晶組織を有する磁気抵抗効果素子を製造する際に、少なくとも磁化自由層を形成した後に、３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理を施す工程を行うものである。

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【００１５】
本発明の磁気メモリ装置の製造方法は、対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成であり、強磁性層のうち一方が磁化固定層であり他方が磁化自由層であり、強磁性層のうち少なくとも磁化自由層はアモルファスあるいは微結晶組織を有する磁気抵抗効果素子と、この磁気抵抗効果素子を厚み方向に挟むワード線及びビット線とを備えた磁気メモリ装置を製造する際に、少なくとも磁化自由層を形成した後に、３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理を施す工程を行うものである。
【００１６】
上述の本発明の磁気抵抗効果素子の構成によれば、強磁性層のうち一方が磁化固定層であり他方が磁化自由層であり、強磁性層のうち少なくとも磁化自由層は、アモルファスあるいは微結晶組織を有し、強磁性層が３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理されていることにより、磁場中熱処理により強磁性層の磁気異方性が制御されるため、磁気抵抗効果素子の抵抗－外部磁場曲線の角形性を改善することや、保磁力のばらつきを改善することが可能になる。
【００１７】
上述の本発明の磁気メモリ装置の構成によれば、磁気抵抗効果素子と、磁気抵抗効果素子を厚み方向に挟むワード線及びビット線とを備え、磁気抵抗効果素子が上記の本発明の磁気抵抗効果素子の構成であることにより、磁場中熱処理により強磁性層の磁気異方性が制御されて、磁気抵抗効果素子の抵抗－外部磁場曲線の角形性を改善し、保磁力のばらつきを改善することが可能になるため、磁気抵抗効果素子のアステロイド曲線の形状が改善され、磁気メモリ装置における情報の選択書き込みが容易に安定して行えるようになる。
【００１８】
上述の本発明の磁気抵抗効果素子の製造方法によれば、少なくとも磁化自由層を形成した後に、３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理を施す工程を行うことにより、少なくとも磁化自由層の磁気異方性を制御して、磁気抵抗効果素子の抵抗－外部磁場曲線の角形性や保磁力のばらつきが改善された磁気抵抗効果素子を製造することが可能になる。
【００１９】
上述の本発明の磁気メモリ装置の製造方法によれば、少なくとも磁化自由層を形成した後に、３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理を施す工程を行うことにより、少なくとも磁化自由層の磁気異方性を制御して、磁気抵抗効果素子の抵抗－外部磁場曲線の角形性や保磁力のばらつきが改善され、情報の選択書き込みが容易に安定して行える磁気メモリ装置を製造することが可能になる。
【００２０】
【発明の実施の形態】
本発明は、対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子であって、強磁性層のうち一方が磁化固定層であり他方が磁化自由層であり、強磁性層のうち少なくとも磁化自由層は、アモルファスあるいは微結晶組織を有し、強磁性層が３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理されている磁気抵抗効果素子である。
【００２１】
また本発明は、上記磁気抵抗効果素子において、磁化自由層がＦｅＣｏＢ、ＦｅＣｏＮｉＢ、ＦｅＣｏＳｉＢから選ばれる材料から成る構成とする。
【００２２】
また本発明は、上記磁気抵抗効果素子において、上記中間層として絶縁体もしくは半導体から成るトンネルバリア層を用いたトンネル磁気抵抗効果素子である構成とする。
【００２３】
また本発明は、上記磁気抵抗効果素子において、積層フェリ構造を有する構成とする。
【００２４】

本発明は、対の強磁性層が中間層を介して対向されてなり、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子と、磁気抵抗効果素子を厚み方向に挟むワード線及びビット線とを備え、強磁性層のうち一方が磁化固定層であり他方が磁化自由層であり、強磁性層のうち少なくとも磁化自由層は、アモルファスあるいは微結晶組織を有し、強磁性層が３００℃以上磁化自由層の結晶化温度以下で磁場中熱処理されている磁気メモリ装置である。

【００２５】

また本発明は、上記磁気メモリ装置において、磁化自由層がＦｅＣｏＢ、ＦｅＣｏＮｉＢ、ＦｅＣｏＳｉＢから選ばれる材料から成る構成とする。

【００２６】

また本発明は、上記磁気メモリ装置において、磁気抵抗効果素子が中間層として絶縁体もしくは半導体から成るトンネルバリア層を用いたトンネル磁気抵抗効果素子である構成とする。

【００２７】

また本発明は、上記磁気メモリ装置において、磁気抵抗効果素子が積層フェリ構造を有する構成とする。

【００２８】

まず、本発明の磁気抵抗効果素子の一実施の形態の概略構成図を図１に示す。この図１に示す実施の形態は、本発明をトンネル磁気抵抗効果素子（以下、ＴＭＲ素子と称する。）に適用した場合を示している。

【００２９】

このＴＭＲ素子１は、シリコン等からなる基板２上に、下地層３と、反強磁性層４と、強磁性層である磁化固定層５と、トンネルバリア層６と、強磁性層である磁化自由層７と、トップコート層８とがこの順に積層されて構成されている。即ち、強磁性層の一方が磁化固定層５とされ、他方が磁化自由層７とされた、いわゆるスピンバルブ型のＴＭＲ素子を構成しており、対の強磁性層である磁化固定層５と磁化自由層７とでトンネルバリア層６を挟み込むことにより、強磁性トンネル接合９を形成している。

そして、磁気メモリ装置等にこのＴＭＲ素子１を適用した場合には、磁化自由層７が情報記録層となり、そこに情報が記録される。

【００３０】

反強磁性層４は、強磁性層の一方である磁化固定層５と反強磁性的に結合することにより、書き込みのための電流磁界によっても磁化固定層５の磁化を反転させず、磁化固定層５の磁化の向きを常に一定とするための層である。即ち、図１に示すＴＭＲ素子１においては、他方の強磁性層である磁化自由層７だけを外部磁場等によって磁化反転させる。磁化自由層７は、ＴＭＲ素子１を例えば磁気メモリ装置等に適用した場合に情報が記録される層となるため、情報記録層とも称される。

反強磁性層４を構成する材料としては、Ｆｅ、Ｎｉ、Ｐｔ、Ｉｒ、Ｒｈ等を含むＭｎ合金、Ｃｏ酸化物、Ｎｉ酸化物等を使用することができる。

【００３１】

図１に示すスピンバルブ型のＴＭＲ素子１においては、磁化固定層５は、反強磁性層４と反強磁性的に結合することによって磁化の向きを一定とされる。このため、書き込みの際の電流磁界によっても磁化固定層５の磁化は反転しない。

【００３２】

トンネルバリア層６は、磁化固定層５と磁化自由層７とを磁気的に分離するとともに、トンネル電流を流すための層である。

トンネルバリア層６を構成する材料としては、例えばＡｌ、Ｍｇ、Ｓｉ、Ｌｉ、Ｃａ等の酸化物、窒化物、ハロゲン化物等の絶縁材料を使用することができる。

【００３３】

このようなトンネルバリア層６は、スパッタリング法や蒸着法等によって成膜された金属膜を、酸化又は窒化することにより得ることができる。

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また、有機金属と、酸素、オゾン、窒素、ハロゲン、ハロゲン化ガス等とを用いるＣＶＤ法によっても得ることができる。

【００３４】

本実施の形態においては、特に強磁性層である磁化固定層５、磁化自由層７を含む強磁性トンネル接合９が、３００℃以上で磁場中熱処理が施されている構成とする。

このような構成とすることにより、Ｒ－Ｈ曲線の角形性を向上し、保磁力のばらつきを低減することができる。

【００３５】

この磁場中熱処理における磁場の向きは、強磁性層５，７の磁化容易軸と平行にすることが好ましい。

【００３６】

強磁性層、特に磁化自由層７には、Ｆｅ、Ｃｏ、Ｎｉのいずれか、あるいは、これら複数以上を主成分としたアモルファスまたは微結晶の材料が好ましい。

【００３７】

尚、Ｆｅ、Ｃｏ、Ｎｉを主成分とした合金例えばＦｅＣｏ等は、通常の膜厚では結晶質であるが、例えば膜厚１ｎｍ程度とごく薄くした場合には、アモルファスに近い状態になるため、上述した３００℃以上の熱処理の効果が得られる。しかしながら、この合金には結晶磁気異方性が存在し、この結晶磁気異方性は熱処理による制御が困難であるため、アモルファス材料に比べると効果が小さくなる。

【００３８】

ここで、磁化自由層７が、Ｃｏ７２Ｆｅ８Ｂ２０（原子％）の組成のアモルファス強磁性材料から成る構成のスピンバルブ型ＴＭＲ素子について、３００℃での静磁場中熱処理を施したものと、２５０℃での静磁場中熱処理を施したものをそれぞれ実際に作製し、これらについて抵抗－外部磁場曲線（Ｒ－Ｈ曲線）を測定した結果を図２に示す。

図２から明らかなように、３００℃で熱処理したＴＭＲ素子では、２５０℃で熱処理したＴＭＲ素子に比べ、Ｒ－Ｈ曲線の角形性が向上すると共にバルクハウゼンノイズも低減された。従って、本発明によれば、アステロイド曲線の形状も改善されて書き込み特性が向上し、書き込みエラーの低減を図ることが可能となる。

【００３９】

この３００℃以上の熱処理条件で特性が改善される原因は定かでないが、材料の結晶化温度より低く、キュリー温度に近い温度であることが関係していると考えられる。

【００４０】

磁場中熱処理を行う熱処理炉は、例えば図３に示す構成とする。

この熱処理炉は、真空チャンバー３１の外にヒーター３２を配置し、さらに外側にマグネット３３を配置して成る。

【００４１】

この熱処理炉において、磁場中熱処理は次のようにして行う。

まず、ＴＭＲ素子が形成されるウェハ３０を、真空チャンバー３１内のラック３４に、マグネット３３による磁場３５の方向にウェハ３０の主面３０Ａが平行になるように載置する。

そして、ヒーター３２により加熱すると共に、マグネット３３により磁場を印加することによって、ウェハ３０のＴＭＲ素子に対して磁場中熱処理を行うことができる。

【００４２】

また、磁場中熱処理の温度の上限は、強磁性層に用いるアモルファスまたは微結晶の材料の結晶化温度により決定されるが、さらにＴＭＲ素子の耐熱性との兼ね合いから、高くとも４００℃以下とする。

【００４３】

磁場中熱処理は、強磁性層の磁化反転特性を改善する目的から行っているため、少なくとも磁化自由層７に、より好ましくは磁化自由層７及び磁化固定層５の双方に処理を施すようにする。

これにより、ＴＭＲ素子１の磁気特性の改善を図る効果をより顕著に得られる。

【００４４】

また、例えば上述の熱処理をより効果的なものにするためには、磁化自由層７に用いるアモルファスまたは微結晶の材料の膜厚を１ｎｍ以上、１５ｎｍ以下とすることが望ましい。この範囲内にあることによって良好な磁気特性を確保できる。磁化自由層７の膜厚が１ｎｍ未満である場合には、熱による相互拡散により磁気特性が大幅に損なわれ、逆に磁化自由層７の膜厚が１５ｎｍを上回る場合には、ＴＭＲ素子１の保磁力が過剰に高くなるので実用上不適当となるおそれがある。

【００４５】

また、同様に、磁化固定層５にもアモルファスまたは微結晶の材料を用いる場合に、上述の熱処理をより効果的なものにするためには、磁化固定層５に用いるアモルファスまたは微結晶の材料の膜厚を０．５ｎｍ以上、６ｎｍ以下とすることが望ましい。この範囲内にあることによって良好な磁気特性を確保できる。磁化固定層５の膜厚が０．５ｎｍ未満である場合には、熱による相互拡散により磁気特性が大幅に損なわれ、逆に磁化固定層５の膜厚が６ｎｍを上回る場合には、反強磁性層４との交換結合磁界を充分に得られなくなるおそれがある。

【００４６】

上述の本実施の形態のＴＭＲ素子１によれば、３００℃以上磁化自由層７の結晶化温度以下で磁場中熱処理が施されている構成とすることにより、強磁性層５，７の磁気異方性を制御して、Ｒ－Ｈ曲線の角形性を向上し、バルクハウゼンノイズを低減することができる。また、保磁力Ｈｃのばらつきを抑制して、ＴＭＲ素子１のアステロイド曲線の形状を改善することができる。

【００４７】

これにより、例えば多数のＴＭＲ素子を有して成る磁気メモリ装置にＴＭＲ素子１を適用した場合に、ＴＭＲ素子１のアステロイド曲線の形状を改善して、書き込み特性を向上することにより、書き込みエラーを低減することができる。

また、ＴＭＲ素子を有して成る磁気ヘッドや磁気センサに適用した場合には、反転磁界の設計値からのずれを抑制して、製造歩留まりを向上することや動作不良を防止することが可能になる。

【００４８】

尚、本発明においては、図１に示すような磁化固定層５及び磁化自由層７のそれぞれが単層から構成されたＴＭＲ素子１に限定されない。

例えば図４に示すように、磁化固定層５が、第１の磁化固定層５ａと第２の磁化固定層５ｂとで非磁性導電体層５ｃを挟み込んでなる積層フェリ構造とされる場合であっても、本発明の効果を得ることができる。

【００４９】

図４に示すＴＭＲ素子１０では、第１の磁化固定層５ａが反強磁性層４と接しており、これらの層間に働く交換相互作用によって、第１の磁化固定層５ａは強い一方向の磁気異方性を持つ。また、第２の磁化固定層５ｂは、トンネルバリア層６を介して磁化自由層７と対向し、スピンの向きが磁化自由層７と比較され直接ＭＲ比に関わる強磁性層となるため、参照層とも称される。

【００５０】

積層フェリ構造の非磁性導電体層５ｃに用いられる材料としては、例えばＲｕ、Ｒｈ、Ｉｒ、Ｃｕ、Ｃｒ、Ａｕ、Ａｇ等が挙げられる。図４のＴＭＲ素子１０において、その他の層は図１に示したＴＭＲ素子１とほぼ同様の構成であるため、図１と同じ符号を付して詳細な説明を省略する。

【００５１】

この積層フェリ構造を有するＴＭＲ素子１０においても、３００℃以上磁化自由層７の結晶化温度以下で磁場中熱処理が施された構成とすることにより、図１に示したＴＭＲ素子１と同様に、Ｒ－Ｈ曲線の角形性を向上し、バルクハウゼンノイズを低減することができ

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る。また、保磁力Ｈｃのばらつきを抑制して、ＴＭＲ素子１０のアステロイド曲線の形状を改善することができる。

【００５２】

尚、上述の実施の形態では、磁気抵抗効果素子としてＴＭＲ素子（トンネル磁気抵抗効果素子）１，１０を用いたが、本発明は、対の強磁性層が中間層を介して対向され、膜面に対して垂直に電流を流して磁気抵抗変化を得る構成を有するその他の磁気抵抗効果素子にも適用することができる。

例えば中間層としてＣｕ等の非磁性導電層を用いた巨大磁気抵抗効果素子（ＧＭＲ素子）で、膜面に対して垂直に電流を流して磁気抵抗効果を得る構成、即ちいわゆるＣＰＰ型のＧＭＲ素子にも本発明を適用することができる。

【００５３】

さらに、磁化固定層や反強磁性体の材料、磁化固定層側における積層フェリ構造の有無等は、本発明の本質を損なわない限り種々の変形が可能である。

【００５４】

尚、磁場中熱処理における磁場の強度の範囲は、上述の実施の形態のＴＭＲ素子１のように磁化自由層７が磁化固定層５より上層側にある構成（いわゆるボトムスピン型）では、３００℃以上の磁場中熱処理が反強磁性層４から磁化固定層５にかかるバイアスを決定する熱処理を兼ねるため、磁化固定層５の構造、膜厚、特性により異なる。

例えば、磁化固定層５が膜厚２ｎｍのＣｏＦｅ膜のみ（単層）から成り、反強磁性層４の材料がＦｅＭｎやＲｈＭｎ、ＩｒＭｎ等である場合には、１ｋＯｅ程度の磁場で充分である。

この磁化固定層５が膜厚２ｎｍのＣｏＦｅ膜のみ（単層）である構成でも、反強磁性層４の材料がＰｔＭｎ等である場合には、３ｋＯｅ程度必要となる。

さらに、図４に示したＴＭＲ素子１０等、磁化固定層５が積層フェリ構造を有することにより、強固な反強磁性結合が形成される場合には、この反強磁性結合を形成している複数の磁性層すべてが同じ方向の磁化を有するようにする必要がある。例えばＣｏＦｅ（２ｎｍ）／Ｒｕ（０．８ｎｍ）／ＣｏＦｅ（２ｎｍ）のような構造の磁化固定層５である場合には、１０ｋＯｅ程度の磁場が必要となる。

一方、磁場の大きさの上限は特にないが、磁場を大きくするためには磁界印加手段を大型化する必要があるため、適度な大きさに設定される。

【００５５】

上述のようなＴＭＲ素子１，１０等の磁気抵抗効果素子は、例えばＭＲＡＭ等の磁気メモリ装置に用いられて好適である。以下、本発明のＴＭＲ素子を用いたＭＲＡＭについて、図を参照しながら説明する。

【００５６】

本発明のＴＭＲ素子を有するクロスポイント型のＭＲＡＭアレイを、図５に示す。このＭＲＡＭアレイは、複数のワード線ＷＬと、これらワード線ＷＬと直交する複数のビット線ＢＬとを有し、ワード線ＷＬとビット線ＢＬとの交点に本発明のＴＭＲ素子が配置されて成るメモリセル１１とを有する。即ち、このＭＲＡＭアレイでは、３×３のメモリセル１１がマトリクス状に配置される。

【００５７】

尚、ＭＲＡＭアレイに用いられるＴＭＲ素子としては、図１に示したＴＭＲ素子１に限定されず、積層フェリ構造を有する図４に示すＴＭＲ素子１０等、膜面に対して垂直に電流を流すことによって磁気抵抗変化を得る構成の磁気抵抗効果素子において磁場中３００℃以上で熱処理されており、少なくとも磁化自由層７を含む強磁性層がアモルファス材料から成る構成であればいかなる構成であっても構わない。

【００５８】

また、メモリ素子に多数あるメモリセルから１つのメモリセルを取り出して、断面構造を図６に示す。

各メモリセル１１は、図６に示すように、例えばシリコン基板１２上に、ゲート電極１３

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、ソース領域１４及びドレイン領域１５からなるトランジスタ１６を有する。ゲート電極１３は、読み出し用のワード線ＷＬ１を構成している。ゲート電極１３上には、絶縁層を介して書き込み用のワード線（前述したワード書き込み線に相当する）ＷＬ２が形成されている。トランジスタ１６のドレイン領域１５にはコンタクトメタル１７が接続され、さらにコンタクトメタル１７には下地層１８が接続されている。この下地層１８上の書き込み用のワード線ＷＬ２の上方に対応する位置に、本発明のＴＭＲ素子１が形成されている。このＴＭＲ素子１上に、ワード線ＷＬ１及びＷＬ２と直交するビット線（前述したビット書き込み線に相当する）ＢＬが形成されている。尚、下地層１８は、平面位置の異なるＴＭＲ素子１とドレイン領域１５との電気的接続をする役割から、バイパスとも称される。

また、各ワード線ＷＬ１，ＷＬ２とＴＭＲ素子１とを絶縁するための層間絶縁膜１９及び絶縁膜２０と、全体を保護するパッシベーション膜（図示せず）等を有して成る。

【００５９】

このＭＲＡＭは、３００℃以上結晶化温度以下の磁場中熱処理により磁化自由層７の磁気異方性が制御されたＴＭＲ素子１を用いているので、Ｒ－Ｈ曲線においてノイズが低減し、アステロイド特性が向上するので、書き込みエラーの低減を図ることできる。

【００６０】

ここで、本発明の製造方法によりＭＲＡＭを製造する場合のプロセスフローの形態を、図７Ａ及び図７Ｂにそれぞれ示す。

基板にＣＭＯＳ回路（例えば図６のトランジスタ１６）を形成した後、ワード線（例えば図６のＷ２）を形成し、ワード線の埋め込みを行い、表面を平坦化した後、ＴＭＲ膜を成膜する工程までは、図７Ａ及び図７Ｂで共通になっている。

【００６１】

図７Ａに示すプロセスフローでは、ＴＭＲ膜を成膜した後、すぐ磁場中熱処理を行い、その後バイパス形成工程即ち図６の下地層１８のパターニング、素子部形成工程即ちＴＭＲ素子１のパターニング、素子の埋め込み工程即ちＴＭＲ素子１を絶縁膜で埋め込む工程、ビット線形成工程、ビット線の埋め込み工程の各工程を行うようにしている。

また、図７Ｂに示すプロセスフローでは、ＴＭＲ膜を成膜し、その後バイパス形成工程、素子部形成工程、素子の埋め込み工程、ビット線形成工程、ビット線の埋め込み工程の各工程を行った後、磁場中熱処理を行うようにしている。

【００６２】

いずれにしても、ＴＭＲ膜を成膜した後に磁場中熱処理を施すのが望ましいが、少なくともＴＭＲ膜のうち磁化自由層７を成膜した後にする必要がある。

【００６３】

尚、例えば磁化固定層及び磁化自由層の配置が上述した実施の形態の構成（いわゆるボトムスピン型）とは逆である構成、即ち磁化自由層を基板側に、磁化固定層及び反強磁性層を磁化自由層よりも上層に形成する構成（いわゆるトップスピン型）では、磁化自由層の強磁性膜を成膜してから３００℃以上で磁場中熱処理を行った後、磁化固定層及び反強磁性層を成膜し、その後反強磁性層を規則化する（上述したバイアスを決定する）ための磁場中熱処理を３００℃未満で行うことが考えられる。

この場合、磁場中熱処理を２回行うことになるが、磁化固定層及び反強磁性層を成膜した後に３００℃以上の磁場中熱処理を行う場合と比較すると、ＴＭＲ膜の表面に近い磁化固定層及び反強磁性層に３００℃以上の温度の影響が及ばないという利点を有する。

【００６４】

（実施例）

以下、本発明を適用した具体的な実施例について、実験結果に基づいて説明する。

尚、図６に示したように、ＭＲＡＭにはＴＭＲ素子１以外にスイッチング用のトランジスタ１６が存在するが、本実施例ではＴＭＲ特性を調べるために、図８及び図９に示すような強磁性トンネル接合のみを形成したウェハにより特性の測定・評価を行った。

まず、強磁性トンネル接合の磁化自由層に種々の材料を用いた場合の、熱処理温度依存性

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について調べた。

【００６５】

＜サンプル１＞

図８に平面図、図９に図８のＡ－Ａにおける断面図をそれぞれ示すように、特性評価用素子ＴＥＧ（Ｔｅｓｔ　Ｅｌｅｍｅｎｔ　Ｇｒｏｕｐ）として、基板２１上にワード線ＷＬとビット線ＢＬとが直交して配置され、これらワード線ＷＬとビット線ＢＬとの交差する部分にＴＭＲ素子２２が形成された構造を作製した。このＴＥＧは、ＴＭＲ素子２２が短軸０．５μｍ×長軸１．０μｍの楕円形状であり、ワード線ＷＬ及びビット線ＢＬの両端にそれぞれ端子パッド２３，２４が形成され、ワード線ＷＬとビット線ＢＬとをAl_2O_3から成る絶縁膜２５，２６によって互いに電気的に絶縁した構成となっている。

【００６６】

具体的には、次のようにして図８及び図９に示すＴＥＧを作製した。

まず、表面に熱酸化膜（厚さ２μｍ）が形成された厚さ０．６ｍｍのシリコンから成る基板２１を用意した。

次に、この基板２１上にワード線の材料を成膜し、フォトリソグラフィによってマスクした後にワード線以外の部分をＡｒプラズマにより選択的にエッチングし、ワード線ＷＬを形成した。このとき、ワード線ＷＬ以外の領域は、基板２１の深さ５ｎｍまでエッチングした。

その後、ワード線ＷＬを覆って絶縁膜２６を形成し、表面を平坦化した。

【００６７】

続いて、下記の層構成（１）からなるＴＭＲ素子２２を、公知のリソグラフィ法及びエッチングにより作製した。層構成（１）は、／の左側が基板側となっており、（）内は膜厚を示す。

Ｔａ（３ｎｍ）／Ｃｕ（１００ｎｍ）／ＰｔＭｎ膜（２０ｎｍ）／ＣｏＦｅ（３ｎｍ）／Ｒｕ（０．８ｎｍ）／ＣｏＦｅ（２．５ｎｍ）／Ａｌ（１ｎｍ）－O_x／磁化自由層（ｔｎｍ）／Ｔａ（５ｎｍ）－（１）

【００６８】

尚、上記の層構成（１）のうち、磁化自由層の組成をＣｏ７２Ｆｅ８Ｂ２０（原子％）とし、磁化自由層の膜厚ｔを４ｎｍとした。

また、各ＣｏＦｅ膜の組成を、Ｃｏ７５Ｆｅ２５（原子％）とした。

【００６９】

トンネルバリア層６のＡｌ－O_x膜は、まず金属Ａｌ膜をＤＣスパッタ法により１ｎｍ堆積させ、その後酸素／アルゴンの流量比を１：１とし、チャンバーガス圧を０．１ｍＴｏｒｒとし、ＩＣＰ（誘導結合プラズマ）からのプラズマにより金属Ａｌ膜をプラズマ酸化させることにより形成した。酸化時間はＩＣＰプラズマ出力に依存するが、本実施例では３０秒とした。

【００７０】

また、トンネルバリア層６のＡｌ－O_x膜以外の膜は、ＤＣマグネトロンスパッタ法で成膜した。

【００７１】

次に、磁場中熱処理炉にて、１０ｋＯｅの磁界中、２００～３６０℃で、５時間の熱処理を行い、反強磁性層であるＰｔＭｎ層の規則化熱処理を行い、強磁性トンネル接合９を形成した。

続いて、ＴＭＲ素子２２及びその下の絶縁膜２６をパターニングして、図８に示す平面パターンを有するＴＭＲ素子２２を形成する。

さらに、Al_2O_3をスパッタすることにより、厚さ１００ｎｍ程度の絶縁層２５を成膜し、さらにフォトリソグラフィによりビット線ＢＬ及び端子パッド２４を形成し、図８及び図９に示したＴＥＧを得た。

【００７２】

＜サンプル２＞

磁化自由層７の組成をＣｏ７０．５Ｆｅ４．５Ｓｉ１５Ｂ１０（原子％）とし、磁化自由層７の膜厚を４ｎｍとした以外はサンプル１と同様にしてＴＥＧを得た。

【００７３】

＜サンプル３＞

磁化自由層７の組成をＣｏ３５Ｎｉ３５Ｆｅ１０Ｂ２０（原子％）とし、磁化自由層７の膜厚を４ｎｍとした以外はサンプル１と同様にしてＴＥＧを得た。

【００７４】

＜サンプル４＞

磁化自由層７の組成をＣｏ７５Ｆｅ２５（原子％）とし、磁化自由層７の膜厚を２ｎｍとした以外はサンプル１と同様にしてＴＥＧを得た。

【００７５】

＜サンプル５＞

磁化自由層７の組成をＣｏ９０Ｆｅ１０（原子％）とし、磁化自由層７の膜厚を２ｎｍとした以外はサンプル１と同様にしてＴＥＧを得た。

【００７６】

そして、得られた各サンプル１～サンプル５のＴＥＧに対して、下記のようにしてＲ－Ｈ曲線の測定を行って、さらにＲ－Ｈ曲線から保磁力のばらつきを求めた。

【００７７】

（Ｒ－Ｈ曲線の測定）

通常のＭＲＡＭ等の磁気メモリ装置では、電流磁界によって磁気抵抗効果素子を磁化反転させて情報を書き込むが、本実施例では、外部磁界によって磁気抵抗効果素子を磁化させることにより、抵抗値の測定を行った。即ち、まずＴＭＲ素子２２の磁化自由層を磁化反転させるための外部磁界を磁化自由層の磁化容易軸に対して平行となるように印加した。測定のための外部磁界の大きさは、５００Ｏｅとした。

【００７８】

次に、磁化自由層の磁化容易軸の一方側から見て－５００Ｏｅから＋５００Ｏｅまで掃引すると同時に、ワード線ＷＬの端子パッド２３とビット線ＢＬの端子パッド２４とにかかるバイアス電圧が１００ｍＶとなるように調節して、強磁性トンネル接合にトンネル電流を流した。このときの各外部磁界に対する抵抗値を測定してＲ－Ｈ曲線を得た。

【００７９】

（保磁力Ｈｃのばらつき）

上記の測定方法によりＲ－Ｈ曲線を測定し、Ｒ－Ｈ曲線から、磁化固定層と磁化自由層の磁化が反平行の状態であって抵抗が高い状態での抵抗値と、磁化固定層と磁化自由層の磁化が平行の状態であって抵抗が低い状態での抵抗値との平均値を求め、この平均値の抵抗値が得られるときの外部磁界の値を保磁力Ｈｃとした。この保磁力Ｈｃを、同様に作製された素子（ＴＥＧ）５００個に対して行い、これらの標準偏差ΔＨｃを求めた。そして、ΔＨｃ／（Ｈｃの平均値）を保磁力Ｈｃのばらつきの値とした。

尚、書き込み特性の向上を図るといった観点から、保磁力Ｈｃのばらつきは、６％以下であることが好ましい。

【００８０】

サンプル１～サンプル５のそれぞれについて、磁化自由層７の組成及び膜厚を表１に示し、また横軸に熱処理温度をとり、縦軸に保磁力Ｈｃのばらつきをとり、プロットして図１０に示す。

【００８１】

【表１】

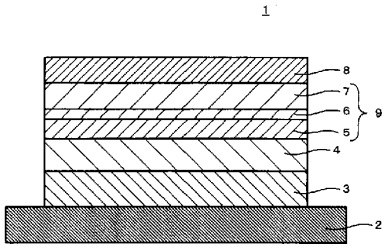
サンプルNo.	層構成	磁化自由層組成（原子%）	膜厚（nm）
1	1	$Co_{72}Fe_{8}B_{20}$	4
2	1	$Co_{70.5}Fe_{4.5}Si_{15}B_{10}$	4
3	1	$Co_{35}Ni_{35}Fe_{10}B_{20}$	4
4	1	$Co_{75}Fe_{25}$	2
5	1	$Co_{90}Fe_{10}$	2

【００８２】
図１０から明らかなように、サンプル１～サンプル３のように、アモルファス材料を磁化自由層７に用いて、かつ磁場中熱処理の温度を３００℃以上とすることにより、保磁力Ｈｃのばらつきを抑えることができることがわかる。
【００８３】
このことから、アモルファス材料を磁化自由層７に用い、かつ３００℃以上の磁場中熱処理を施すことにより、ＴＭＲ素子の保磁力Ｈｃのばらつきを抑えて、ＭＲＡＭの書き込み特性を改善する効果が得られることがわかる。
【００８４】
尚、サンプル１及びサンプル３と、サンプル２とを比較すると、サンプル２の方がキュリー温度や結晶化温度が高くなるが、図１０の保磁力Ｈｃのばらつきについても、同等のばらつき抑制効果を得るのにサンプル２の方がやや高い温度を要することがわかる。
【００８５】
尚、本発明の磁気抵抗効果素子（ＴＭＲ素子等）は、前述した磁気メモリ装置のみならず、磁気ヘッド及びこの磁気ヘッドを搭載したハードディスクドライブや磁気センサ、集積回路チップ、さらにはパソコン、携帯端末、携帯電話を始めとする各種電子機器、電子機器等に適用することができる。
【００８６】
本発明は、上述の実施の形態に限定されるものではなく、本発明の要旨を逸脱しない範囲でその他様々な構成が取り得る。
【００８７】
【発明の効果】
上述の本発明の磁気抵抗効果素子及びその製造方法によれば、Ｒ－Ｈ曲線の角形性の改善、保磁力のばらつきの改善を図ることができる。
これにより、例えば磁気抵抗効果素子を磁気メモリ装置に適用した場合に、書き込みエラーを低減することができ、優れた書き込み特性が得られる。
【００８８】
また、本発明の磁気メモリ装置及びその製造方法によれば、優れた書き込み特性を実現することができる。
【図面の簡単な説明】
【図１】本発明の一実施の形態のＴＭＲ素子の概略構成図である。
【図２】磁場中熱処理の温度が３００℃の場合と２５０℃の場合でＴＭＲ素子の抵抗－外部磁場曲線を比較した図である。
【図３】磁場中熱処理に用いる熱処理炉の一形態を示す図である。
【図４】積層フェリ構造を有するＴＭＲ素子の概略構成図である。
【図５】本発明のＴＭＲ素子をメモリセルとして有する、クロスポイント型ＭＲＭアレイの要部を示す概略構成図である。

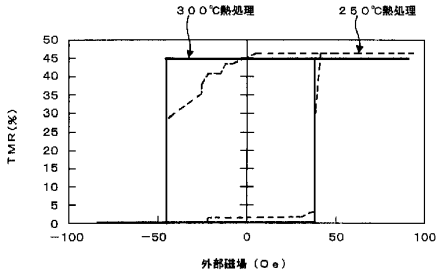
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【図６】図３に示すメモリセルの拡大断面図である。
【図７】Ａ、Ｂ　本発明によりＭＲＡＭを製造する場合のプロセスフローの形態を示した図である。
【図８】ＴＭＲ素子の評価用のＴＥＧの平面図である。
【図９】図８のＡ－Ａにおける断面図である。
【図１０】熱処理温度と保磁力Ｈｃのばらつきとの関係を示す図である。
【符号の説明】
１，１０，２２　トンネル磁気抵抗効果素子（ＴＭＲ素子）、２，２１　基板、３　下地層、４　反強磁性層、５　磁化固定層、５ａ　第１の磁化固定層、５ｂ第２の磁化固定層（参照層）、５ｃ　非磁性導電体層、６　トンネルバリア層、７　磁化自由層、９　強磁性トンネル接合、１１　メモリセル、２３，２４　パッド、３０　ウェハ、３２　ヒーター、３３　マグネット、ＷＬ，ＷＬ１，ＷＬ２　ワード線、ＢＬ　ビット線

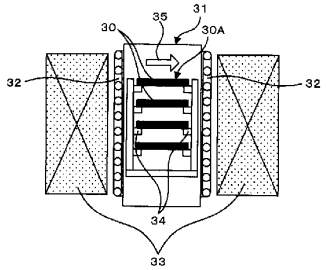
【図１】



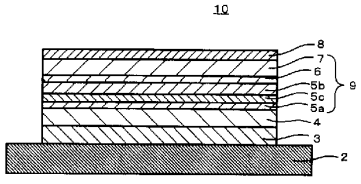
【図２】



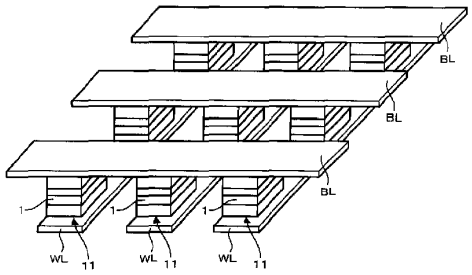
【図３】



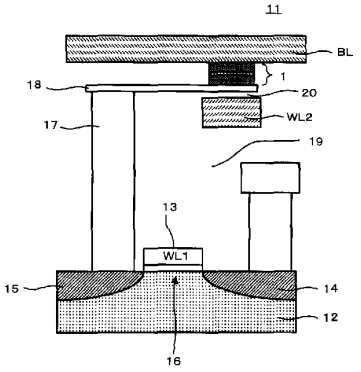
【図４】



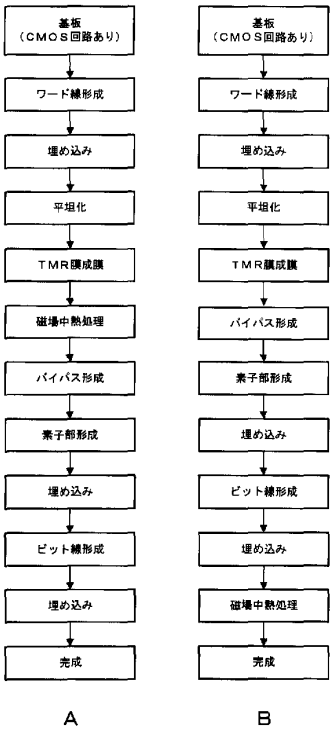
【図５】



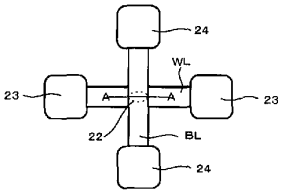
【図６】



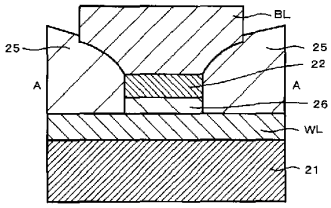
【図７】



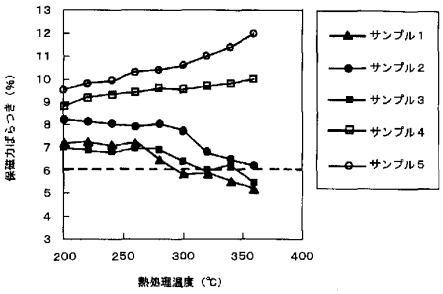
【図８】



【図９】



【図１０】



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5E049 AA01 AA04 AA07 AC01 AC05 BA06
5F083 FZ10 GA27 JA36 JA37 JA38 JA39 LA12 LA16 MA06 MA19

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Filing Date:	14-Feb-2013
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Billy Aaron Schulman/Stacy Johnson
Attorney Docket Number:	NAGI-0005

Filed as Large Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension - 2 months with $0 paid	1252	1	600	600
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	Amendment Submitted/Entered with Filing of CPA/RCE		2	6	
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2		NAGI_0005IDSLetter_List.pdf	382754 9d46bff5c0f9731c6fae79bd462f49864f9ac058	yes	4
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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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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 13/767,290	Filing Date 02/14/2013	☐ 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 $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ 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

AMENDMENT	03/25/2015	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 2	Minus	** 20	= 0	X $80 =	0
	Independent (37 CFR 1.16(h))	* 1	Minus	***3	= 0	X $420 =	0
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	0

AMENDMENT		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
	☐ 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.
** 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 number found in the appropriate box in column 1.

LIE
/ANNETTE SMITH/

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.

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 13/767,290	Filing Date 02/14/2013	☐ 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 $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ 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

AMENDMENT	03/25/2015	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 2	Minus	** 20	= 0	X $80 =	0
	Independent (37 CFR 1.16(h))	* 1	Minus	***3	= 0	X $420 =	0
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	0

AMENDMENT		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
	☐ 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.

** 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 number found in the appropriate box in column 1.

LIE
/ANNETTE SMITH/

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.

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

NOTICE OF ALLOWANCE AND FEE(S) DUE

881 7590 04/23/2015

STITES & HARBISON PLLC
1199 NORTH FAIRFAX STREET
SUITE 900
ALEXANDRIA, VA 22314

EXAMINER
CHAMBLISS, ALONZO

ART UNIT	PAPER NUMBER
2897	

DATE MAILED: 04/23/2015

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005	2082

TITLE OF INVENTION: Magnetic Tunnel Junction Device

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	07/23/2015

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 1/2 the amount of undiscounted fees, and micro entity fees are 1/2 the amount of small entity 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 and an extra copy of the form should be submitted. 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: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
or Fax (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

881 7590 04/23/2015
STITES & HARBISON PLLC
1199 NORTH FAIRFAX STREET
SUITE 900
ALEXANDRIA, VA 22314

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

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 facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005	2082

TITLE OF INVENTION: Magnetic Tunnel Junction Device

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	07/23/2015

EXAMINER	ART UNIT	CLASS-SUBCLASS
CHAMBLISS, ALONZO	2897	257-295000

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/SB/47; Rev 03-02 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 _____
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 has been filed for recordation as set forth in 37 CFR 3.11. 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. The following fee(s) are submitted:
- ❑ Issue Fee
- ❑ Publication Fee (No small entity discount permitted)
- ❑ Advance Order - # of Copies _____

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
- ❑ A check is enclosed.
- ❑ Payment by credit card. Form PTO-2038 is attached.
- ❑ The director is hereby authorized to charge the required fee(s), any deficiency, or credits any overpayment, to Deposit Account Number _____ (enclose an extra copy of this form).

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 (10-13) Approved for use through 10/31/2013. OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

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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
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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005	2082

881 7590 04/23/2015

STITES & HARBISON PLLC
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SUITE 900
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	
ART UNIT	PAPER NUMBER
2897	

DATE MAILED: 04/23/2015

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.

PTOL-85 (Rev. 02/11)

Notice Requiring Inventor's Oath or Declaration	Application No. 13/767,290	Applicant(s) Shinji YUASA	
	Examiner CHAMBLISS, ALONZO	Art Unit 2897	

This notice is an attachment to the Notice of Allowability (PTOL-37), or the Notice of Allowability For A Design Application (PTOL-37D).

An inventor's oath or declaration in compliance with 37 CFR 1.63 or 1.64 executed by or with respect to each inventor has not yet been submitted.

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 inventor (for any inventor for which a compliant oath, declaration, or substitute statement has not yet been submitted) MUST be filed no later than the date on which the issue fee is paid. See 35 U.S.C. 115(f). Failure to timely comply will result in ABANDONMENT of this application.

A properly executed inventor's oath to declaration has not been received for the following inventor(s):

If applicant previously filed one or more oaths, declarations, or substitute statements, applicant may have received an informational notice regarding deficiencies therein.

The following deficiencies are noted:

INFORMAL ACTION PROBLEMS

- A properly executed inventor's oath or declaration has not been received for the following inventor(s): **Shinji YUASA**.
  Applicant may submit the inventor's oath or declaration at any time before the Notice of Allowance and Fee(s) Due, PTOL-85, is mailed.

Questions relating to this Notice should be directed to the Application Assistance Unit at 571-272-4200.

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 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, 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. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to 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)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Notice of Allowability	Application No. 13/767,290	Applicant(s) YUASA, SHINJI	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	AIA (First Inventor to File) Status No

-- 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 RCE filed on 3/25/15*.
   ☐ 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 and 5*. 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. *10/591,947* .
      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 3/25/15
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 *see Detailed Action*.

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DETAILED ACTION

1. The present application is being examined under the pre-AIA first to invent provisions.

Continued Examination Under 37 CFR 1.114

2. A request for continued examination under 37 CFR 1.114, including the fee set forth in 37 CFR 1.17(e), was filed in this application after final rejection. Since this application is eligible for continued examination under 37 CFR 1.114, and the fee set forth in 37 CFR 1.17(e) has been timely paid, the finality of the previous Office action has been withdrawn pursuant to 37 CFR 1.114. Applicant's submission filed on 3/25/15 has been entered.

Information Disclosure Statement

3. The information disclosure statement (IDS) submitted on 3/25/15 was filed before the mailing date of the notice of allowance on 4/14/15. The submission is in compliance with the provisions of 37 CFR 1.97. Accordingly, the information disclosure statement is being considered by the examiner.

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."

Any inquiry concerning the communication or earlier communications from the examiner should be directed to Alonzo Chambliss whose telephone number is (571) 272-1927.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Fernando L. Toledo can be reached on (571) 272-1867. 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 PMR or Public PMR. Status information for unpublished applications is available through Private PMR only. For more information about the PMR system see http://pair-kect.uspto.gov. Should you have questions on access to the Private PMR system contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free) or EBC_Support@uspto.gov.

AC/April 14, 2015 /Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Customized PTO/SB/08a+b (07-09)

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	13/767,290
	Confirmation #	2082
	Filing Date	February 14, 2013
	First Inventor	YUASA
	Art Unit	2897
	Examiner	Chamblis, Alonzo
Sheet 1 of 1	Docket #	NAGI-0005

U.S. PATENT DOCUMENTS				
Initial (*)	**Document No.** Number – Kind Code	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Corresponds to**
	US-2003/0203189	10-30-2003	FUTAMOTO et al.	JP2001023140
	US-2004/0001372	01-01-2004	HIGO et al.	JP2004031694
	US-6,819,586	11-16-2004	ANTHONY et al.	
	US-2005/0047027	03-03-2005	LIN, et al.	

FOREIGN PATENT DOCUMENTS				
Initial (*)	**Country-Number-Kind Code** if known	**Publ. Date** MM-DD-YYYY	**Name** Patentee or Applicant	**Trans-lation**
	JP2004022599 (A)	01-22-2004	MIZUGUCHI TETSUA et al.	Yes

NON PATENT LITERATURE DOCUMENTS		
Exam. Initial*	Include NAME of the author (in CAPS), Title of Article/Item, Date, Page(s), Volume-Issue No., Publisher, City and/or Country where published	**Trans-lation**
	SHANG, et al "The First-principles Study of Electronic Structure of Fe/MgO/Fe Magnetic Tunnel Junctions Interface", 2005, pp.2255-2258, vols. 475-479, Materials Science Forum	
	MEYERHEIM, et al "Surface X-Ray Diffraction Analysis of the MGO/FE(001) Interface: Evidence for an FEO Layer", 2002, pp. 144433-1- 144433-7, vol. 65, Physical Review	
	DJAYAPRAWIRA, et al, "230% Room-Temperature Magnetoresistance in COFEB/MGO/COFEB Magnetic Tunnel Junctions" 2005, pp. 092502-1 – 092502-3, vol. 86, Appl. Phys. Lett.	
	MIYOKAWA, et al., "X-Ray Absorption and X-Ray Magnetic Circular Dichroism Studies of a Monatomic FE(001) Layer Facing a Single-Crystalline", 2005, pp. L9-L11, vol. 44, no. 1, Japanese Journal of Applied Physics	
	KLAUA, et al, "Growth, Structure, Electronic, and Magnetic Properties of MGO/FE(001) Bilayers and FE/MGO/FE(001) Trilayers" 2001, vol. 64, pp. 134411-1 – 134411-8, Physical Review B	
	MITANI, et al, "FE/MGO/FECO(100) Expitaxial Magnetic Tunnel Junctions Prepared by Using in situ Plasma Oxidation" May 15, 2003, pp. 8041-8043, vo. 93, no. 10, parts 2 & 3, J. Appl. Phys.	
	YUASA, et al, "Giant Room-Temperature Magnetoresistance in Single-Crystal FE/MGO/FE Magnetic Tunnel Junctions" December 2004, pp. 868-871, vol. 3, Nature materials	
	NOZAKI, et al, "Bias Voltage Effect on Tunnel Magnetoresistance in Fully Epitaxial MGO Double-Barrier Magnetic Tunnel Junctions" 2005, pp. 082501-1-082501-3, vol. 86, Appl. Phys. Lett.	

2355LT:00005:346994:1:ALEXANDRIA

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /AC/

	BUTLER, et al. "Spin-Dependent Tunneling and Conductance of FE/MGO/FE Sandwiches", 2001, pp. 054416-1 – 054416-11, vol. 63, Physical Review	
	ZHANG, et al, "Large Magnetoresistance in BCC. CO/MGO/CO and FECO/MGO/FECO Tunneling Junctions", November 17, 2012, pp. 1-9	
	BOUBETA, et al "Magnetization Reversal and Magnetic Anisotropies in Epitaxial FE/MGO and Fe/MgO/Fe heterostructures grown on Si(001)", February 15, 2003, pp. 2126-2134, vol. 93, no. 4, J. Appl. Phys.	

Examiner Signature	/Alonzo Chambliss/ (04/14/2015)	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 the applicant.*

2355LT:00005:346994:1:ALEXANDRIA

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /AC/

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	56	"20030203189" "20040001372" "6,819,586" "20050047027"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2015/04/14 00:08
L2	10	(("20030203189") or ("20040001372") or ("6,819,586") or ("20050047027")).PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2015/04/14 00:08
L3	216	ferromagnetic with crystalliz$5 same (heat anneal$3)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2015/04/14 00:23
L5	308	ferromagnetic with crystalliz$5 same (heat$3 anneal$3)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2015/04/14 00:34
L6	105	5 AND ((H01L43/08 OR B82Y10/00 OR H01L27/11507 OR H01L28/55 OR H01L27/22 OR G11C11/16 OR G11C11/15 OR G11C11/161).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2015/04/14 00:39
L7	107	5 AND ((H01L43/08 OR B82Y10/00 OR H01F10/3254 OR H01F10/132 OR G11C11/16 OR G11C11/15 OR G11C11/161).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2015/04/14 00:45

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L9	239	ferromagnetic with crystalliz$5 same (heat$3 anneal$3)	US-PGPUB; USPAT; UPAD	OR	ON	2015/04/14 00:45

4/14/2015 12:46:11 AM
C:\Users\achambliss\Documents\EAST\Workspaces\13870490.wsp

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Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA ET AL.
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC- SEARCHED		
Symbol	Date	Examiner
H01L43/12,43/10, 27/222; H01F10/132, 10/3254, 10/16; B82Y25/00, 10/00	10/26/14	AC
H01F10/132, 10/3254; G11C11/161, 11/15; H01L28/55, 27/11507, 27/22; B82Y10/00	4/14/15	AC

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner

SEARCH NOTES		
Search Notes	Date	Examiner
East text search only - see attached printout	7/3/13	AC
Updated previous East text search only - see attached printout	12/18/13	AC
Updated previous East text search only - see attached printout	5/4/14	AC
Updated previous East text search only - see attached printout	10/26/14	AC
Updated previous East text search only - see attached printout	4/14/15	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner
H01F	10/132, 10/3254	4/14/15	AC
G11C	11/161, 11/15	4/14/15	AC
H01L	28/55, 27/11507, 27/22	4/14/15	AC
B82Y	10/00	4/14/15	AC
257	288,295,427	4/14/15	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	**US Subclass / CPC Group**	**Date**	**Examiner**
365	171	4/14/15	AC
438	3	4/14/15	AC

CPC Issue Classification - Application Number: 13767290

Examiner: Alonzo Chambliss **Date Created:** Apr 14, 2015 12:53 AM

Family ID: 34975880

US App. No. (5) & Documents (8): 13/767290 (20130228883 A1), 13/400340 (20120161262 A1, 8405134 B2), 12/923643 (20110031570 A1, 8319263 B2), 12/659827 (20100181632 A1), 10/591947 (20070195592 A1, 7884403 B2)

Foreign Documents (19): JP2012033957A, WO2005088745A8, JP2012039144A, EP1737055A1, JP2012054577A, EP1737055B1, JP2012151494A, JP4963744B2, KR100867662B1, JP5120680B2, JP2009021626A, WO2005088745A1, TW200531323A, TWI334663B, KR20060122970A, EP1737055A4, JP5152734B2, JP5002788B2, JP4082711B2

Allocations (8)

No.	Symbol	Type			Endorsed By	CPC Version
1	H01F 10/3254	F			EP	2013-01-01
2	H01L 43/10	I			US	2013-01-01
3	H01L 43/08	I			EP	2013-01-01
4	B82Y 25/00	I			EP	2013-01-01
5	H01L 43/12	I			EP	2013-01-01
6	H01L 27/228	I			EP	2013-01-01
7	G11C 11/16	I			EP	2013-01-01
8	B82Y 10/00	A			EP	2013-01-01

Combination Sets (0)

No.	Symbol	Type	Set	Rank	Endorsed By	CPC Version

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA, SHINJI
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

CPC						
Symbol					**Type**	**Version**
H01F		10	/	3254	F	2013-01-01
H01F		10	/	132	I	2013-01-01
G11C		11	/	15	I	2013-01-01
H01L		28	/	55	I	2013-01-01
H01L		27	/	22	A	2013-01-01
H01L		27	/	11507	I	2013-01-01
B82Y		10	/	00	A	2013-01-01
B82Y		25	/	00	I	2013-01-01
G11C		11	/	16	I	2013-01-01
H01L		27	/	228	I	2013-01-01
H01L		43	/	08	I	2013-01-01
H01L		43	/	12	I	2013-01-01
H01L		43	/	10	I	2013-01-01
			/			
			/			

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

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	2	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897	4/15/15	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1B

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA, SHINJI
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

US ORIGINAL CLASSIFICATION		INTERNATIONAL CLASSIFICATION												
CLASS	SUBCLASS	CLAIMED					NON-CLAIMED							
257	295	H	0	1	L	21 / 02 (2006.0)								
CROSS REFERENCE(S)		H	0	1	L	21 / 00 (2006.0)								
		G	1	1	C	11 / 14 (2006.01.01)								
CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)													
257	427													
438	3													
365	171													

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 2	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897 (Primary Examiner)	4/15/15 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1B

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Page 368

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13767290	YUASA, SHINJI
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

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

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1														
	2														
	3														
	4														
2	5														

NONE (Assistant Examiner) (Date)	**Total Claims Allowed:** 2	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897 4/15/15 (Primary Examiner) (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1B

IN THE U.S. PATENT AND TRADEMARK OFFICE

U.S. Appl. No.:	13/767,290	Confirmation No.:	2082
Title:	MAGNETIC TUNNEL JUNCTION DEVICE		
Inventor(s):	YUASA, Shinji		
Filed:	February 14, 2013		
Art Unit:	2897		
Examiner:	Chambliss, Alonzo		
Docket No.:	NAGI-0005/NBT		
Customer No.:	000881		

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

Submission of Oath/Declaration

Honorable Commissioner:

In response to the Notice Requiring Inventor's Oat or Declaration (PTO-2306) received on April 23, 2015 with the Notice of Allowance and in compliance with 37 CFR 1.63, Applicants submit herewith the Oath/Declaration in the above-identified application. It will be noted that the Surcharge for Late Filing of the Oath was charged to our Deposit Account on September 16, 2013.

Further and favorable action is requested.

Respectfully submitted,

Date: July 8, 2015

Nicholas Trenkle

By: Nicholas Trenkle
Registration No.: 54,500

STITES & HARBISON PLLC ◆ 1199 North Fairfax St. ◆ Suite 900 ◆ Alexandria, VA 22314
TEL: 703-739-4900 ◆ FAX: 703-739-9577 ◆ CUSTOMER NO. 000881

2355LT:00005:361263:1:ALEXANDRIA

Doc Code: OATH • Document Description: Oath or declaration filed — Customized PTOAIA/08 (08-12)

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63) – and POWER *[NOTE: Earliest of US or PCT application filing date must be on or after September 16, 2012]* ☐ Declaration Submitted with Initial Filing ☒ Declaration Submitted after Initial Filing		
	Docket No.	NAGI-0005
	1st Inventor	YUASA
		COMPLETE IF KNOWN
	Appl. No.	*13/767,290*
	Filing Date	*February 14, 2013*
	Art Unit	2897
	Examiner	Chambliss, Alonzo

TITLE OF INVENTION	Magnetic Tunnel Junction Device

As the below named inventor(s), I hereby declare that:

This declaration is directed to:

☐ The attached application,

☒ US Application No. 13/767,290
filed on February 14, 2013

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than (5) years, or both.

Further, I have reviewed and understand the contents of the above-identified application; and I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

LEGAL NAME OF SOLE OR FIRST INVENTOR			
Given Name (First and Middle (if any))	Shinji	FAMILY NAME or SURNAME	YUASA
Full Mailing Address	c/o National Institute of Advanced Industrial Science and Technology Tsukuba Central 2, 1-1, Umezono 1-chome, Tsukuba-shi, Ibaraki, 305-8568, JAPAN		
Residence - City, State, Country (if different from mailing address)	"same as above"		
SIGN AND DATE HERE	Inventor's Signature Shinji Yuasa	Date	26. May 2015

☐ *Additional inventors named on supplemental sheet provided herewith*

2355LT:00005;323562;1;ALEXANDRIA

Electronic Acknowledgement Receipt

EFS ID:	22860458
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Billy Aaron Schulman/Stacy Johnson
Filer Authorized By:	Billy Aaron Schulman
Attorney Docket Number:	NAGI-0005
Receipt Date:	08-JUL-2015
Filing Date:	14-FEB-2013
Time Stamp:	16:29:29
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		NAGI_0005Letter_Declaration.pdf	105737 ad47e5faacf12d5fbfd355dc1434e925b8651271	yes	2

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Transmittal Letter	1	1
	Oath or Declaration filed	2	2
Warnings:			
Information:			
	Total Files Size (in bytes):	105737	

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.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
or Fax (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

881 7590 04/23/2015
STITES & HARBISON PLLC
1199 NORTH FAIRFAX STREET
SUITE 900
ALEXANDRIA, VA 22314

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

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 facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/767,290	02/14/2013	Shinji YUASA	NAGI-0005	2082

TITLE OF INVENTION: Magnetic Tunnel Junction Device

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	07/23/2015

EXAMINER	ART UNIT	CLASS-SUBCLASS
CHAMBLISS, ALONZO	2897	257-295000

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/SB/47; Rev 03-02 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 **Nicholas Trenkle**
2 **Stites & Harbison, PLLC.**
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 has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

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

1) JAPAN SCIENCE AND TECHNOLOGY AGENCY Saitama, JAPAN
2) NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY Tokyo, JAPAN

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

4a. The following fee(s) are submitted:
☒ Issue Fee
☐ Publication Fee (No small entity discount permitted)
☐ Advance Order - # of Copies _____

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
☐ A check is enclosed.
☒ Payment by credit card. Form PTO-2038 is attached.
☒ The director is hereby authorized to charge the required fee(s), any deficiency, or credits any overpayment, to Deposit Account Number **12-0555** (enclose an extra copy of this form).

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 Nicholas Trenkle Date July 20, 2015
Typed or printed name **Nicholas Trenkle** Registration No. **54,500**

PTOL-85 Part B (10-13) Approved for use through 10/31/2013. OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

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Western Digital v IP Bridge
Page 374

Electronic Patent Application Fee Transmittal

Application Number:	13767290
Filing Date:	14-Feb-2013
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Billy Aaron Schulman/Stacy Johnson
Attorney Docket Number:	NAGI-0005

Filed as Large Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Utility Appl Issue Fee	1501	1	960	960

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**960**

Electronic Acknowledgement Receipt	
EFS ID:	22966560
Application Number:	13767290
International Application Number:	
Confirmation Number:	2082
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Billy Aaron Schulman/Stacy Johnson
Filer Authorized By:	Billy Aaron Schulman
Attorney Docket Number:	NAGI-0005
Receipt Date:	20-JUL-2015
Filing Date:	14-FEB-2013
Time Stamp:	16:40:26
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$960
RAM confirmation Number	3726
Deposit Account	120555
Authorized User	STITES & HARBISON PLLC
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)	

Charge any Additional Fees required under 37 C.F.R. Section 1.19 (Document supply fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.20 (Post Issuance fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Issue Fee Payment (PTO-85B)	NAGI_0005IssueFeeTransmittal.pdf	109641 c302b400202e3ddc30b1dcada0c103a844488230	no	1
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	30458 ef50c3ea5eda5d4489f763a8af7e327945da0b25	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	140099		

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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.

Substitute for Form 1449/PTO	Application #	To Be Determined
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Confirmation #	
	Filing Date	Concurrently Herewith
	First Inventor	Yuasa
	Art Unit	
	Examiner	
Sheet 2 of 12	Docket #	NAGI.0005

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Exam. Initial*	Document No. Number – Kind Code	Publ. Date MM/DD/YYYY	Name Patentee or Applicant	Relevance Passages/Figs.
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Change(s) applied to document, /C.L./ 7/24/2015

Examiner Signature	/Alonzo Chambliss/ (07/02/2013)	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 the applicant.*

[4] Corresponds to JP 2004-12805 listed above
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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /AC/

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ISSUE NOTIFICATION

The projected patent number and issue date are specified above.

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 0 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 Application Information Retrieval (PAIR) WEB site (http://pair.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 Data Management (ODM) at (571)-272-4200.

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