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Application Number: 15428842 Document Date: 02/09/2017

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Doc Code: PA..
Document Description: Power of Attorney

PTO/AIA/82B (07-13)
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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)	Dec 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.

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

UTILITY PATENT APPLICATION TRANSMITTAL

(Nonprovisional application under 37 CFR 1.53(b))
(Filing date after Sept. 16, 2012)

Docket No.	P11338US02/NBT
1st Inventor	YUASA, Shinji
Title	MAGNETIC TUNNEL JUNCTION DEVICE

APPLICATION ELEMENTS and ACCOMPANYING APPLICATION PAPERS

- ☒ See Fee Determination Below
- ☒ Applicant asserts **small entity status**
- ☒ Specification [total pages = 27]
- ☒ Drawings [total sheets = 10]
- ☒ Inv. Oath or Declaration [total sheets = 1]
  - ☐ Newly executed (original or copy)
  - ☒ A Copy from a prior appl. *(for cont./div.)*
- ☒ Application Data Sheet
- ☐ Power of Attorney (PTO/AIA/82**B**) **and**
  - ☐ Transmittal for Power (PTO/AIA/82**A**)
- ☒ Power of Attorney **&** ☐ 37 CFR 3.37(c) Statement
- ☐ Power of Attorney – included with Declaration
- ☐ Information Disclosure Statement
- ☐ Preliminary Amendment
- ☐ Nonpublication Request
- ☐

CORRESPONDENCE ADDRESS – the address associated with CUSTOMER NUMBER **881**

☒ This is a CONTINUATION APPLICATION of prior Application No. US 14/837,558 (as noted in the ADS).

IF a petition for extension of time (EOT) is required in the prior application for copendency with the present application and IF that petition for EOT is not filed on this date or previously, applicant hereby petitions under 37 CFR §1.136(a) for an EOT in the prior application of as many months as are required to render this submission copending with the prior application. The Commissioner is authorized to charge any fee or additional fee due in connection with this request to Deposit Account No. 12-0555.

Further to Rule 1.57(a), the entire disclosure of the prior application is hereby incorporated by reference.

PATENT APPLICATION FEE DETERMINATION: as filed, including Preliminary Amendment if any

STATUS of Applicant is: ☐ MICRO ☐ SMALL ☒ LARGE

FEE FOR	CALCULATION	$	$	$	FEE DUE $
☒ BASIC - via EFS		70	70	280	280
☒ SEARCH		150	300	600	600
☒ EXAMINATION		180	360	720	720
☒ TOTAL CLAIMS	22 - 20 = 2 (extra)	× 20 =	× 40 =	× 80 =	160
☒ INDEP. CLAIMS	2 - 3 = 0 (extra)	× 105 =	× 210 =	× 420 =	0
☐ MUL. DEP. CLAIM	claims	195	390	780	
☐ APPL. SIZE	# × .75 – 100 = ?, extra 50s = ?	× 100 =	× 200 =	× 400 =	
				TOTAL	1760

☐ **No payment** is enclosed, and no charge should be made to our deposit account.

☒ **Payment** of **$1760** is made by **ELECTRONIC FUNDS TRANSFER** - submitted concurrently herewith.

If no payment or an insufficient payment is enclosed and a fee is due in connection herewith, the Director is authorized to charge any fee or additional fee due in connection herewith to Deposit Account No. 12-0555.

Attorney Name: Nick Trenkle
Registration No.: 54500
Telephone No.: 703-739-4900
Facsimile No.: 703-739-9577

Signed (for) by: /Stephen J. Weyer/
Registration No.: 43259
Date: February 9, 2017

STITES & HARBISON PLLC • 1800 Diagonal Road • Suite 325 • Alexandria, VA 22314

2355LT:10004:401967:1:ALEXANDRIA

PTO/AIA/14 (11-15)
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	P11338US02/NBT
	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	00881		
Email Address	iplaw@stites.com	Add Email	Remove Email

Application Information:

Title of the Invention	Magnetic Tunnel Junction Device		
Attorney Docket Number	P11338US02/NBT	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	10	**Suggested Figure for Publication (if any)**	

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	P11338US02/NBT
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

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	00881		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim 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.
When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	Continuation of	14837558	2015-08-27

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	P11338US02/NBT
	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)
US14837558	Continuation of	US13767290	2013-02-14	9123463	2015-09-01
Prior Application Status	Patented				Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)	Patent Number	Issue Date (YYYY-MM-DD)
US13767290	Continuation of	US13400340	2012-02-20	8405134	2013-03-26
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
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					Remove
Application Number	Continuity Type	Prior Application Number		Filing or 371(c) 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.					Add

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. 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. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)[i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

			Remove
Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)
2004-313350	JP	2004-10-28	
			Remove
Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)
2004-071186	JP	2004-03-12	
Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.			Add

PTO/AIA/14 (11-15)
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	P11338US02/NBT
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

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

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

PTO/AIA/14 (11-15)
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	P11338US02/NBT
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	P11338US02/NBT
	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 — Remove

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 For Applicant:			
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. Add

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	P11338US02/NBT
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

Applicant 2 Remove

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 For Applicant:			
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. Add

Assignee Information including Non-Applicant Assignee 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.

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

Remove

If the Assignee or Non-Applicant Assignee is an Organization check here. ☐

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	P11338US02/NBT
	Application Number	
Title of Invention	Magnetic Tunnel Junction Device	

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

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1			
Address 2			
City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button. Add

Signature:

Remove

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Stephen J. Weyer/			Date (YYYY-MM-DD)	2017-02-09
First Name	Stephen J.	Last Name	WEYER	Registration Number	43259

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

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.**

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 the Freedom of Information Act requires disclosure of these records.

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 CooperationTreaty.

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 inspections 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.

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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What is claimed is:

1. A magnetic tunnel junction (MTJ) device, comprising:

a first electrode comprising a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed over the first electrode, the barrier layer comprising a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented; and

a second electrode disposed over the barrier layer and comprising a second ferromagnetic material layer.

2. The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers is partially crystalized.

3. The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers is entirely crystalized.

4. The MTJ device of claim 1, wherein the second ferromagnetic material layer includes Co, Fe, and B.

5. The MTJ device of claim 2, wherein the second ferromagnetic material layer includes Co, Fe, and B.

6. The MTJ device of claim 3, wherein the second ferromagnetic material layer includes Co, Fe, and B.

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7. The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

8. The MTJ device of claim 4, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

9. The MTJ device of claim 5, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

10. The MTJ device of claim 6, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

11. The MTJ device of claim 1, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

12. The MTJ device of claim 11, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device 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 barrier layer,

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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 Planck's constant, Δs is an effective thickness of the barrier layer that is approximately equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer determined using a cross-sectional transmission electron microscope image.

13. The MTJ device of claim 1, wherein the MgO layer includes oxygen vacancy defects.

14. The MTJ device of claim 14, wherein a value of x in MgO_x for the MgO layer due to the oxygen vacancy defects is greater than 0.9 and less than 1.

15. A magnetic tunnel junction (MTJ) device, comprising:
a first electrode made of a first CoFeB layer;
a barrier layer made of a magnesium oxide (MgO) layer that is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented; and
a second electrode made of a second CoFeB layer, and
wherein the barrier layer is located between the first electrode and the second electrode.

16. The MTJ device of claim 15, wherein each of the first and second CoFeB layers is partially crystalized.

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17. The MTJ device of claim 15, wherein each of the first and second CoFeB layers is entirely crystalized.

18. The MTJ device of claim 15, wherein each of the first and second CoFeB layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

19. The MTJ device of claim 15, wherein a barrier height φ of the MgO layer is in a range of 0.2 to 0.5 eV.

20. The MTJ device of claim 19, wherein the barrier height φ of the MgO layer is obtained by fitting J-V characteristics of the MTJ device 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 MgO 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 Planck's constant, Δs is an effective thickness of the MgO layer that is approximately equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the MgO layer determined using a cross-sectional transmission electron microscope image.

21. The MTJ device of claim 15, wherein the MgO layer includes oxygen vacancy defects.

22. The MTJ device of claim 19, wherein the MgO layer includes oxygen

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vacancy defects.

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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 14/837,558 filed on August 27, 2015, which is a Continuation of U.S. Application 13/767,290 filed on February 14, 2013, which 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 13/767,290 filed on February 14, 2013, which claims priority 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 antiparallel as shown in Fig. 8(B), the electric

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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 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.

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[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%, 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

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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 ($0 < x < 1$) 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

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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.

[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.

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[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 $\times$ (Rap-Rp)/Rap).

[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.

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[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 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

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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)

[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

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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 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

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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).

[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.

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[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. 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

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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.

[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

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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 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

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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. 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

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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 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.

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[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 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

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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 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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FIG. 1 (A)

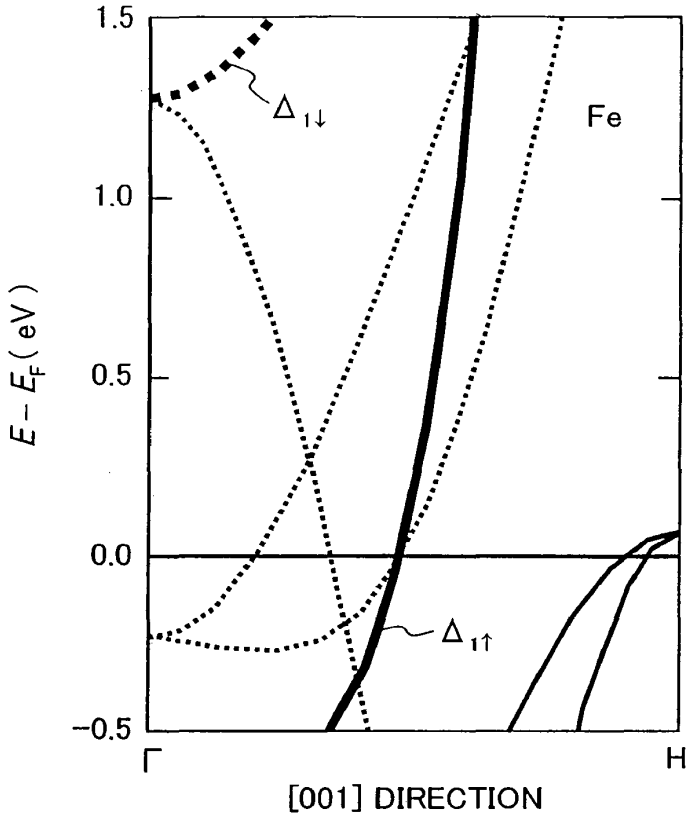

1.5
1.0
0.5
0.0
−0.5
$E - E_F$ (eV)
$\Delta_{1\downarrow}$
$\Delta_{1\uparrow}$
Fe
Γ
H
[001] DIRECTION

FIG. 1 (B)

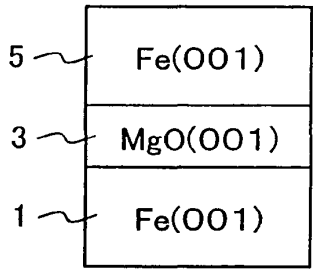

5
Fe(001)
3
MgO(001)
1
Fe(001)

FIG. 2 (A)

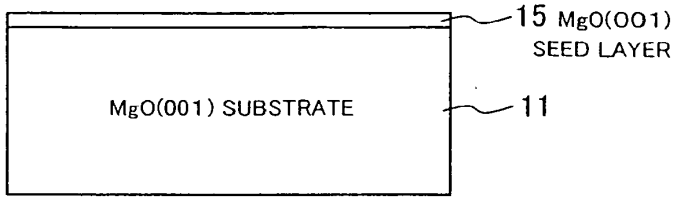


FIG. 2 (B)

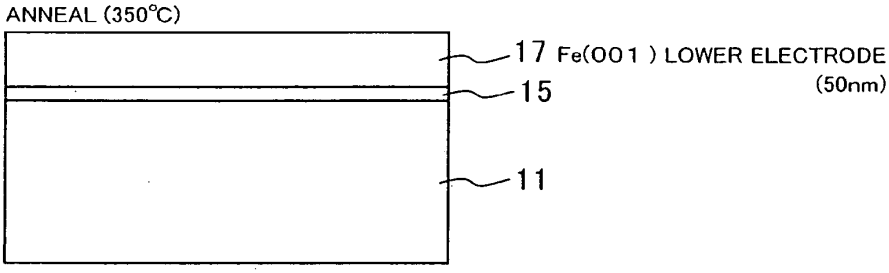


FIG. 2 (C)

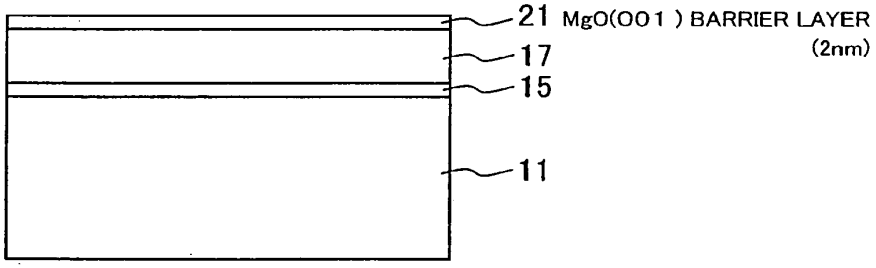


FIG. 2 (D)

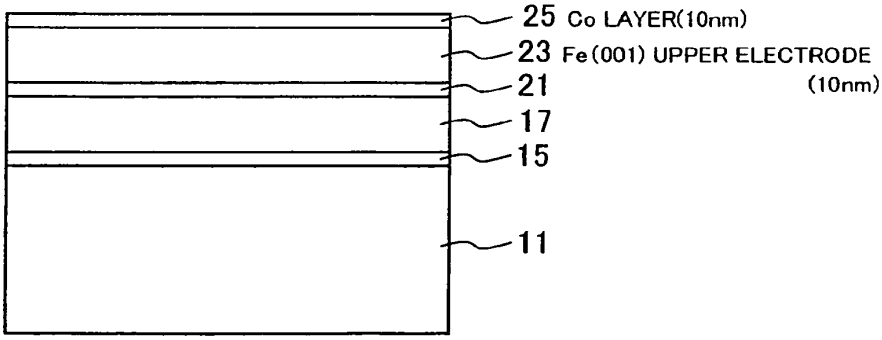


FIG. 3 (A)

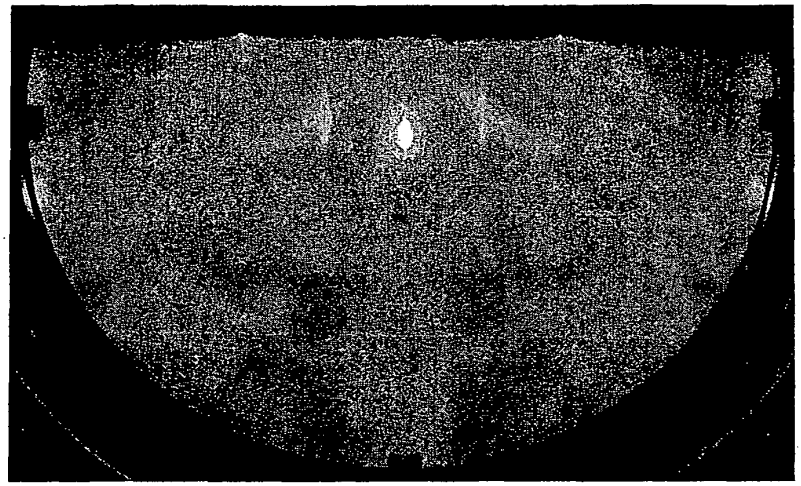


FIG. 3 (B)

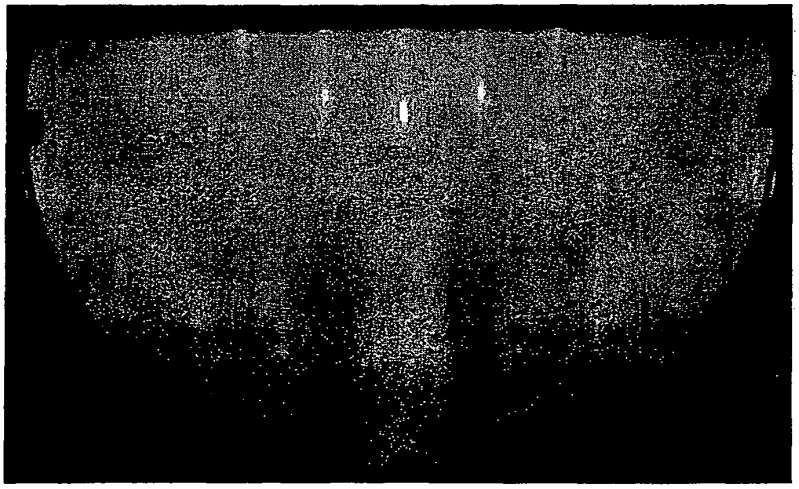
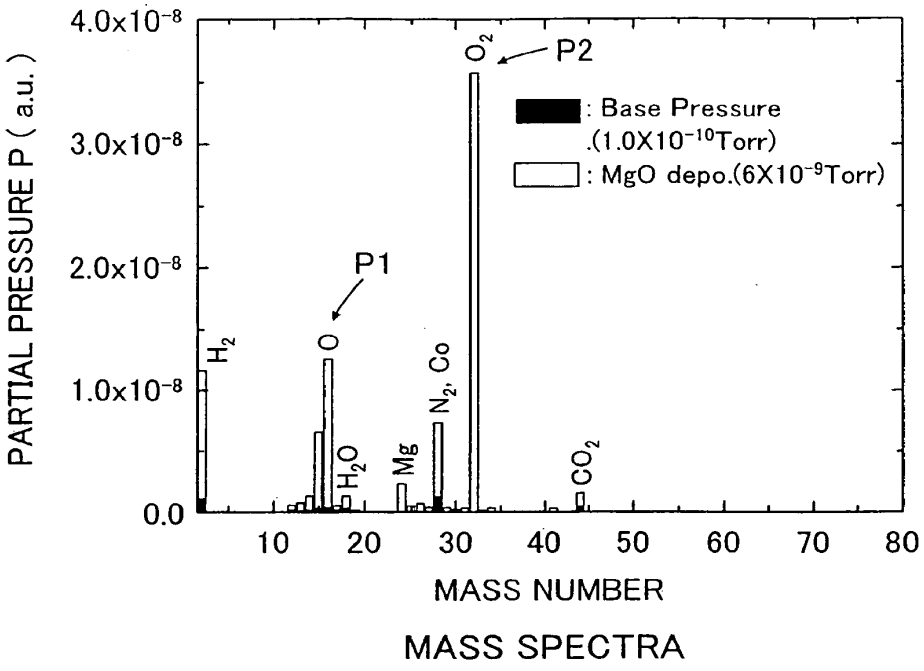
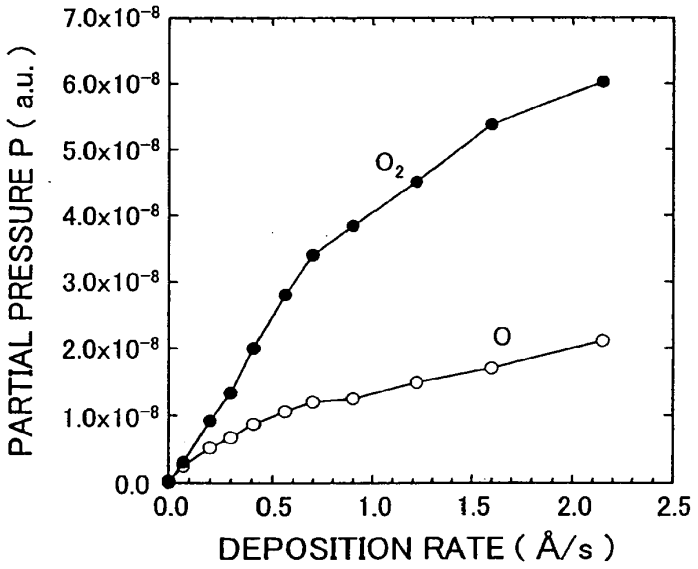


FIG. 4



MASS SPECTRA

FIG. 5



OXYGEN PARTIAL PRESSURE DURING MgO EVAPORATION

FIG. 6

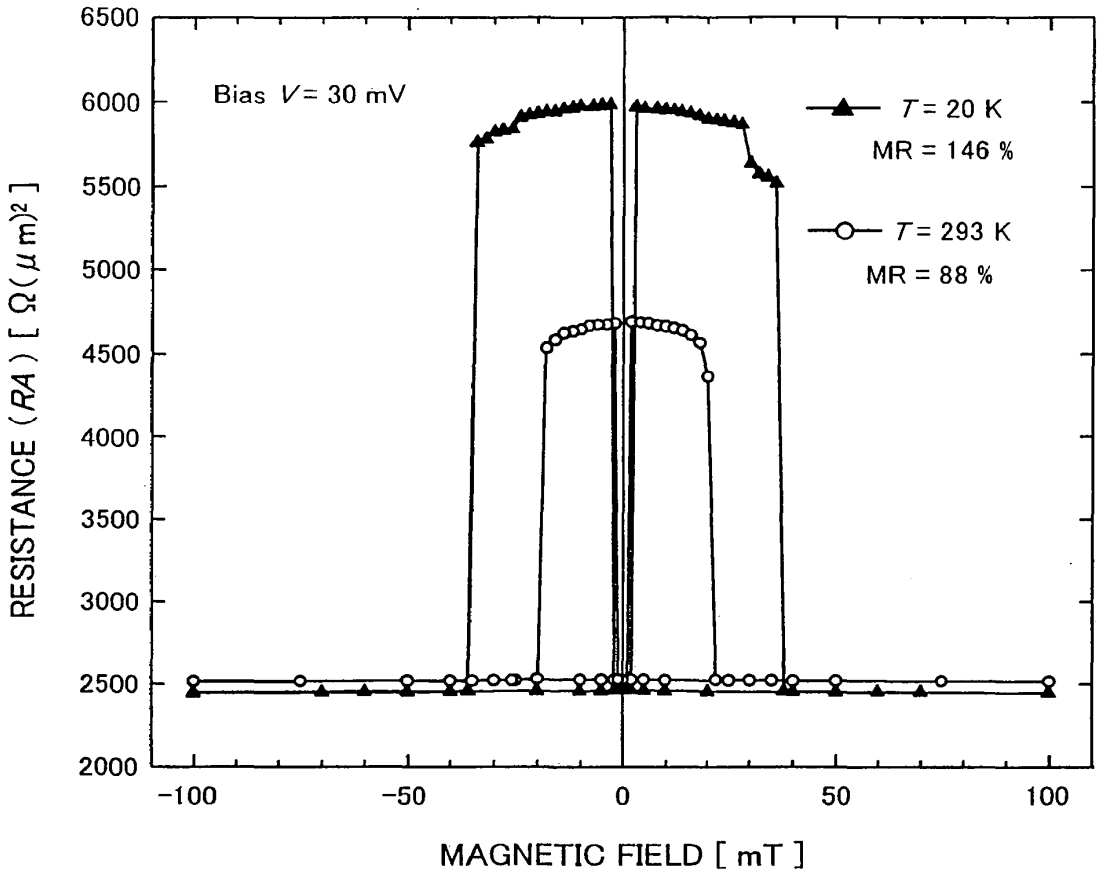

Bias V = 30 mV
T = 20 K
MR = 146 %
T = 293 K
MR = 88 %
RESISTANCE (RA) [Ω(μm)²]
MAGNETIC FIELD [mT]
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
−100
−50
0
50
100

FIG. 7 (A)

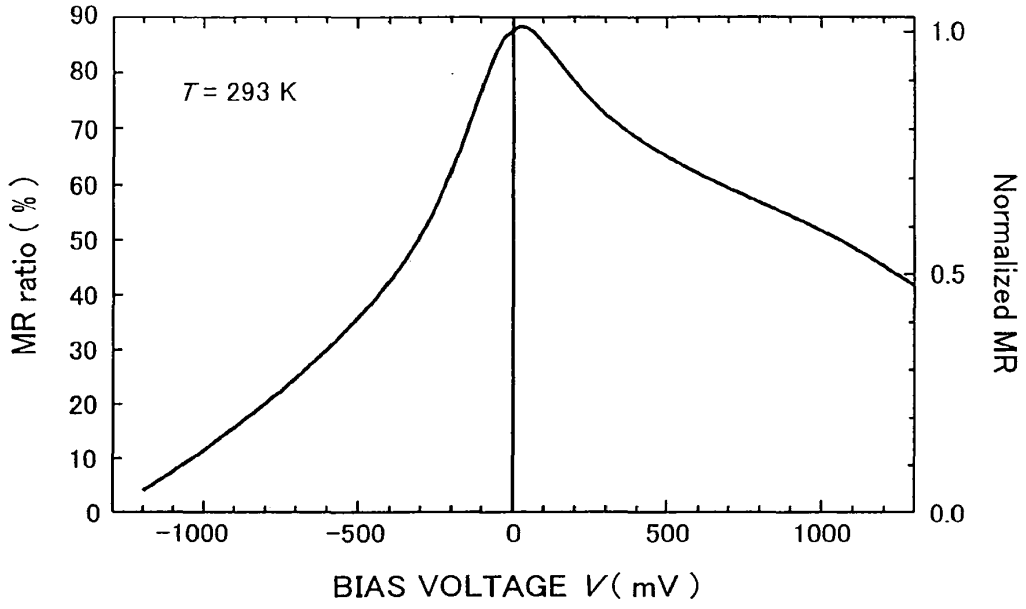

T = 293 K
MR ratio (%)
Normalized MR
BIAS VOLTAGE V(mV)
90
80
70
60
50
40
30
20
10
0
1.0
0.5
0.0
−1000
−500
0
500
1000

FIG. 7 (B)

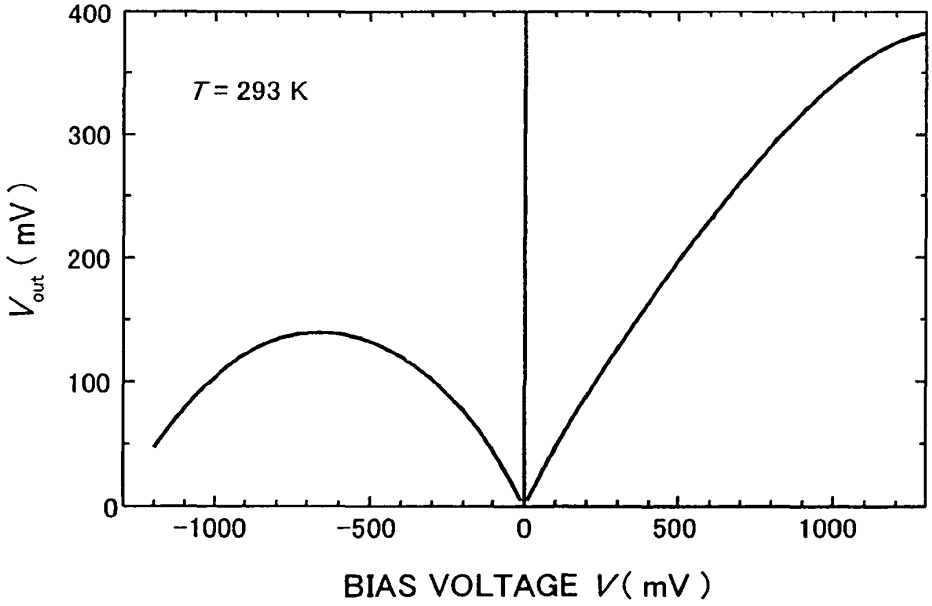
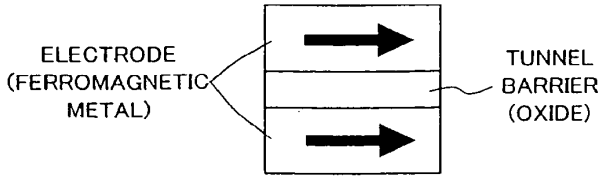
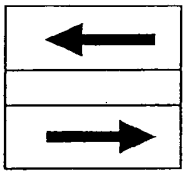

T = 293 K
V_{out} (mV)
BIAS VOLTAGE V(mV)
400
300
200
100
0
−1000
−500
0
500
1000

FIG. 8 (A)



Prior Art

FIG. 8 (B)



Prior Art

FIG. 9 (A)

Prior Art

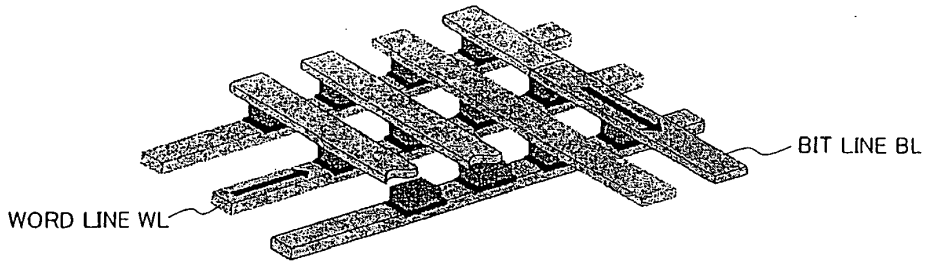


FIG. 9 (B)

Prior Art

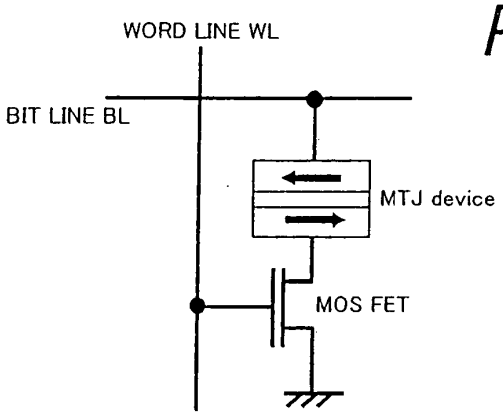
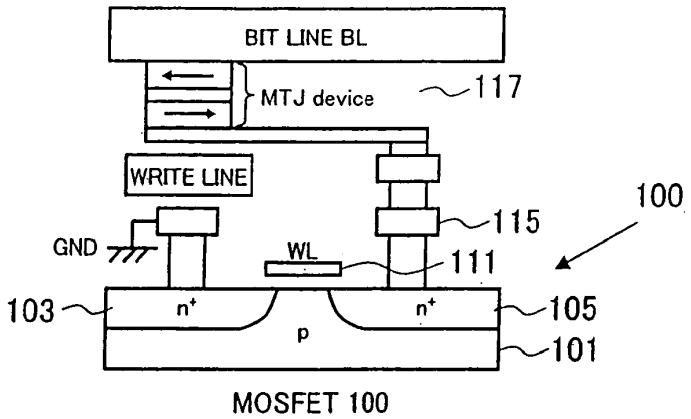


FIG. 9 (C)

Prior Art



MOSFET 100

FIG. 10

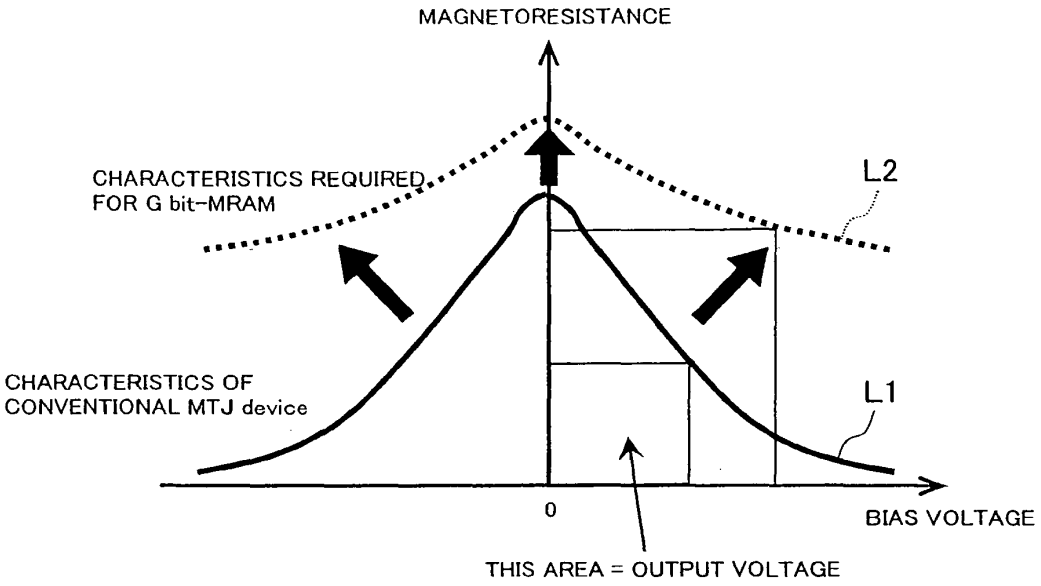
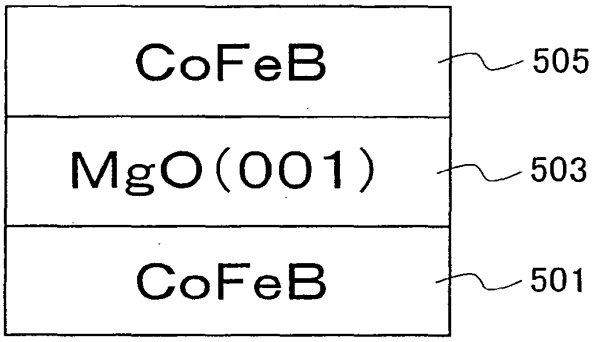

MAGNETORESISTANCE
CHARACTERISTICS REQUIRED FOR G bit-MRAM
L2
CHARACTERISTICS OF CONVENTIONAL MTJ device
L1
0
BIAS VOLTAGE
THIS AREA = OUTPUT VOLTAGE

FIG. 11



Doc Code: OATH • Document Description: Oath or declaration filed — Customized PTO/AIA/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

Doc Code: PA..
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PTO/AIA/82B (07-13)
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Application Number	Filing Date

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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.)

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OR

Firm or Individual Name					
Address					
City		State		Zip	
Country					
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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.

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Application Number	New Application
Filing Date	On Even Date Herewith
First Named Inventor	YUASA
Title	Magnetic Tunnel Junction Device
Art Unit	
Examiner Name	
Attorney Docket Number	P11338US01/NBT

SIGNATURE of Applicant or Patent Practitioner

Signature	/B. Aaron Schulman/	Date (Optional)	August 27, 2015
Name	B. Aaron Schulman	Registration Number	31877
Title (if Applicant is a juristic entity)			
Applicant Name (if Applicant is a juristic entity)			

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Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Stephen John Weyer/Gregory Kleitsch
Attorney Docket Number:	P11338US02/NBT

Filed as Large Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
UTILITY APPLICATION FILING	1011	1	280	280
UTILITY SEARCH FEE	1111	1	600	600
UTILITY EXAMINATION FEE	1311	1	720	720
Pages:				
Claims:				
CLAIMS IN EXCESS OF 20	1202	2	80	160
Miscellaneous-Filing:				
Petition:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		1760

Electronic Acknowledgement Receipt	
EFS ID:	28315661
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Stephen John Weyer/Gregory Kleitsch
Filer Authorized By:	Stephen John Weyer
Attorney Docket Number:	P11338US02/NBT
Receipt Date:	09-FEB-2017
Filing Date:	
Time Stamp:	16:56:34
Application Type:	Utility under 35 USC 111(a)

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RAM confirmation Number	021017INTEFSW16571900
Deposit Account	120555
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37 CFR 1.19 (Document supply fees)

37 CFR 1.20 (Post Issuance fees)

37 CFR 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	Transmittal of New Application	P11338US02_UTILITY_TRANSMITTAL.pdf	158866 abfaad543e7303db250f5884eeb6522d51aa2745	no	1
Warnings:					
Information:					
2	Application Data Sheet	P11338US02_UTILITY_ADS.pdf	1880917 b451ac7855cfb1800d8b11999938e79e25039af9	no	9
Warnings:					
Information:					
3		P11338US02_UTILITY_SPEC.pdf	173626 4b27ca59f6442c4e918d1861d55f2ff2ab081337	yes	27

Multipart Description/PDF files in .zip description

Document Description	Start	End
Abstract	27	27
Claims	22	26
Specification	1	21

Warnings:					
Information:					
4	Drawings-other than black and white line drawings	P11338US02_UTILITY_FIGURES.pdf	279249 72c27f09d4ff9f9faf15131941c283b16fb393c4	no	10
Warnings:					
Information:					
5	Oath or Declaration filed	P11338US02_UTILITY_DECLARATION.pdf	71534 cdac0aea359ed37a63f05b00cd1ead9c7f9a0554	no	1

Warnings:					
Information:					
6		P11338US02_UTILITY_POAS.pdf	387581 038ac0cf3960e22d563ba571929bca2e569c9110	yes	3

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Power of Attorney	3	3
	Power of Attorney	2	2
	Transmittal Letter	1	1

Warnings:					
Information:					
7	Fee Worksheet (SB06)	fee-info.pdf	36844 5df0680a84be8789b4b17e7df3f4c2d698efba21	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	2988617		

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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: 15/428,842

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))	22 minus 20 =	* 2			OR	x 80 =	160
INDEPENDENT CLAIMS (37 CFR 1.16(h))	2 minus 3 =	*				x 420 =	0.00
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).						0.00
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							0.00
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL			TOTAL	1760

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	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
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
15/428,842	02/09/2017	2827	1760	P11338US02/NBT	22	2

CONFIRMATION NO. 9576

881
STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

FILING RECEIPT

OC000000089318075

Date Mailed: 02/21/2017

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

Power of Attorney: The patent practitioners associated with Customer Number 00881

Domestic Priority data as claimed by applicant

This application is a CON of 14/837,558 08/27/2015
which is a CON of 13/767,290 02/14/2013 PAT 9123463
which 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

Permission to Access Application via Priority Document Exchange: Yes

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If Required, Foreign Filing License Granted: 02/16/2017

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 15/428,842**

Projected Publication Date: 06/01/2017

Non-Publication Request: No

Early Publication Request: No

Title

Magnetic Tunnel Junction Device

Preliminary Class

365

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT

CONFIRMATION NO. 9576

881
STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

PUBLICATION NOTICE

OC000000091774986

Title: Magnetic Tunnel Junction Device

Publication No.US-2017-0155042-A1
Publication Date:06/01/2017

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.

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

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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):	国立研究開発法人科学技術振興機構 国立研究開発法人産業技術総合研究所

２０１７年　６月　６日

特許庁長官
Commissioner,
Japan Patent Office

小宮義則

【書類名】　特許願
【整理番号】　P04-1160
【提出日】　平成16年10月28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
　つくばセンター内
　【氏名】　湯浅　新治
【特許出願人】
　【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
【特許出願人】
　【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
【選任した代理人】
　【識別番号】　100105463
　【弁理士】
　【氏名又は名称】　関谷　三男
【選任した代理人】
　【識別番号】　100102576
　【弁理士】
　【氏名又は名称】　渡辺　敏章
【選任した代理人】
　【識別番号】　100108394
　【弁理士】
　【氏名又は名称】　今村　健一
　【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、
$P\alpha=(D\alpha\uparrow(E_F)-D\alpha\downarrow(E_F))/(D\alpha\uparrow(E_F)+D\alpha\downarrow(E_F))$、$\alpha=1,2$　（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$Fe\Delta_1$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^{-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。

【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ｋΩμm^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。

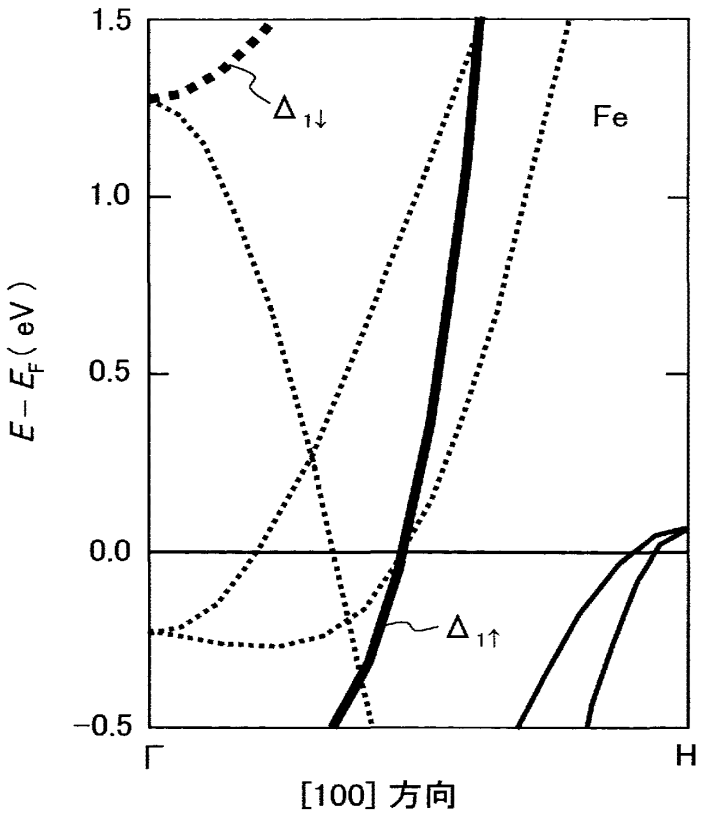
【符号の説明】

【００３３】

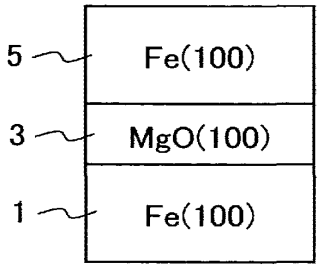
１…第１のＦｅ（１００）層、３…単結晶$ＭｇＯ_{x}$（１００）あるいは（１００）結晶面が優先配向した多結晶$ＭｇＯ_{x}$層（０＜ｘ＜１）、５…第２のＦｅ（１００）層、１１…単結晶$ＭｇＯ_{x}$（１００）あるいは（１００）結晶面が優先配向した多結晶$ＭｇＯ_{x}$基板（０＜ｘ＜１）、１５…ＭｇＯ（１００）シード層、１７…エピタキシャルＦｅ（１００）下部電極（第１電極）、２１…ＭｇＯバリア層（１００）、２３…エピタキシャルＦｅ（１００）上部電極（第２電極）、５０３…単結晶$ＭｇＯ_{x}$（００１）あるいは（００１）結晶面が優先配向した多結晶$ＭｇＯ_{x}$層（０＜ｘ＜１）、５０１…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】

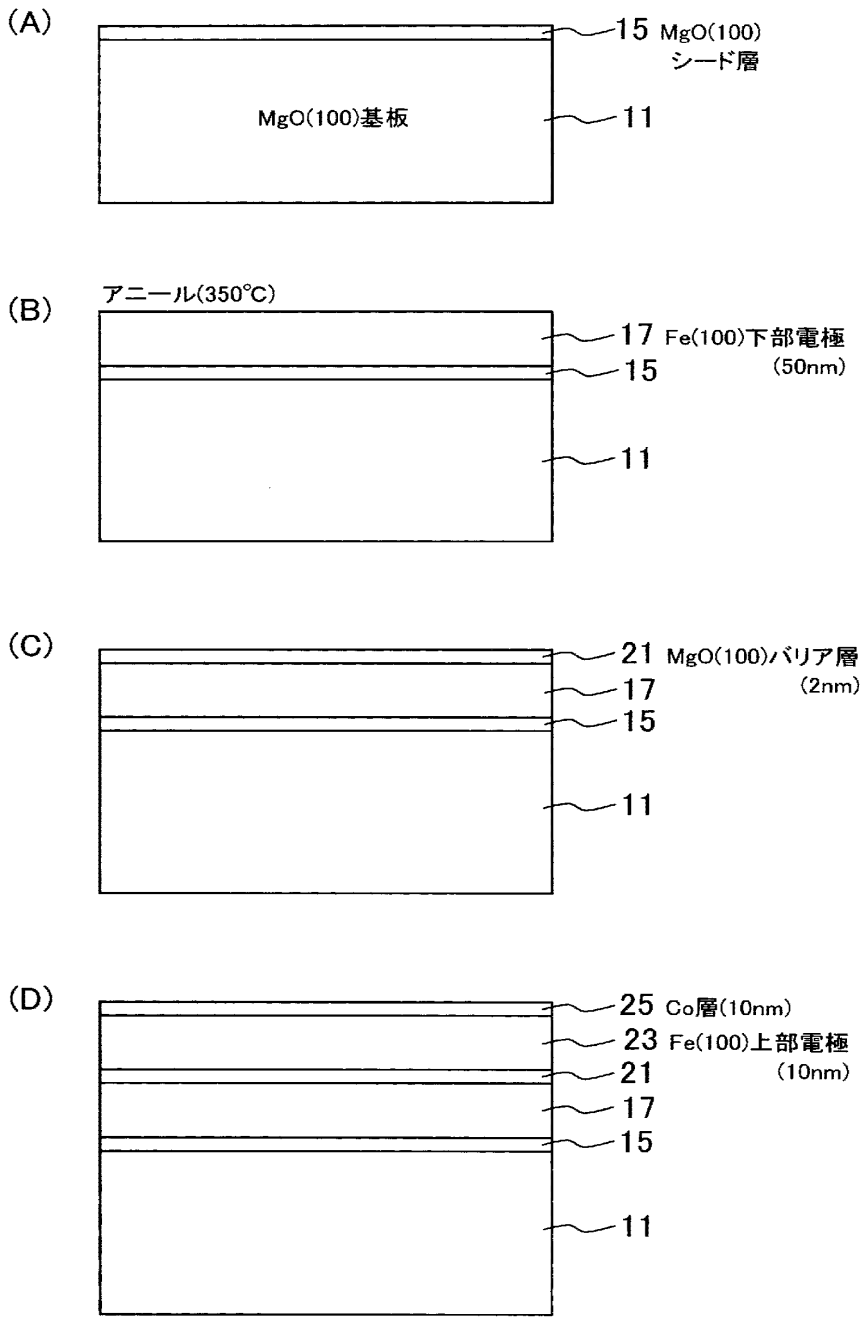
(A)


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)

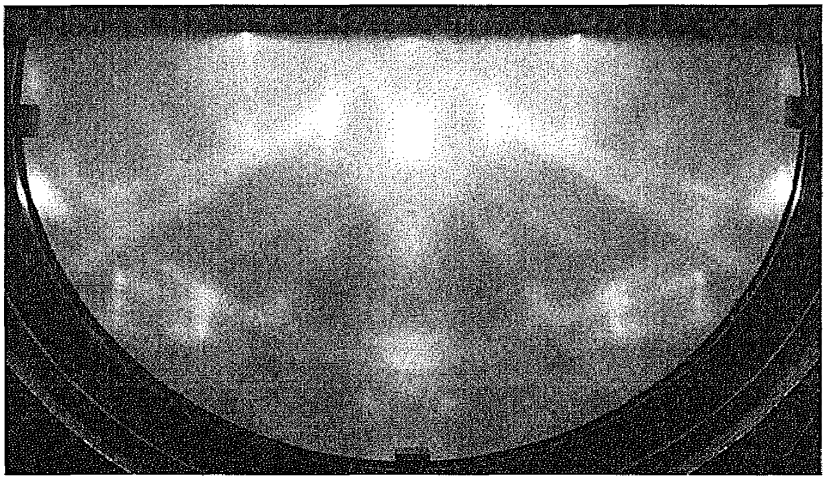

5
Fe(100)
3
MgO(100)
1
Fe(100)

【図２】

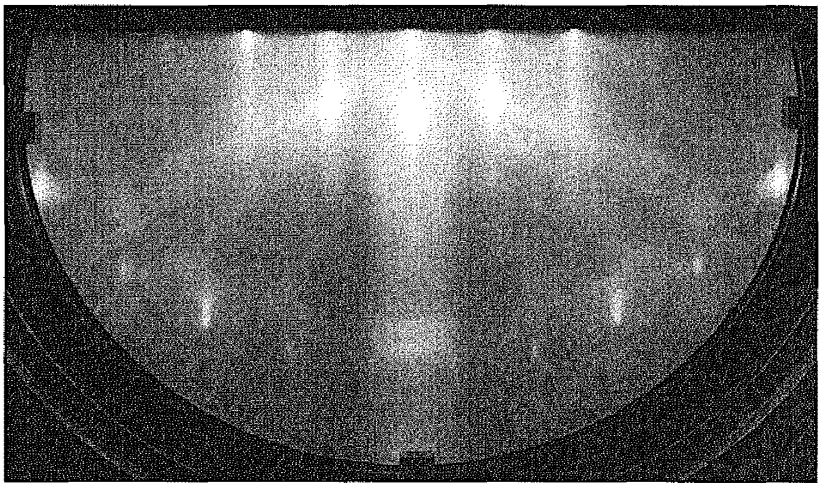

(A)
15 MgO(100)
シード層
MgO(100)基板
11
(B)
アニール(350℃)
17 Fe(100)下部電極
(50nm)
15
11
(C)
21 MgO(100)バリア層
(2nm)
17
15
11
(D)
25 Co層(10nm)
23 Fe(100)上部電極
(10nm)
21
17
15
11

【図３】

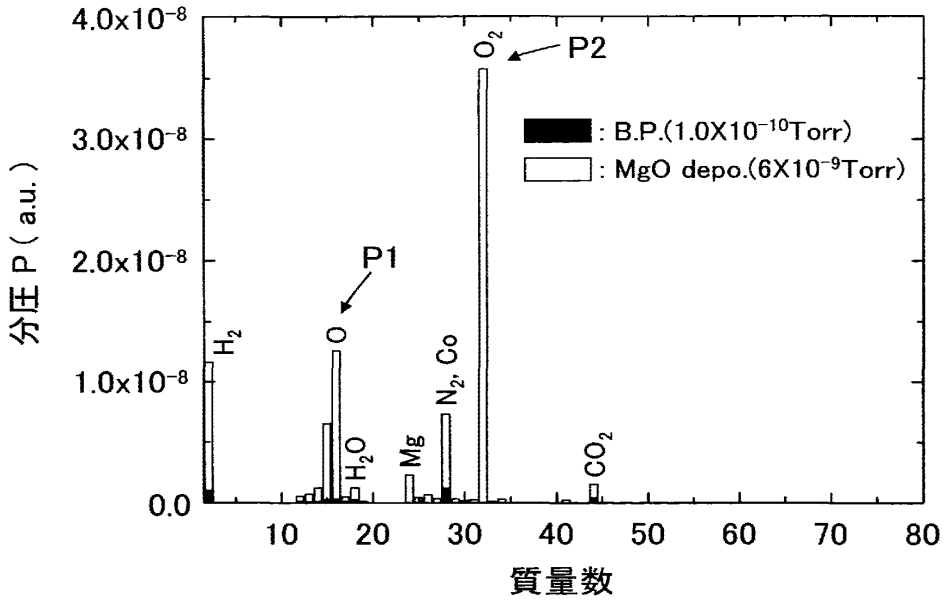
(a)



(b)

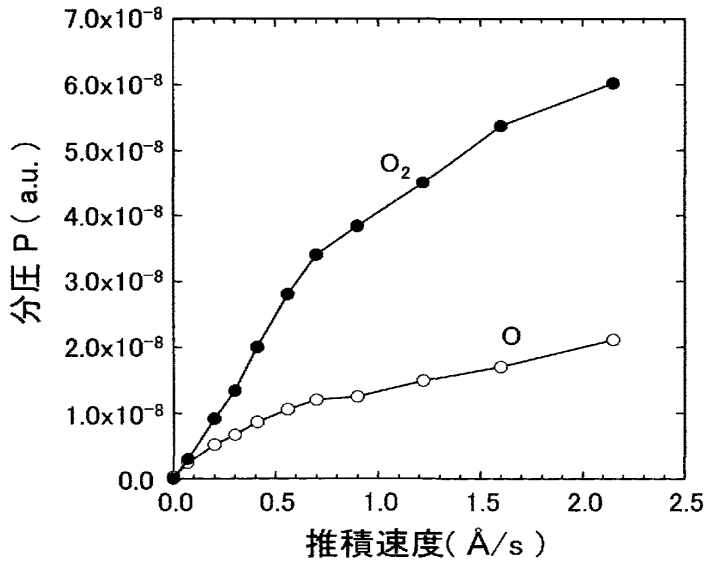


【図４】



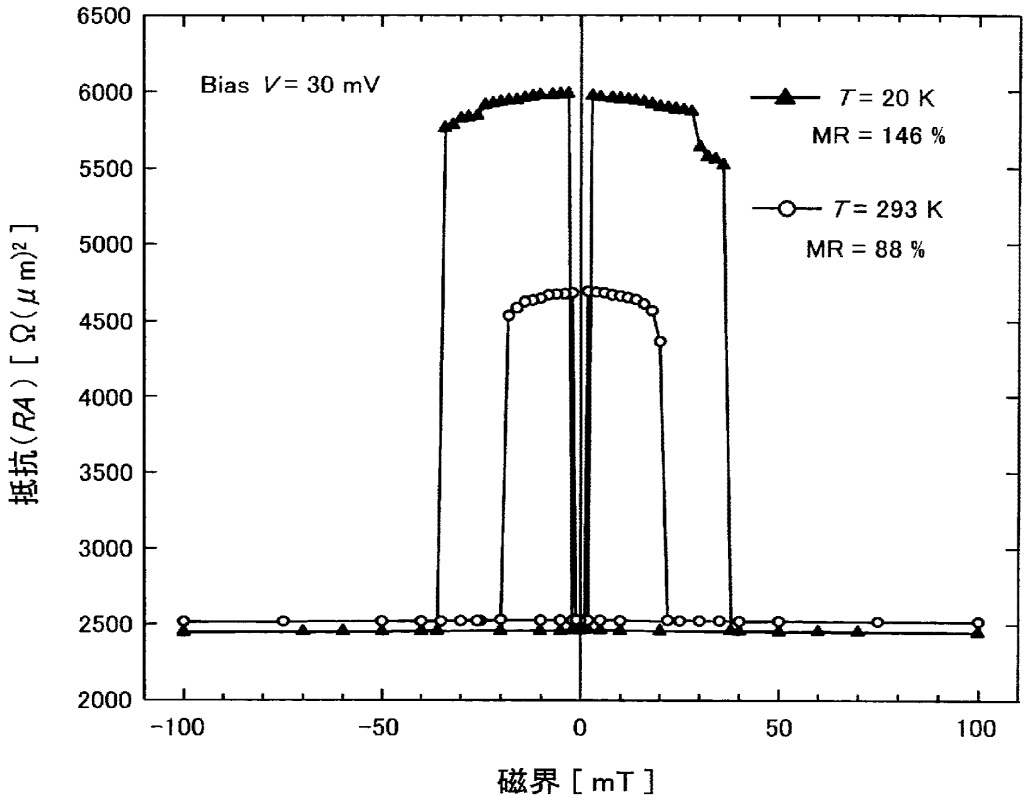
Massスペクトル

【図５】

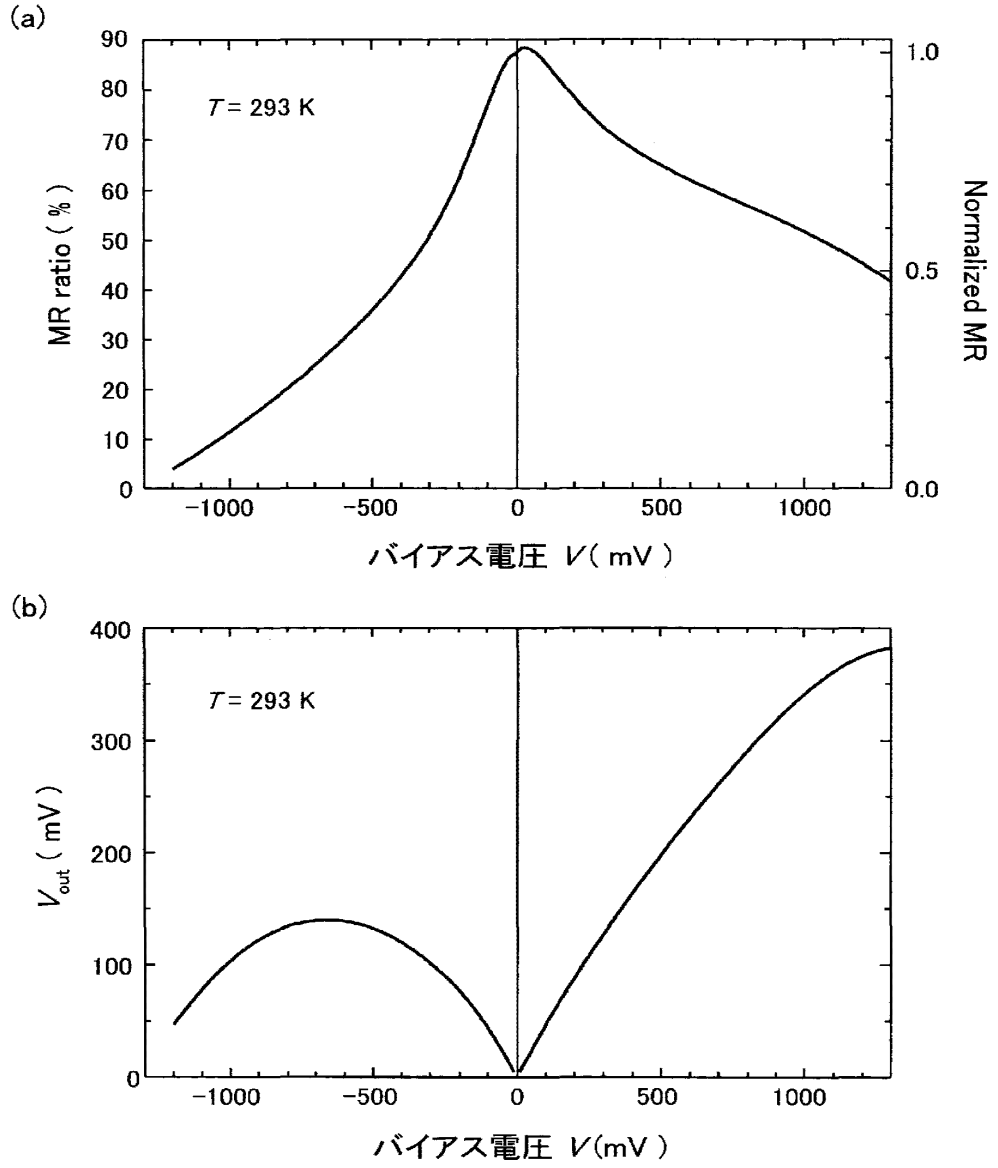


MgO蒸着中の酸素分圧

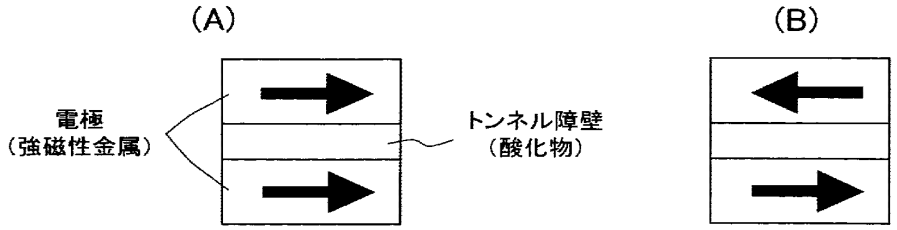
【図６】


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

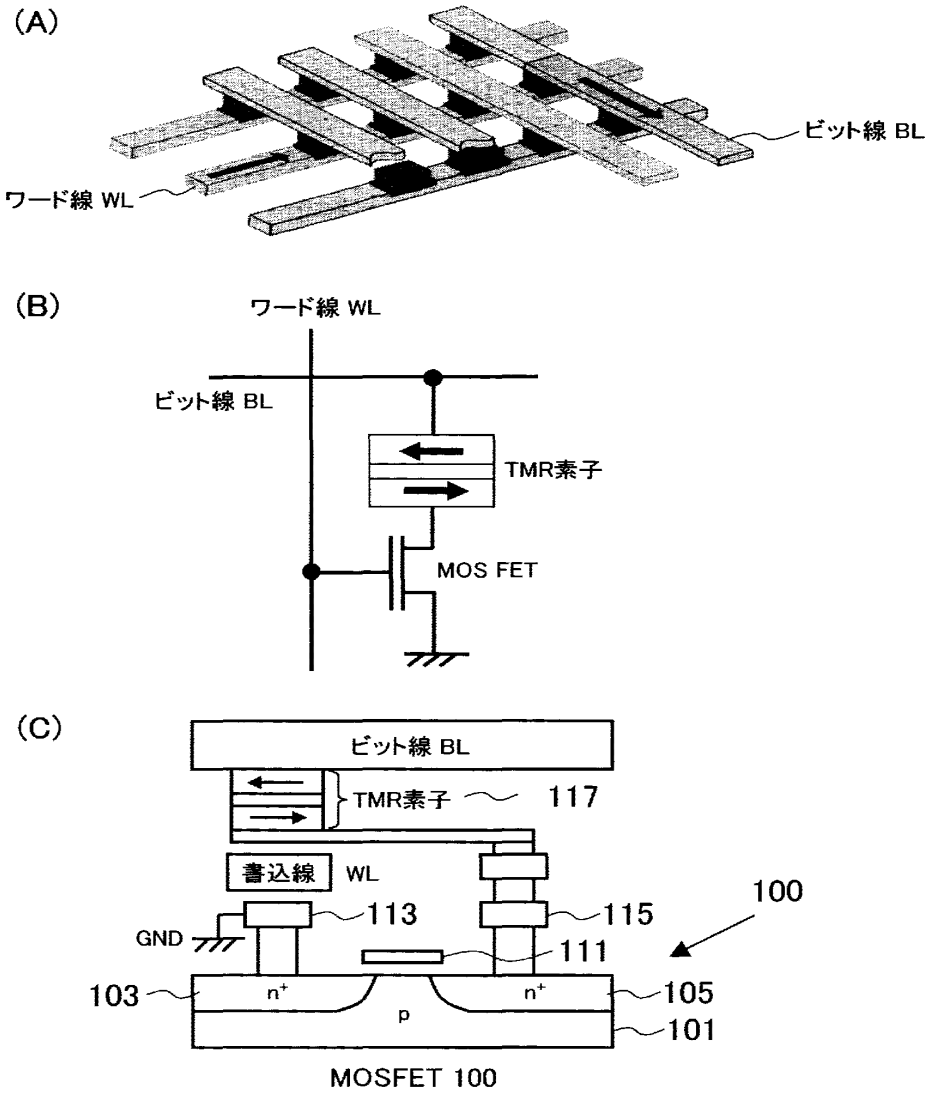
【図７】


(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)

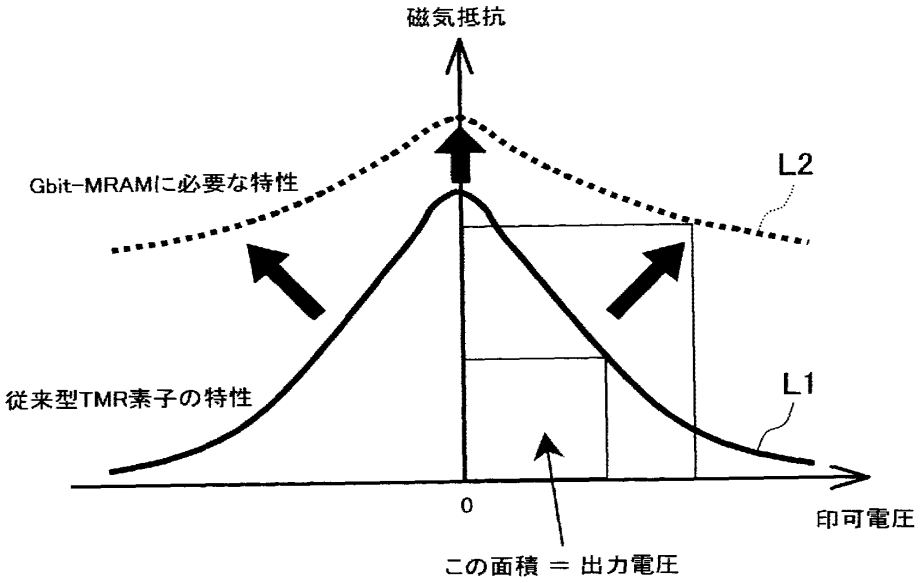
【図８】



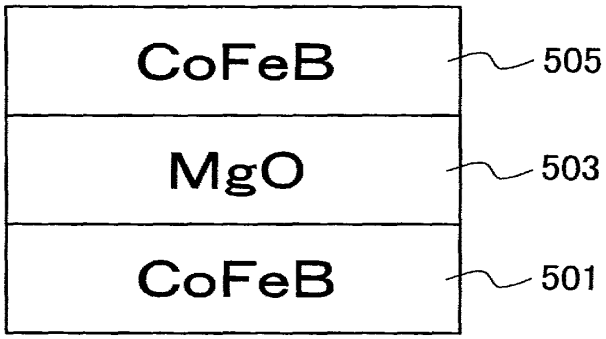
【図９】


(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

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　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 EX1012
Western Digital v IP Bridge
Page 88

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

５０３３６０１１５

20150423

名称変更

埼玉県川口市本町四丁目１番８号

国立研究開発法人科学技術振興機構

３０１０２１５３３

20010402

新規登録

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

３０１０２１５３３

20130719

名称変更　住所変更

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

３０１０２１５３３

20150401

名称変更

東京都千代田区霞が関１－３－１

国立研究開発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　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):	国立研究開発法人科学技術振興機構 国立研究開発法人産業技術総合研究所

２０１７年　６月　６日

特許庁長官
Commissioner,
Japan Patent Office

小宮義則

【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
　つくばセンター内
　【氏名】　湯浅　新治
【特許出願人】
　【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
【特許出願人】
　【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
【選任した代理人】
　【識別番号】　100105463
　【弁理士】
　【氏名又は名称】　関谷　三男
【選任した代理人】
　【識別番号】　100102576
　【弁理士】
　【氏名又は名称】　渡辺　敏章
【選任した代理人】
　【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、$P\alpha=(D\alpha\uparrow(E_F)-D\alpha\downarrow(E_F))/(D\alpha\uparrow(E_F)+D\alpha\downarrow(E_F))$、$\alpha=1,2$　（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（２×１０－８Ｐａ）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。

【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、１０－９Ｔｏｒｒ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。

【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―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１０－６Ｐａ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】

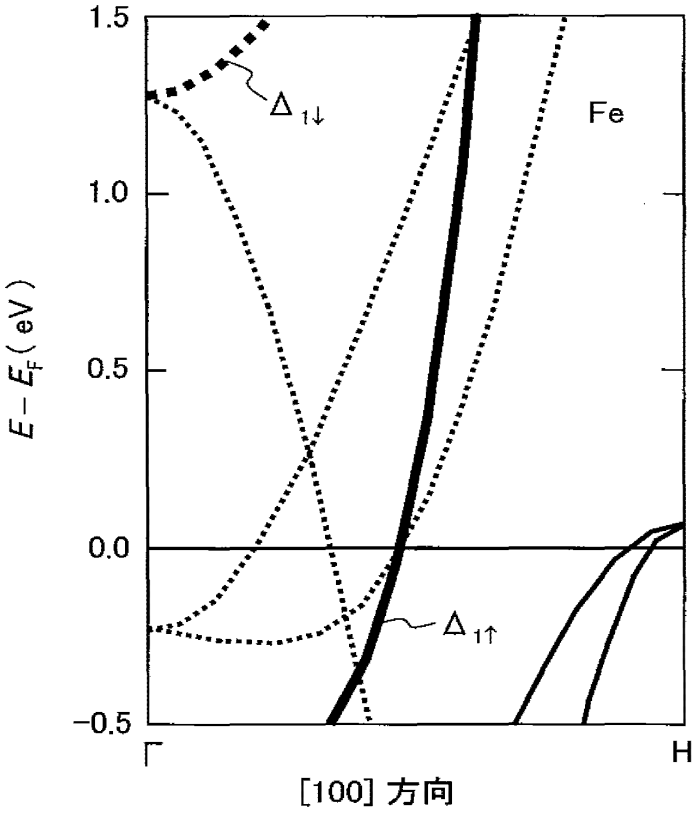
【００３２】

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（

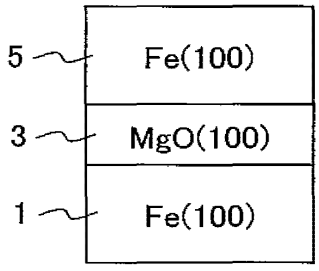
ｘ＜１）、１５…ＭｇＯ（１００）シード層、１７…エピタキシャルＦｅ（１００）下部電極（第１電極）、２１…ＭｇＯ（１００）バリア層、２３…エピタキシャルＦｅ（１００）上部電極（第２電極）。

【書類名】図面
【図１】

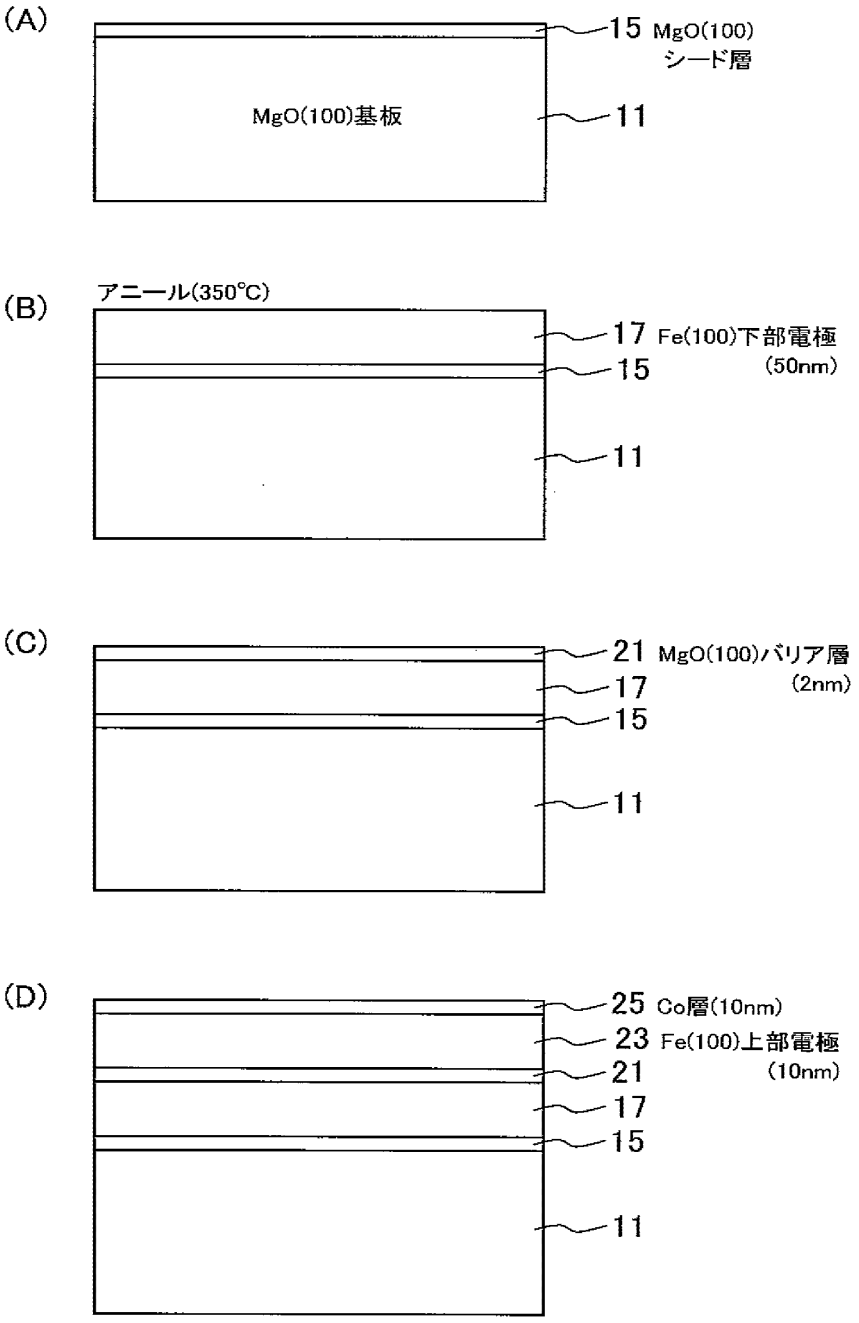
(A)


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)

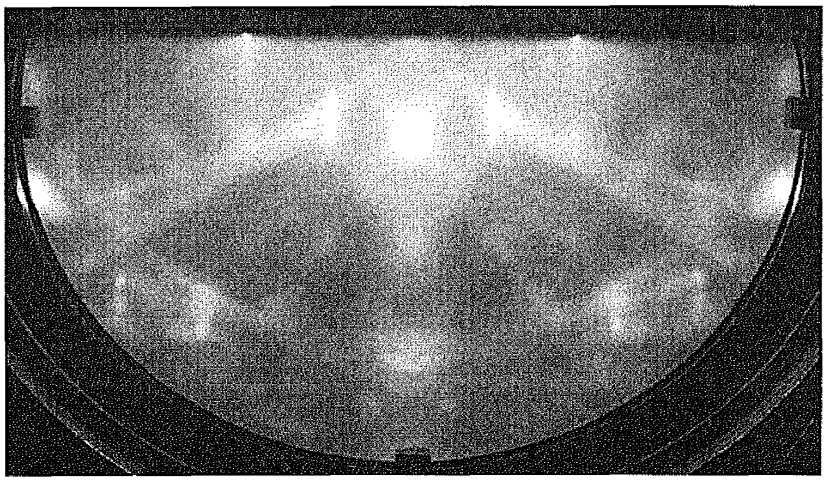

5
Fe(100)
3
MgO(100)
1
Fe(100)

【図２】

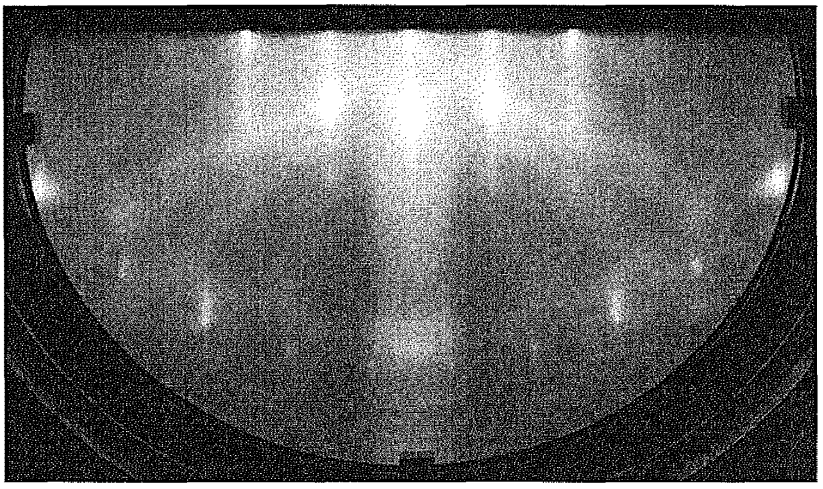

(A)
15 MgO(100)
シード層
MgO(100)基板
11
(B)
アニール(350℃)
17 Fe(100)下部電極
(50nm)
15
11
(C)
21 MgO(100)バリア層
(2nm)
17
15
11
(D)
25 Co層(10nm)
23 Fe(100)上部電極
(10nm)
21
17
15
11

【図３】

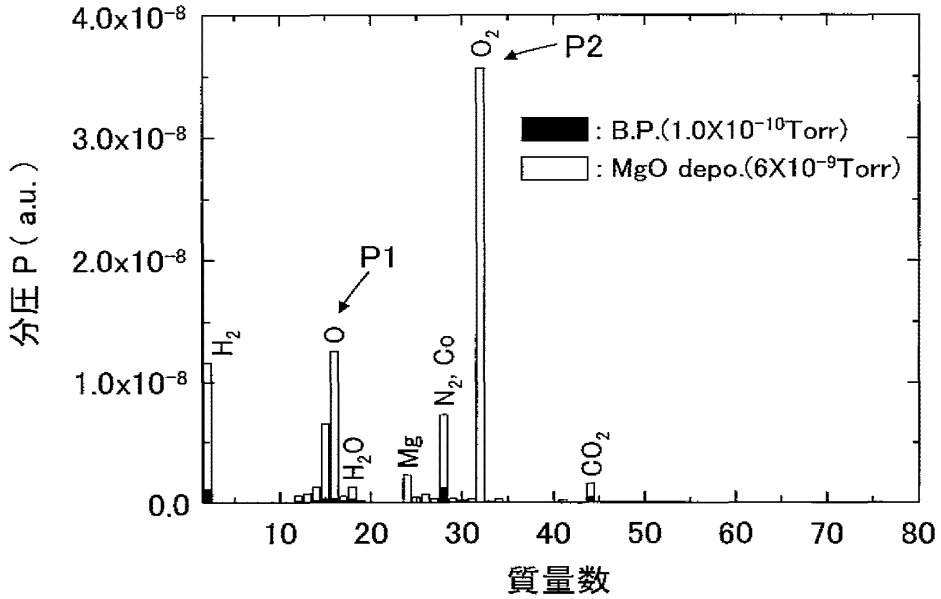
(a)



(b)

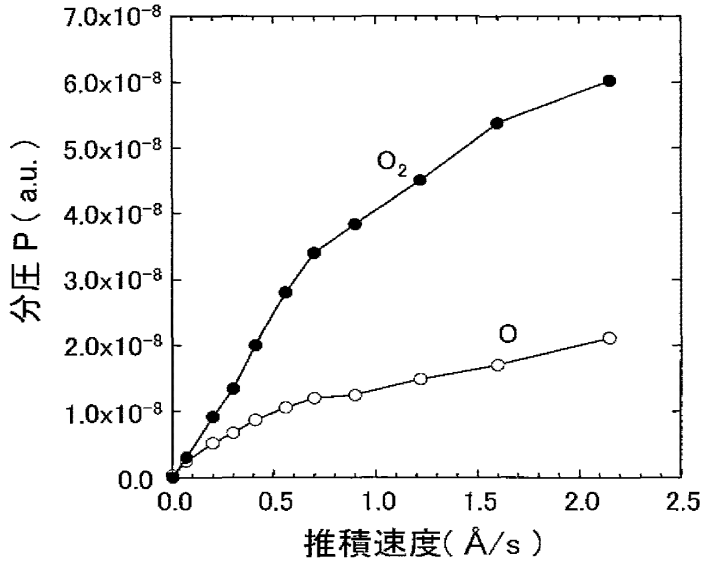


【図４】



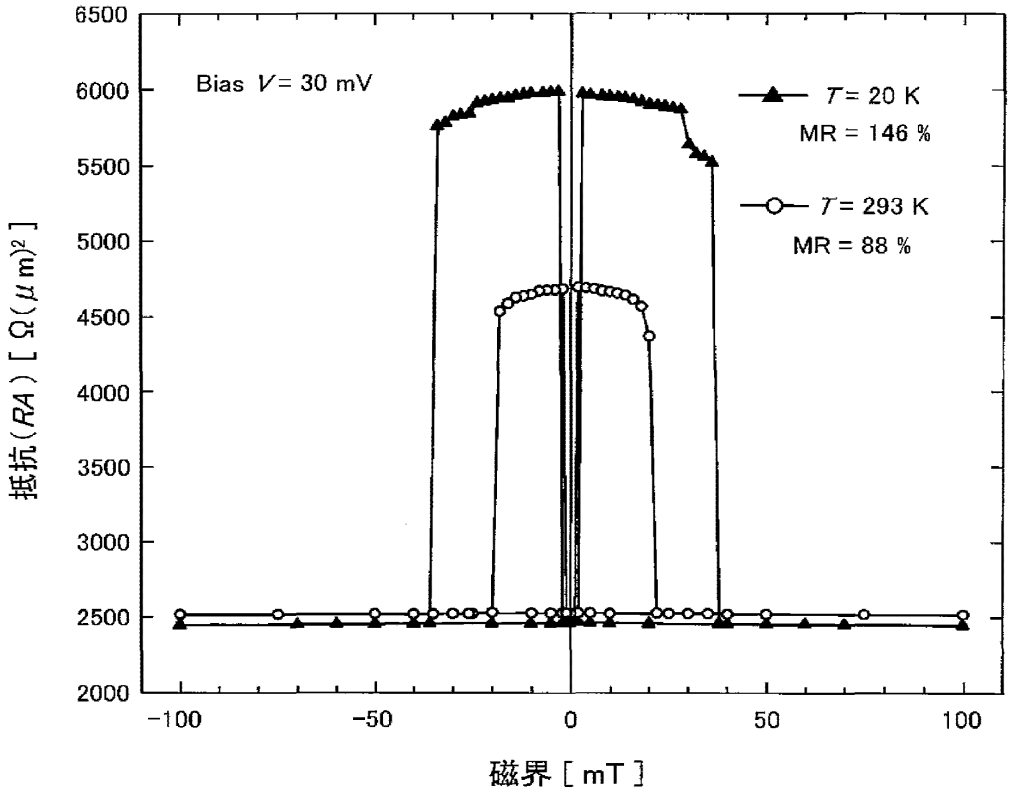
Massスペクトル

【図５】

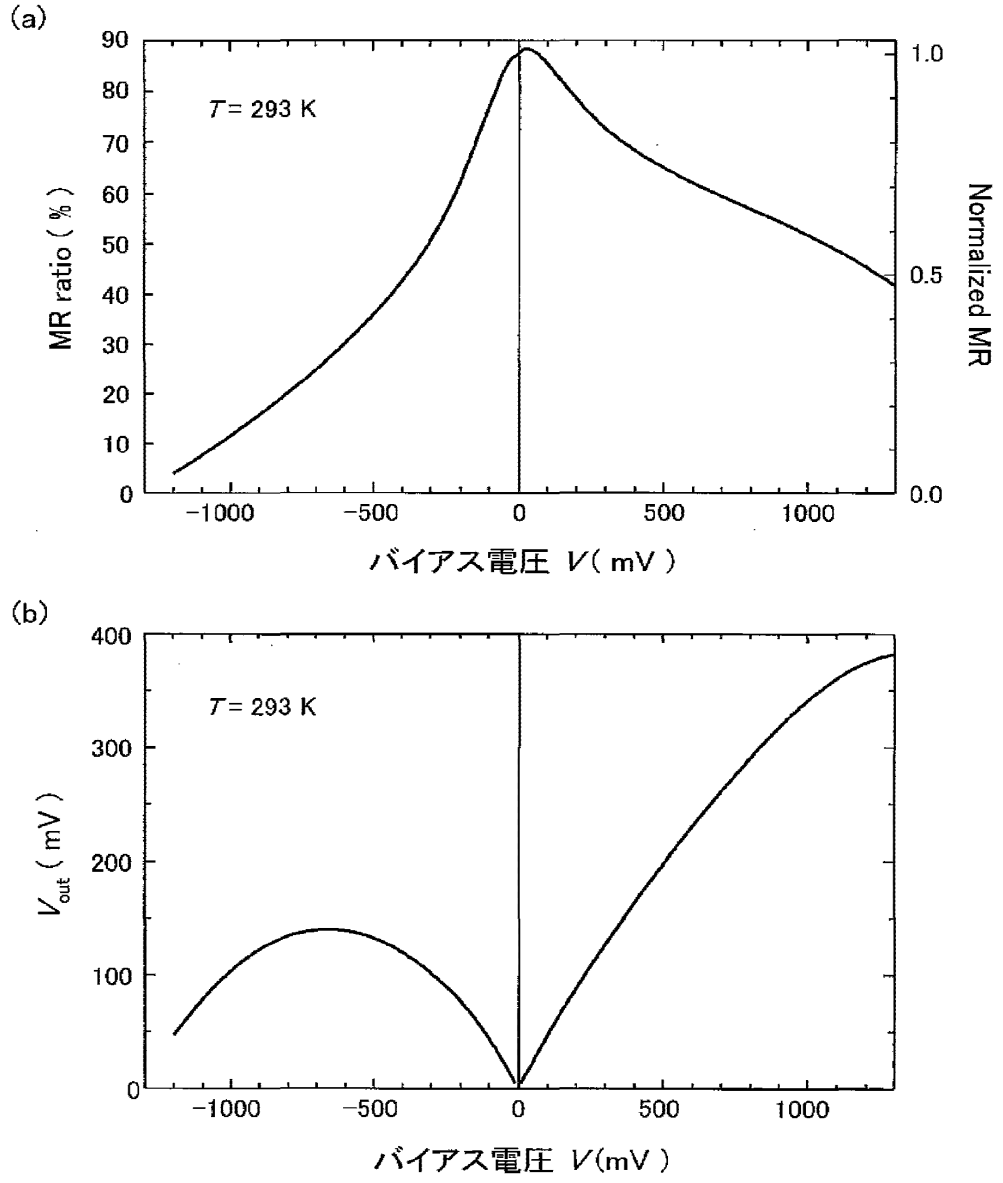


MgO蒸着中の酸素分圧

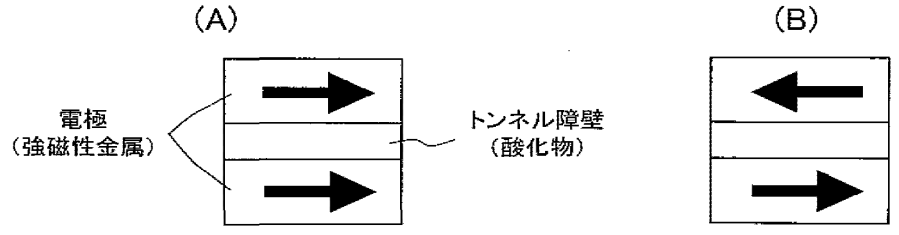
【図６】


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

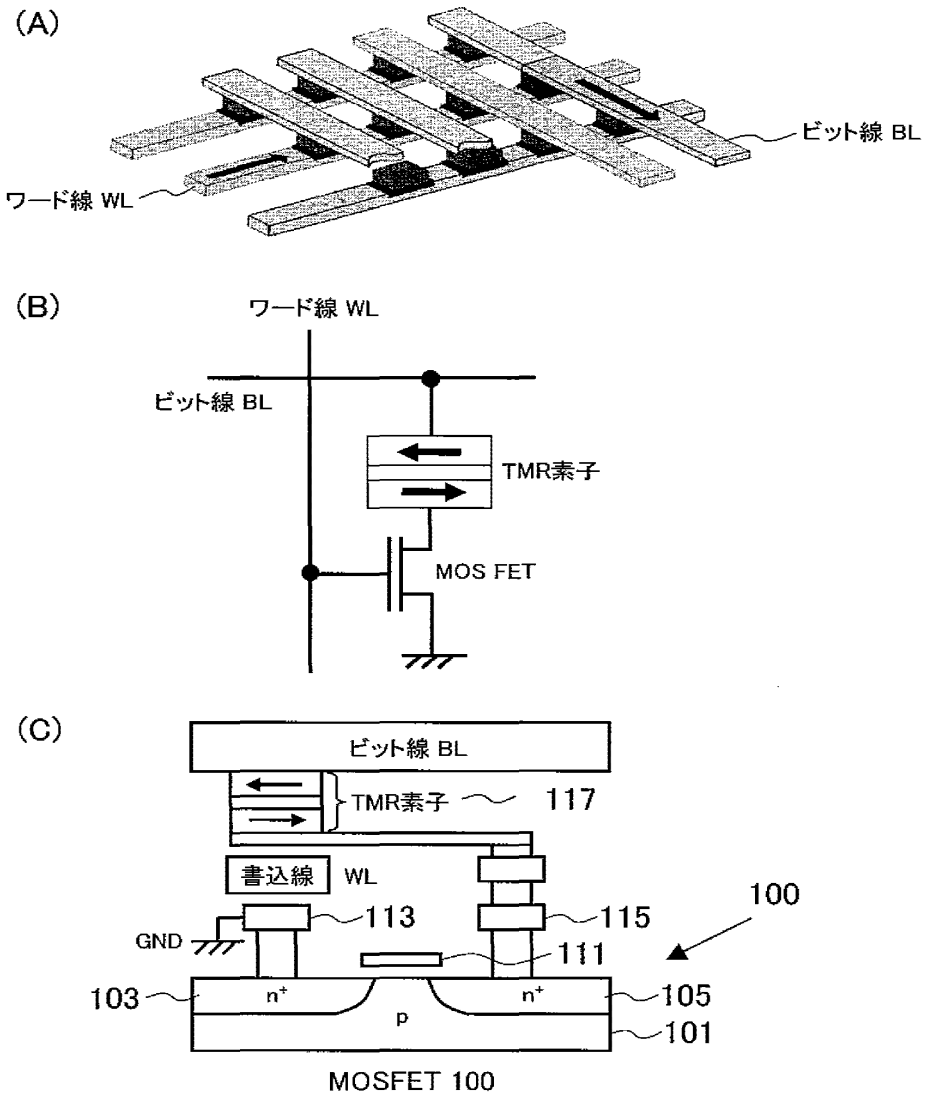
【図７】


(a)
T = 293 K
MR ratio (%)
Normalized MR
バイアス電圧 V(mV)
(b)
T = 293 K
V_{out} (mV)
バイアス電圧 V(mV)

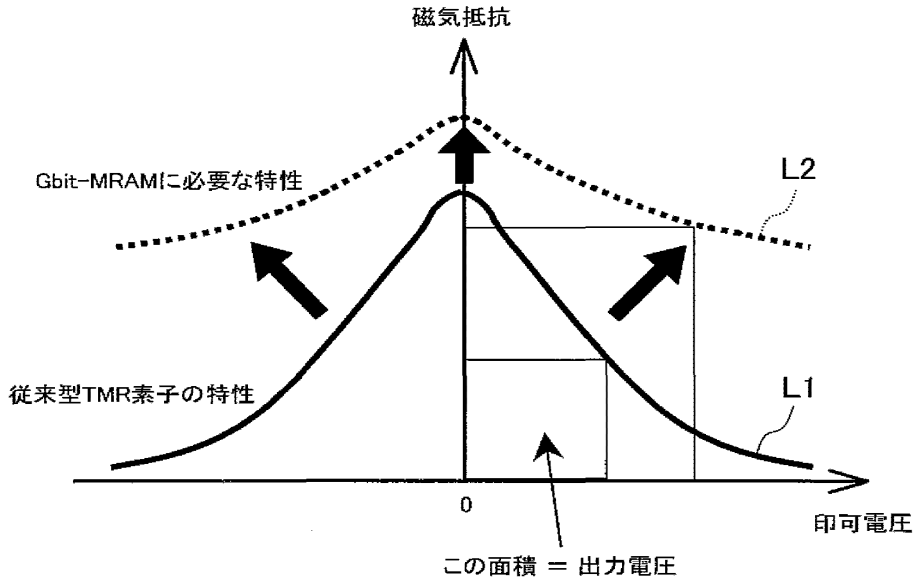
【図８】


(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
GND
113
115
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
　【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
【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

甲　住所　東京都千代田区霞が関１丁目３番１号
　　氏名　独立行政法人産業技術総合研究所
　　理事長　吉川弘之

乙　住所　埼玉県川口市本町四丁目１番８号
　　氏名　独立行政法人科学技術振興機構
　　理事長　沖村憲樹

出願人履歴

５０３３６０１１５

20031001

新規登録

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

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

５０３３６０１１５

20150423

名称変更

埼玉県川口市本町四丁目１番８号

国立研究開発法人科学技術振興機構

３０１０２１５３３

20010402

新規登録

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

３０１０２１５３３

20130719

名称変更　住所変更

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

３０１０２１５３３

20150401

名称変更

東京都千代田区霞が関１―３―１

国立研究開発法人産業技術総合研究所

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.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 07/03/2017

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	

ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
07/03/2017	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. 15/428,842	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 *2/9/17*.

☐ 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) *1-22* 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) *1-22* 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 *2/9/17* 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.

Priority

2. 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 March 10, 2005.

Drawings

3. The formal drawings filed on 2/9/17 have been approved by the examiner.

Double Patenting

4. 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); *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 1-14 are rejected under 35 U.S.C. 101 as claiming the same invention as that of claim 1 of prior U.S. Patent No. 8,405,134. This is a statutory double patenting rejection.

6. Claims 15-22 are rejected under 35 U.S.C. 101 as claiming the same invention as that of claim 4 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 product of the instant invention.

Conclusion

7. 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/June 25, 2017

/Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Notice of References Cited	Application/Control No. 15/428,842	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	CPC Classification	US Classification
*	A	US-8,319,263 B2	11-2012	Yuasa; Shinji	B82Y25/00	257/295
*	B	US-9,123,463 B2	09-2015	Yuasa; Shinji	B82Y25/00	1/1
*	C	US-8,405,134 B2	03-2013	Yuasa; Shinji	B82Y25/00	257/295
*	D	US-7,884,403 B2	02-2011	Yuasa; Shinji	B82Y25/00	257/295
	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	CPC Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

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

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in 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	258	257/$.ccls. and CoFeB and (MgO magnesium adj3 oxide) same (second top upper) near5 (Fe ferromagnetic)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2017/06/25 12:25
L2	118	438/$.ccls. and CoFeB and (MgO magnesium adj3 oxide) same (second top upper) near5 (Fe ferromagnetic)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2017/06/25 12:25
L3	232	1 AND ((H01L43/08 OR H01L43/10 OR H01L43/12 OR H01L43/02 OR H01L27/222 OR G11C11/161).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2017/06/25 12:27

6/ 25/ 2017 12:30:46 PM
C:\ Users\ achambliss\ Documents\ EAST\ Workspaces\ 15068212.wsp

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	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	06/25/2017								
	1	✓								
	2	✓								
	3	✓								
	4	✓								
	5	✓								
	6	✓								
	7	✓								
	8	✓								
	9	✓								
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	18	✓								
	19	✓								
	20	✓								
	21	✓								
	22	✓								

WD EX1012
Western Digital v IP Bridge
Page 122

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC- SEARCHED		
Symbol	Date	Examiner
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	6/25/17	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	6/25/17	AC

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

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

BIB DATA SHEET

CONFIRMATION NO. 9576

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
15/428,842	02/09/2017 RULE	257	2897	P11338US02/NBT

APPLICANTS

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

INVENTORS

Shinji YUASA, Ibaraki, JAPAN;

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

This application is a CON of 14/837,558 08/27/2015 PAT 9608198
which is a CON of 13/767,290 02/14/2013 PAT 9123463
which 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 ****

02/16/2017

Foreign Priority claimed	☑ Yes ☐ No	☐ Met after Allowance	STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
35 USC 119(a-d) conditions met	☑ Yes ☐ No		JAPAN	10	22	2
Verified and Acknowledged	/ALONZO CHAMBLISS/ Examiner's Signature	Initials				

ADDRESS

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314
UNITED STATES

TITLE

Magnetic Tunnel Junction Device

FILING FEE RECEIVED		
1760	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).

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 08/29/2017
STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	

ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
08/29/2017	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

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Applicant-Initiated Interview Summary	Application No.	Applicant(s)	
	15/428,842	YUASA, SHINJI	
	Examiner	Art Unit	
	ALONZO CHAMBLISS	2897	

All participants (applicant, applicant's representative, PTO personnel):

(1) *ALONZO CHAMBLISS*. (3)_____.

(2) *Nicholas B. Trenkle*. (4)_____.

Date of Interview: *21 August 2017*.

Type: ☒ Telephonic ☐ Video Conference
☐ Personal [copy given to: ☐ applicant ☐ applicant's representative]

Exhibit shown or demonstration conducted: ☐ Yes ☒ No.
If Yes, brief description: _____.

Issues Discussed ☐101 ☐112 ☐102 ☐103 ☒Others
(For each of the checked box(es) above, please describe below the issue and detailed description of the discussion)

Claim(s) discussed: *1 and 15*.

Identification of prior art discussed: *US 8,405,134*.

Substance of Interview
(For each issue discussed, provide a detailed description and indicate if agreement was reached. Some topics may include: identification or clarification of a reference or a portion thereof, claim interpretation, proposed amendments, arguments of any applied references etc...)

Applicant's attorney called the examiner to discuss the statutory double patenting rejection using the above prior art. The 3 issues discussed were a substrate, a single-crystalline magnesium oxide in which (0001) crystal plane is preferrentially oriented, and the first and second ferromagnetic material layer being an electrode. The examiner maintained the rejection but the attorney disagreed with the examiner. The attorney can file a formal response to the non-final rejection on 7/3/17 to place his remarks on the record. Also, if the examiner reviews the attorney's formal remarks and changes his postion. The application would still be rejected under non-statutory double patenting. Therefore, it is suggested that the attorney file a terminal disclaimer along with the formal response .

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

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

☐ Attachment

/ALONZO CHAMBLISS/ Primary Examiner, Art Unit 2897	

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Summary of Record of Interview Requirements

Manual of Patent Examining Procedure (MPEP), Section 713.04, Substance of Interview Must be Made of Record
A complete written statement as to the substance of any face-to-face, video conference, or telephone interview with regard to an application must be made of record in the application whether or not an agreement with the examiner was reached at the interview.

Title 37 Code of Federal Regulations (CFR) § 1.133 Interviews
Paragraph (b)

In every instance where reconsideration is requested in view of an interview with an examiner, a complete written statement of the reasons presented at the interview as warranting favorable action must be filed by the applicant. An interview does not remove the necessity for reply to Office action as specified in §§ 1.111, 1.135. (35 U.S.C. 132)

37 CFR §1.2 Business to be transacted in writing.
All business with the Patent or Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office. No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt.

The action of the Patent and Trademark Office cannot be based exclusively on the written record in the Office if that record is itself incomplete through the failure to record the substance of interviews.

It is the responsibility of the applicant or the attorney or agent to make the substance of an interview of record in the application file, unless the examiner indicates he or she will do so. It is the examiner's responsibility to see that such a record is made and to correct material inaccuracies which bear directly on the question of patentability.

Examiners must complete an Interview Summary Form for each interview held where a matter of substance has been discussed during the interview by checking the appropriate boxes and filling in the blanks. Discussions regarding only procedural matters, directed solely to restriction requirements for which interview recordation is otherwise provided for in Section 812.01 of the Manual of Patent Examining Procedure, or pointing out typographical errors or unreadable script in Office actions or the like, are excluded from the interview recordation procedures below. Where the substance of an interview is completely recorded in an Examiners Amendment, no separate Interview Summary Record is required.

The Interview Summary Form shall be given an appropriate Paper No., placed in the right hand portion of the file, and listed on the "Contents" section of the file wrapper. In a personal interview, a duplicate of the Form is given to the applicant (or attorney or agent) at the conclusion of the interview. In the case of a telephone or video-conference interview, the copy is mailed to the applicant's correspondence address either with or prior to the next official communication. If additional correspondence from the examiner is not likely before an allowance or if other circumstances dictate, the Form should be mailed promptly after the interview rather than with the next official communication.

The Form provides for recordation of the following information:
- Application Number (Series Code and Serial Number)
- Name of applicant
- Name of examiner
- Date of interview
- Type of interview (telephonic, video-conference, or personal)
- Name of participant(s) (applicant, attorney or agent, examiner, other PTO personnel, etc.)
- An indication whether or not an exhibit was shown or a demonstration conducted
- An identification of the specific prior art discussed
- An indication whether an agreement was reached and if so, a description of the general nature of the agreement (may be by attachment of a copy of amendments or claims agreed as being allowable). Note: Agreement as to allowability is tentative and does not restrict further action by the examiner to the contrary.
- The signature of the examiner who conducted the interview (if Form is not an attachment to a signed Office action)

It is desirable that the examiner orally remind the applicant of his or her obligation to record the substance of the interview of each case. It should be noted, however, that the Interview Summary Form will not normally be considered a complete and proper recordation of the interview unless it includes, or is supplemented by the applicant or the examiner to include, all of the applicable items required below concerning the substance of the interview.

A complete and proper recordation of the substance of any interview should include at least the following applicable items:
1) A brief description of the nature of any exhibit shown or any demonstration conducted,
2) an identification of the claims discussed,
3) an identification of the specific prior art discussed,
4) an identification of the principal proposed amendments of a substantive nature discussed, unless these are already described on the Interview Summary Form completed by the Examiner,
5) a brief identification of the general thrust of the principal arguments presented to the examiner,
   (The identification of arguments need not be lengthy or elaborate. A verbatim or highly detailed description of the arguments is not required. The identification of the arguments is sufficient if the general nature or thrust of the principal arguments made to the examiner can be understood in the context of the application file. Of course, the applicant may desire to emphasize and fully describe those arguments which he or she feels were or might be persuasive to the examiner.)
6) a general indication of any other pertinent matters discussed, and
7) if appropriate, the general results or outcome of the interview unless already described in the Interview Summary Form completed by the examiner.

Examiners are expected to carefully review the applicant's record of the substance of an interview. If the record is not complete and accurate, the examiner will give the applicant an extendable one month time period to correct the record.

Examiner to Check for Accuracy

If the claims are allowable for other reasons of record, the examiner should send a letter setting forth the examiner's version of the statement attributed to him or her. If the record is complete and accurate, the examiner should place the indication, "Interview Record OK" on the paper recording the substance of the interview along with the date and the examiner's initials.

PTO/AIA/26 (04-14)
Approved for use through 07/31/2016. 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) P11338US02/BAS

In re Application of: YUASA, et al.

Application No.: 15/428,842

Filed: February 9, 2017

For: MAGNETIC TUNNEL JUNCTION DEVICE

The applicant, Japan Science and Technology Agency, owner of 50 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. 8,405,134 as the term of said **prior patent** is presently shortened by any terminal disclaimer. The applicant 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 applicant 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. ☐ The undersigned is the applicant. If the applicant is an assignee, the undersigned is authorized to act on behalf of the assignee.

I hereby acknowledge that any willful false statements made are punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

2. ☑ The undersigned is an attorney or agent of record. Reg. No. 54,500

Nicholas Trenkle — October 2, 2017
Signature — Date

Nicholas Trenkle
Typed or printed name

Title — 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.

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.

PTO/AIA/26 (04-14)
Approved for use through 07/31/2016. 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) P11338US02/BAS

In re Application of: YUASA, et al.

Application No.: 15/428,842

Filed: February 9, 2017

For: MAGNETIC TUNNEL JUNCTION DEVICE

The applicant, National Institute of Advanced Industrial Science and Technology, owner of 50 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. 8,406,134 as the term of said **prior patent** is presently shortened by any terminal disclaimer. The applicant 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 applicant 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. ☐ The undersigned is the applicant. If the applicant is an assignee, the undersigned is authorized to act on behalf of the assignee.

I hereby acknowledge that any willful false statements made are punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

2. ☑ The undersigned is an attorney or agent of record. Reg. No. 54,500

Nicholas Trenkle — October 2, 2017
Signature — Date

Nicholas Trenkle
Typed or printed name

Title — 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.

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.

Electronic Patent Application Fee Transmittal

Application Number:	15428842
Filing Date:	09-Feb-2017
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Stephen John Weyer/Stacy Johnson
Attorney Docket Number:	P11338US02/NBT

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:				
CLAIMS IN EXCESS OF 20	1202	3	80	240
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Extension - 1 month with $0 paid	1251	1	200	200
Miscellaneous:				
STATUTORY OR TERMINAL DISCLAIMER	1814	2	160	320
		Total in USD ($)		**760**

Electronic Acknowledgement Receipt	
EFS ID:	30542750
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
Title of Invention:	Magnetic Tunnel Junction Device
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Stephen John Weyer/Stacy Johnson
Filer Authorized By:	Stephen John Weyer
Attorney Docket Number:	P11338US02/NBT
Receipt Date:	02-OCT-2017
Filing Date:	09-FEB-2017
Time Stamp:	17:37:02
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$760
RAM confirmation Number	100317INTEFSW17372600
Deposit Account	
Authorized User	
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		P11338US02Transmittal_Response_TerminalDisclaimers.pdf	1273004 74ff97e79b060b6bf67d1a2987a1e4ceb4fc30c9	yes	15

Multipart Description/PDF files in .zip description

Document Description	Start	End
Transmittal Letter	1	1
Amendment/Req. Reconsideration-After Non-Final Reject	2	2
Claims	3	6
Applicant Arguments/Remarks Made in an Amendment	7	13
Terminal Disclaimer Filed	14	14
Terminal Disclaimer Filed	15	15

Warnings:

Information:

2	Fee Worksheet (SB06)	fee-info.pdf	34407 fbb288733a76f199dc6619ddd5112598adb349eb	no	2

Warnings:

Information:

Total Files Size (in bytes):	1307411

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 #	15428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2897
	Examiner	Alonzo Chambliss
Total number of pages in this submission =	Docket #	P11338US02/NBT

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
- ☐ Information Disclosure Statement
- ☒ Terminal Disclaimer
- ☐
- ☐

FEES CALCULATION: For claims if required and/or other fees as shown below:

STATUS of Applicant is:		☐ MICRO	☐ SMALL	☒ LARGE	FEE DUE
FEE FOR	CALCULATION	$	$	$	$
☒ TOTAL CLAIMS	25 - 22 = 3 (extra)	× 20 =	× 40 =	× 80 =	240
☒ INDEP. CLAIMS	3 - 3 = 0 (extra)	× 105 =	× 210 =	× 420 =	0
☒ Extension of Time for ONE month(s) *(serving as constructive EOT Petition)* =					200
☒ Other fee for Two Terminal Disclaimers					320
				TOTAL	760

☒ **Payment of $ 760** 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: October 2, 2017

/B. Aaron Schulman/

Signed By Name: B. Aaron Schulman

Attorney of Record Registration No.: 31,877

STITES & HARBISON PLLC • 1800 Diagonal Road. • Suite 325 • Alexandria, VA 22314
TEL: 703-739-4900 • FAX: 703-739-9577 • Customer No. 881

2355LT:10004:418149:1:ALEXANDRIA

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	
YUASA	Confirmation No. 9576
Application Number: 15/428,842	Art Unit 2897
Filed: February 9, 2017	Examiner Alonzo Chambliss
For: MAGNETIC TUNNEL JUNCTION DEVICE	
ATTORNEY DOCKET NO. P11338US02/NBT	

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 July 3, 2017, the period of response to which is set to expire on October 3, 2017. A terminal disclaimer in compliance with 37 C.F.R. 1.321 is being submitted herewith. Please amend the above-referenced application as follows:

IN THE CLAIMS

Claims 1-25 are pending in this application, wherein claims 2, 3, 12-14, 16, 17, and 20-22 are being amended to improve form, and wherein claims 23-25 are being newly added, as follows:

1. (Original) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode comprising a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed over the first electrode, the barrier layer comprising a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented; and

a second electrode disposed over the barrier layer and comprising a second ferromagnetic material layer.

2. (Currently Amended) The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers is partially crystallized~~crystalized~~.

3. (Currently Amended) The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers is entirely crystallized~~crystalized~~.

4. (Original) The MTJ device of claim 1, wherein the second ferromagnetic material layer includes Co, Fe, and B.

5. (Original) The MTJ device of claim 2, wherein the second ferromagnetic material layer includes Co, Fe, and B.

6. (Original) The MTJ device of claim 3, wherein the second ferromagnetic material layer includes Co, Fe, and B.

7. (Original) The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

8. (Original) The MTJ device of claim 4, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

9. (Original) The MTJ device of claim 5, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

10. (Original) The MTJ device of claim 6, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

11. (Original) The MTJ device of claim 1, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

12. (Currently Amended) The MTJ device of claim 11, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device 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 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 Planck's constant, Δs is an effective thickness of the barrier layer that is ~~approximately~~ equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer ~~determined using a cross-sectional transmission electron microscope image~~.

13. (Currently Amended) The MTJ device of claim 1, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1 ~~includes oxygen vacancy defects~~.

14. (Currently Amended) The MTJ device of claim 1[[4]], wherein a value of x in MgO_x for the MgO layer ~~due to the oxygen vacancy defects~~ is greater than 0.9 and less than 1.

15. (Original) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode made of a first CoFeB layer;

a barrier layer made of a magnesium oxide (MgO) layer that is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented; and

a second electrode made of a second CoFeB layer, and

wherein the barrier layer is located between the first electrode and the second electrode.

16. (Currently Amended) The MTJ device of claim 15, wherein each of the first and second CoFeB layers is partially crystallized~~crystalized~~.

17. (Currently Amended) The MTJ device of claim 15, wherein each of the first and second CoFeB layers is entirely crystallized~~crystalized~~.

18. (Original) The MTJ device of claim 15, wherein each of the first and second CoFeB layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

19. (Original) The MTJ device of claim 15, wherein a barrier height φ of the MgO layer is in a range of 0.2 to 0.5 eV.

20. (Currently Amended) The MTJ device of claim 19, wherein the barrier height φ of the MgO layer is obtained by fitting J-V characteristics of the MTJ device 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 MgO 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 Planck's constant, Δs is an effective thickness of the MgO layer that is ~~approximately~~ equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the MgO layer ~~determined using a cross-sectional transmission electron microscope image~~.

21. (Currently Amended) The MTJ device of claim 15, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1~~includes oxygen vacancy defects~~.

22. (Currently Amended) The MTJ device of claim 19, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1~~includes oxygen vacancy defects~~.

23. (New) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode comprising a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed on the first electrode, the barrier layer comprising a magnesium oxide (MgO) layer that is a poly-crystalline MgO in which (001) crystal plane is preferentially oriented; and

a second electrode disposed on the barrier layer and comprising a second ferromagnetic material layer that includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is partially or entirely crystallized.

24. (New) The MTJ device of claim 23, wherein a value of x in MgOx for the MgO layer is greater than 0 and less than 1.

25. (New) The MTJ device of claim 23, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

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 3, 2017 (U.S. Patent Office Paper No. 20130107). 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 1-25 stand for consideration in this application, wherein claims 2, 3, 12-14, 16, 17, and 20-22 are being amended to improve form, and wherein claims 23-25 are being newly added.

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.

Examiner Interview Summary

A telephonic interview was held with Examiner Chambliss on August 21, 2017, relating to the present application. The interview was held to discuss the rejections of claims 1-14 under 35 U.S.C. §101 as being unpatentable over claim 1 of U.S. Patent Application No. 13/400,340 (U.S. Patent No. 8,405,134; "the '134 patent") and claims 15-22 as being unpatentable over claim 4 of the '134 patent on grounds of double patenting, which were issued in the Office Action mailed on July 3, 2017.

During the interview, Applicants' representative presented arguments that, because claim 1 of the '134 patent requires a tunnel barrier layer that comprises "a single-crystalline magnesium oxide in which (001) crystal plane is preferentially oriented or a poly-crystalline magnesium oxide in which (001) crystal plane is preferentially oriented," while independent claim 1 of the present application requires a barrier layer that more narrowly comprises "a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented," it would be possible to literally infringe claim 1 of the '134 patent with an embodiment in which a tunnel barrier layer comprises a single-crystalline magnesium oxide without also literally infringing claim 1 of the present application, and, therefore, the subject matter of claim 1 of the

present application is, for this reason alone, clearly different from and not identical to the subject matter of claim 1 of the '134 patent.

In reply to these arguments, the Examiner asserted that, due to the use of the term "or" in claim 1 of the '134 patent, the limitation of claim 1 of the present application noted above would "read on" the corresponding limitation of claim 1 of the '134 patent. Applicants' representative then noted the test for double patenting under 35 U.S.C. 101 that is outlined in 804.II.A of the MPEP and explained that while such an analysis may be appropriate, for example, in making a determination of anticipation under 35 U.S.C. §102, such an analysis is not appropriate for determination of whether a statutory basis for a double patenting rejection exists. In reply, the Examiner expressed that he would need to conduct a further review of the requirements for double patenting rejections outlined in section 804.II.A of the MPEP and was not able to reach an agreement or make a determination on this point during the interview.

Applicants respectfully thank Examiner Chambliss for his consideration in conducting the above-discussed interview with Applicants' representative. Additionally, in accordance with the suggestion from the Examiner in the Applicant-Initiated Interview Summary that was issued by the USPTO on August 29, 2017, Applicants are submitting a terminal disclaimer in compliance with 37 C.F.R. 1.321 herewith. In this regard, Applicants submit that the present application and the '134 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.

Double Patenting Rejections

The Examiner rejected claims 1-14 under 35 U.S.C. §101 as being unpatentable over claim 1 of U.S. Patent Application No. 13/400,340 (U.S. Patent No. 8,405,134; "the '134 patent") and claims 15-22 as being unpatentable over claim 4 of the '134 patent on grounds of double patenting. Applicants have reviewed the above-noted rejections, and hereby respectfully traverse.

In particular, Applicants note that, "[i]n 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).

Accordingly, Applicants respectfully submit that, under the literal-infringement test established by the court in *Vogel*, claims 1-22 of the present application are substantively different from and not identical to claims 1 and 4 of the '134 patent. For example, claim 1 of the '134 patent requires a tunnel barrier layer that comprises "**a single-crystalline magnesium oxide in which (001) crystal plane is preferentially oriented or a poly-crystalline magnesium oxide in which (001) crystal plane is preferentially oriented,**" while independent claim 1 of the present application specifically requires a barrier layer that comprises "a magnesium oxide (MgO) layer that is formed of **a poly-crystalline MgO** in which a (001) crystal plane is preferentially oriented."

Accordingly, it is readily apparent that there are 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 claims 1-14 of the present application, which are directed to a magnetic tunnel junction (MTJ) device comprising a barrier layer that, in contrast to the tunnel barrier layer of the embodiments of a magnetoresistive device noted above, is required to comprise a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented.

To this point, Applicants note that the Supreme Court of the United States has explicitly stated that "[e]ach element contained in a patent claim is deemed material to defining the scope of the patented invention." *Warner-Jenkinson Co. v. Hilton Davis Chemical Co.*, 117 S. Ct. 1040, 1049 (1997). In this regard, the court that established the *Vogel* literal-infringement test subsequently explained that, "[b]y the time of *In re Vogel*,...this court had decided that 'same invention' meant claims to identical subject matter, i.e., that a claim limitation to halogen was not the same as a claim to chlorine and that meat was not the same as pork, or beef, but that a claim to a yard and a claim to 36 inches or three feet were for the same invention despite their differences in wording." *In re Van Ornum*, 686 F.2d 937, 942 (CCPA 1982).

As further elucidated in section 804(II.A) of the MPEP, "the invention defined by a claim reciting a compound having a 'halogen' substituent is not identical to or substantively the same as

a claim reciting the same compound except having a 'chlorine' substituent in place of the halogen because 'halogen' is broader than 'chlorine.'" With respect to language underlying the difference between claim 1 of the '134 patent and claim 1 of the present application noted above, Applicants note that an equivalent framing of the explanation provided in the statement from MPEP quoted above could be stated as "an invention defined by a claim reciting a compound having a 'chlorine' substituent or 'another halogen' substituent is not identical to or substantively the same as a claim reciting the same compound except having a 'chlorine' substituent in place of the halogen because 'chlorine' or 'another halogen' is broader than 'chlorine.'"

Thus, because it would clearly be possible to literally infringe claim 1 of the '134 patent with an embodiment in which a tunnel barrier layer comprises a single-crystalline magnesium oxide without also literally infringing claim 1 of the present application, the subject matter of claim 1 of the present application is, for this reason alone, clearly different from and not identical to or the same as the subject matter of claim 1 of the '134 patent. Moreover, because each of claims 2-14 depends either directly or indirectly from claim 1 and, thus, must each be construed as including all the limitations contained in claim 1, it would also clearly be possible to literally infringe claim 1 of the '134 patent with an embodiment in which a tunnel barrier layer comprises a single-crystalline magnesium oxide without also literally infringing any of claims 2-14 of the present application, which, by virtue of the dependence of each upon claim 1, are each required to comprise a poly-crystalline magnesium oxide layer in which a (001) crystal plane is preferentially oriented. Accordingly, the subject matter of each of claims 2-14 of the present application is, for this reason alone, clearly different from and not identical to or the same as the subject matter of claim 1 of the '134 patent.

For at least these reasons, Applicants respectively submit that claims 1-14 of the present invention as claimed are each distinguishable from, and thus, patentable over, claim 1 of the '134 patent.

Furthermore, Applicants note that, to properly establish a same-invention double patenting rejection under 35 U.S.C. §101, it must be shown, as noted above, that either the claims in an issued patent or the claims in a pending application cannot be literally infringed without literally infringing the claims of the other. The analysis provided in support of the rejections of claims 1-14 of the present application under 35 U.S.C. §101 as being unpatentable over claim 1 of the '134 patent issued in the Office Action, however, fails to even attempt to provide any such showing

under the literal-infringement test established by the court in *Vogel*. Accordingly, Applicants respectfully submit that, because the analysis provided by the Examiner in support of the same-invention double patenting rejections of claims 1-14 lacks the necessary showing under the literal-infringement test, the Examiner has failed to establish a *prima facie* case of unpatentability of claim 1-14 under 35 U.S.C. §101.

As recognized by the Federal Circuit, "[i]f the examination at the initial stage does not produce a *prima facie* case of unpatentability, then without more the applicant is entitled to grant of the patent." *In re Oetiker*, 977 F.2d 1443, 1445 (1990). Accordingly, for this reason alone, Applicants respectively submit that claims 1-14 are patentable over the '134 patent.

As another example, claim 4 of the '134 patent requires, by virtue of its dependence upon claim 3, a tunnel barrier layer that comprises "**a single-crystalline magnesium oxide in which (001) crystal plane is preferentially oriented or a poly-crystalline magnesium oxide in which (001) crystal plane is preferentially oriented,**" while independent claim 15 of the present application specifically requires a barrier layer that is made of "a magnesium oxide (MgO) layer that is **a poly-crystalline layer** in which a (001) crystal plane is preferentially oriented."

Thus, for similar reasons to those discussed above with reference to claim 1 of the present application, because it would clearly be possible to literally infringe claim 4 of the '134 patent with an embodiment in which a tunnel barrier layer comprises a single-crystalline magnesium oxide without also literally infringing claim 15 of the present application, the subject matter of claim 15 of the present application is, for this reason alone, clearly different from and not identical to or the same as the subject matter of claim 4 of the '134 patent. Moreover, because each of claims 16-22 depends either directly or indirectly from claim 15 and, thus, must each be construed as including all the limitations contained in claim 15, it would also clearly be possible to literally infringe claim 4 of the '134 patent with an embodiment in which a tunnel barrier layer comprises a single-crystalline magnesium oxide without also literally infringing any of claims 16-22 of the present application, which, by virtue of the dependence of each upon claim 15, are each required to be made of a magnesium oxide layer that is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented. Accordingly, the subject matter of each of claims 16-22 of the present application is, for this reason alone, clearly different from and not identical to or the same as the subject matter of claim 4 of the '134 patent.

For at least these reasons, Applicants respectively submit that claims 15-22 of the present invention as claimed are each distinguishable from, and thus, patentable over, claim 4 of the '134 patent. Furthermore, Applicants respectfully submit that, because the analysis provided by the Examiner in support of the same-invention double patenting rejections of claims 15-22 under 35 U.S.C. §101 lacks the necessary showing under the literal-infringement test that either the claims in an issued patent or the claims in a pending application cannot be literally infringed without literally infringing the claims of the other, the Examiner has failed to establish a *prima facie* case of unpatentability of claim 15-22 under 35 U.S.C. §101.

Accordingly, Applicants respectively request reconsideration and withdrawal of the rejections of claims 1-22 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.

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

Nicholas B. Trenkle
Registration Number 54,500

STITES & HARBISON PLLC
1800 Diagonal Road
Suite 325
Alexandria, VA 22314
(703) 739-4900 Voice
(703) 739-9577 Fax
Customer No. 00881
October 2, 2017

2355LT:10004:417228:1

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
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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 15/428,842	Filing Date 02/09/2017	☐ 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	10/02/2017	(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))	* 25	Minus	** 22	= 3	X $80 =	240
	Independent (37 CFR 1.16(h))	* 3	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	**240**

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.

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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.**

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Application Number	Application/Control No.	Applicant(s)/Patent under Reexamination	
	15/428,842	YUASA, SHINJI	

Document Code - DISQ	Internal Document – DO NOT MAIL

TERMINAL DISCLAIMER	☒ APPROVED	☐ DISAPPROVED
Date Filed : 10/02/17	This patent is subject to a Terminal Disclaimer	

Approved/Disapproved by:
2 td's Jean Proctor

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NOTICE OF ALLOWANCE AND FEE(S) DUE

881 7590 11/24/2017

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER
CHAMBLISS, ALONZO

ART UNIT	PAPER NUMBER
2897	

DATE MAILED: 11/24/2017

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

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	02/26/2018

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:

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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.

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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.

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PTOL-85 (Rev. 02/11)

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PART B - FEE(S) TRANSMITTAL

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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.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

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	02/26/2018

EXAMINER	ART UNIT	CLASS-SUBCLASS
CHAMBLISS, ALONZO	2897	257-421000

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

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(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:
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- ❑ Publication Fee (No small entity discount permitted)
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4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
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- ❑ Applicant certifying micro entity status. See 37 CFR 1.29
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- ❑ 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.
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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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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 11/24/2017

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	
ART UNIT	PAPER NUMBER
2897	

DATE MAILED: 11/24/2017

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.

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. 15/428,842	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 terminal disclaimer filed on 10/2/17*.
   ☐ 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 *1-22*. 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. ☐ 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*.

DETAILED ACTION

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

Terminal Disclaimer

2. The terminal disclaimer filed on 10/2/17 disclaiming the terminal portion of any patent granted on this application which would extend beyond the expiration date of U.S. Patent No. 8,405,134 has been reviewed and is accepted. The terminal disclaimer has been recorded.

Response to Arguments

3. Applicant's arguments, see remarks, filed 10/2/17, with respect to claims 1-22 have been fully considered and are persuasive. The statutory double patenting rejection of claims 1-22 has been withdrawn.

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

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."

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/November 7, 2017 /Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

CPC						
Symbol					**Type**	**Version**
H01L		43	/	10	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
H01F		10	/	3254	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	/	02	I	2013-01-01
G11C		11	/	161	I	2013-01-01
H01L		27	/	222	I	2013-01-01

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

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 22	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897 (Primary Examiner)	11/7/17 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1B

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

US ORIGINAL CLASSIFICATION		INTERNATIONAL CLASSIFICATION	
CLASS	SUBCLASS	CLAIMED	NON-CLAIMED
257	295		

CROSS REFERENCE(S)					
CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				
257	427				
438	3				
365	171				

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	22	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897	11/7/17	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1B

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	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	17	17												
2	2	18	18												
5	3	19	19												
8	4	21	20												
3	5	22	21												
6	6	20	22												
10	7														
9	8														
4	9														
7	10														
11	11														
12	12														
13	13														
14	14														
15	15														
16	16														

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 22	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897 (Primary Examiner)	11/7/17 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1B

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	259	257/$.ccls. and CoFeB and (MgO magnesium adj2 oxide) same (second top upper) near5 (Fe ferromagnetic)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2017/11/07 22:13
L2	118	438/$.ccls. and CoFeB and (MgO magnesium adj2 oxide) same (second top upper) near5 (Fe ferromagnetic)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2017/11/07 22:19
L5	244	1 AND ((H01L43/08 OR H01L43/10 OR H01L43/12 OR H01L43/02 OR H01L27/222 OR G11C11/161).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2017/11/07 22:31

11/7/2017 10:31:58 PM
C:\Users\achambliss\Documents\EAST\Workspaces\15068212.wsp

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC- SEARCHED		
Symbol	Date	Examiner
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	6/25/17	AC
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	11/7/17	AC

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner

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

SEARCH NOTES		
Search Notes	Date	Examiner
East text search only - see attached printout	6/25/17	AC
Updated prevous East text search only - see attached printout	11/7/17	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner
H01L	43/10, 43/08, 43/12, 43/02, 27/222	11/7/17	AC
G11C	11/161	11/7/17	AC
US PGPUB text search only		11/7/17	AC

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.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 12/14/2017

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	

ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
12/14/2017	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

Supplemental Notice of Allowability	**Application No.** 15/428,842	**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 Notice of Allowance mailed on 11/24/17*.
   ☐ 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 *1-25*. 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.
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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).
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Attachment(s)

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

/ALONZO CHAMBLISS/
Primary Examiner, Art Unit 2897

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

CPC							
Symbol						**Type**	**Version**
H01L		43	/	10		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
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H01F		10	/	3254		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	/	02		I	2013-01-01
G11C		11	/	161		I	2013-01-01
H01L		27	/	222		I	2013-01-01

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

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 25	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897	11/7/17	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1B

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

US ORIGINAL CLASSIFICATION		INTERNATIONAL CLASSIFICATION	
CLASS	SUBCLASS	CLAIMED	NON-CLAIMED
257	295		

CROSS REFERENCE(S)					
CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				
257	427				
438	3				
365	171				

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	25	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897	11/7/17	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1B

WD EX1012
Western Digital v IP Bridge
Page 165

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	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	17	17		33										
2	2	18	18		34										
5	3	19	19		35										
8	4	20	20		36										
3	5	22	21		37										
6	6	21	22		38										
10	7	23	23		39										
9	8	24	24		40										
4	9	25	25		41										
7	10		26		42										
11	11		27		43										
12	12		28		44										
13	13		29		45										
14	14		30		46										
15	15		31		47										
16	16		32												

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 25	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897 (Primary Examiner)	11/7/17 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1B

Customized PTO/SB/30 (07-09)

REQUEST FOR CONTINUED EXAMINATION (RCE) Transmittal

Mail Stop RCE

Application #	15/428,842
Confirmation #	9576
Filing Date	February 9, 2017
First Inventor	YUASA, et al.
Art Unit	2897
Examiner	Chambliss, Alonzo
Docket #	P11338US02/NBT

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	22	- 25	0	X 25 =	X 50 =	X 100 =	0
☒ INDEP. Claims	3	- 3	0	X 115 =	X 230 =	X 460 =	0
☒ *FIRST* RCE				325	650	1300	1300
☐ *SECOND/FURTHER* RCE				475	950	1900	
☐ Extension of Time for month(s) (serving as a constructive EOT Petition)							
☐ Other fee for							
						TOTAL OF ALL FEES =	1300

☒ Payment of **$ 1300** 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: February 23, 2018

Signed By Name: Nicholas Trenkle
Attorney of Record Registration No.: 54,500

STITES & HARBISON PLLC • 1800 Diagonal Road • Suite 325 • Alexandria, VA 22314
TEL: 703-739-4900 • FAX: 703-739-9577 • CUSTOMER NO. 881

2355LT:10004:428840:1:ALEXANDRIA

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	Confirmation No. 9576
YUASA	)	
	)	Art Unit 2897
Application Number: 15/428,842	)	
	)	Examiner
Filed: February 9, 2017	)	Alonzo Chambliss
	)	
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
ATTORNEY DOCKET NO. P11338US02/NBT	)	

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

AMENDMENT AFTER ALLOWANCE UNDER 37 C.F.R. §1.114

Sir:

This is in response to the Notice of Allowance mailed on November 24, 2017. The period during which the issue fee and the publication fee can be paid is set to expire on February 26, 2018. A Request for Continued Examination (RCE) is being submitted concurrently herewith. Please amend the above-referenced application as follows:

IN THE CLAIMS

Claims 1-3, 7-9, and 11-26 are pending in this application, wherein claims 4-6 and 10 are being canceled without prejudice or disclaimer, wherein claims 1-3, 8, 9, 15-17, and 23 are being amended to improve form, and wherein claim 26 is being newly added, all as follows:

1. (Currently Amended) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode comprising a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed over the first electrode, the barrier layer comprising a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented; and

a second electrode disposed over the barrier layer and comprising a second ferromagnetic material layer that includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is entirely crystallized.

2. (Currently Amended) The MTJ device of claim 1, ~~wherein each of the first and second ferromagnetic material layers is partially crystallized.~~ wherein the first ferromagnetic material layer is in direct contact with the barrier layer, and wherein the second ferromagnetic material layer is in direct contact with the barrier layer.

3. (Currently Amended) The MTJ device of claim 1, ~~wherein each of the first and second ferromagnetic material layers is entirely crystallized.~~ wherein the first ferromagnetic material layer is in direct contact with the MgO layer, and wherein the second ferromagnetic material layer is in direct contact with the MgO layer.

4-6. (Canceled).

7. (Original) The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

8. (Currently Amended) The MTJ device of claim 2[[4]], wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

9. (Currently Amended) The MTJ device of claim 3[[5]], wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

10. (Canceled).

11. (Original) The MTJ device of claim 1, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

12. (Previously Presented) The MTJ device of claim 11, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device 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 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 Planck's constant, Δs is an effective thickness of the barrier layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer.

13. (Previously Presented) The MTJ device of claim 1, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1.

14. (Previously Presented) The MTJ device of claim 1, wherein a value of x in MgO_x for the MgO layer is greater than 0.9 and less than 1.

15. (Currently Amended) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode made of a first CoFeB layer;

a barrier layer made of a magnesium oxide (MgO) layer that is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented; and

a second electrode made of a second CoFeB layer, and

wherein the barrier layer is located between the first electrode and the second electrode, and

wherein both the first and second CoFeB layers are entirely crystallized.

16. (Currently Amended) The MTJ device of claim 15, ~~wherein each of the first and second CoFeB layers is partially crystallized.~~ wherein the first CoFeB layer is in direct contact with the MgO layer, and wherein the second CoFeB layer is in direct contact with the MgO layer.

17. (Currently Amended) The MTJ device of claim 15, ~~wherein each of the first and second CoFeB layers is entirely crystallized.~~ wherein the MgO layer and the first CoFeB layer form a first interface of the MTJ, and wherein the MgO layer and the second CoFeB layer form a second interface of the MTJ.

18. (Original) The MTJ device of claim 15, wherein each of the first and second CoFeB layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

19. (Original) The MTJ device of claim 15, wherein a barrier height φ of the MgO layer is in a range of 0.2 to 0.5 eV.

20. (Previously Presented) The MTJ device of claim 19, wherein the barrier height φ of the MgO layer is obtained by fitting J-V characteristics of the MTJ device to an equation (1):

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

where J is a tunnel current density flowing through the MgO 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 Planck's constant, Δs is an effective thickness of the MgO layer that is equivalent to (t_{MgO}-0.5 nm), and t_{MgO} is an actual thickness of the MgO layer.

21. (Previously Presented) The MTJ device of claim 15, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1.

22. (Previously Presented) The MTJ device of claim 19, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1.

23. (Currently Amended) A magnetic tunnel junction (MTJ) device, comprising:

~~a first electrode comprising~~ a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed on the first ferromagnetic material layer~~electrode~~, the barrier layer comprising a magnesium oxide (MgO) layer that is a poly-crystalline MgO in which (001) crystal plane is preferentially oriented; and

~~a second electrode disposed on the barrier layer and comprising~~ a second ferromagnetic material layer that is disposed on the barrier layer and includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is ~~partially or~~ entirely crystallized.

24. (Previously Presented) The MTJ device of claim 23, wherein a value of x in MgOx for the MgO layer is greater than 0 and less than 1.

25. (Previously Presented) The MTJ device of claim 23, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

26. (New) The MTJ device of claim 25, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device 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 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 Planck's constant, Δs is an effective thickness of the barrier layer that is equivalent to (t_{MgO}–0.5 nm), and t_{MgO} is an actual thickness of the barrier layer.

Remarks

The above amendments to the above-captioned application along with the following remarks are being submitted after the Notice of Allowance dated November 24, 2017 as an amendment after allowance under 37 C.F.R. § 1.114. A Request for Continued Examination (RCE) is being submitted concurrently herewith. In view of the above amendments and the following remarks, the Examiner is respectfully requested to give due reconsideration to this application, to confirm the allowability of the claims, and to pass this case to issue.

Status of the Claims

As outlined above, 1-3, 7-9, and 11-26 are pending in this application, wherein claims 4-6 and 10 are being canceled without prejudice or disclaimer, wherein claims 1-3, 8, 9, 15-17, and 23 are being amended to improve form, and wherein claim 26 is being newly added. All amendments to the application are fully supported therein. For example, the amendments to the claims are supported by paragraphs [0035-42] and [0049-50] of the present application as originally filed, as well as by Figures 2(A)-2(D) and 11. Applicants hereby submit that no new matter is being introduced into the application through the submission of this amendment.

The amendments to the claims being submitted herein merely embody corrections that have now been recognized as needed to for proper protection of the invention as claimed. Applicants respectfully submit that the amendments will require no substantial amount of additional work on the part of the Office. In particular, Applicants respectfully submit that each of claims 1, 15, and 23 as amended remains allowable over the prior art of record. Moreover, because claims 2, 3, 7-9, and 11-14, claims 16-22, and claims 24-26 depend either directly or indirectly from claims 1, 15, and 23 respectively, Applicants respectfully submit that claims 2, 3, 7-9, and 11-14, claims 16-22, and claims 24-26 are allowable for at least the same reasons as claims 1, 15, and 23 respectively.

Conclusion

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,

/NicholasBTrenkle/
Nicholas B. Trenkle
Registration Number 54,500

STITES & HARBISON PLLC
1800 Diagonal Road
Suite 325
Alexandria, VA 22314
(703) 739-4900 Voice
(703) 739-9577 Fax
Customer No. 00881
February 23, 2018

2355LT:10004:427682:1

INFORMATION DISCLOSURE STATEMENT		
	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
	Docket #	P11338US02/NBT

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.

☐ 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: February 23, 2018

Nicholas Trenkle

By: Nicholas Trenkle
Registration No.: 43,259

STITES & HARBISON PLLC • 1800 Diagonal Road • Suite 325 • Alexandria, VA 22314
TEL: 703-739-4900 • FAX: 703-739-9577 • CUSTOMER NO. 881

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

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
Sheet 1 of 1	Docket #	P11338US02/NBT

U.S. PATENT DOCUMENTS

Initial (*)	Document No. Number – Kind Code	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Corresponds to
	US-2006/003185	01-05-2006	PARKIN	
	US-7,252,852	08/07/2007	PARKIN	

FOREIGN PATENT DOCUMENTS

Initial (*)	Country-Number-Kind Code If known	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Trans-lation

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

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.*

Electronic Patent Application Fee Transmittal

Application Number:	15428842
Filing Date:	09-Feb-2017
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Stephen John Weyer/Stacy Johnson
Attorney Docket Number:	P11338US02/NBT

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($)
Miscellaneous:				
RCE- 1st Request	1801	1	1300	1300
		Total in USD ($)		**1300**

Electronic Acknowledgement Receipt	
EFS ID:	31877104
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Stephen John Weyer/Stacy Johnson
Filer Authorized By:	Stephen John Weyer
Attorney Docket Number:	P11338US02/NBT
Receipt Date:	23-FEB-2018
Filing Date:	09-FEB-2017
Time Stamp:	17:56:27
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$1300
RAM confirmation Number	022618INTEFSW17571200
Deposit Account	
Authorized User	
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		P11338US92RCE_Response.pdf	642983 ac4af1b9252d6f45fe28ebb599973f647f986a2e	yes	8
	Multipart Description/PDF files in .zip description				
	Document Description		**Start**	**End**	
	Request for Continued Examination (RCE)		1	1	
	Amendment Submitted/Entered with Filing of CPA/RCE		2	8	
Warnings:					
Information:					
2		P11338US02IDSLetter_List.pdf	308913 91b4fe9d18a90d62c4006083339dc5c8ecb32e79	yes	3
	Multipart Description/PDF files in .zip description				
	Document Description		**Start**	**End**	
	Transmittal Letter		1	2	
	Information Disclosure Statement (IDS) Form (SB08)		3	3	
Warnings:					
Information:					
3	Fee Worksheet (SB06)	fee-info.pdf	30659 d55ec90a59e3e0d47dc44708cf6da8e82e9020f6	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	982555		

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.

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
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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 15/428,842	Filing Date 02/09/2017	☐ 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		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	02/23/2018						
	Total (37 CFR 1.16(i))	* 22	Minus	** 25	= 0	X $100 =	0
	Independent (37 CFR 1.16(h))	* 3	Minus	***3	= 0	X $460 =	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.

SLIE
BRENDA L. GRAY

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.

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
Sheet 1 of 1	Docket #	P11338US02/NBT

U.S. PATENT DOCUMENTS

Initial (*)	Document No. Number – Kind Code	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Corresponds to
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Initial (*)	Country-Number-Kind Code If known	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Trans-lation
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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	Trans-lation
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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.*

INFORMATION DISCLOSURE STATEMENT		
	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
	Docket #	P11338US02/NBT

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. In accordance with 37 CFR 1.98(d)(1)-(2), each copy of any patent, publication, pending U.S. application or other information, listed in the accompanying information disclosure statement that is required to be provided was previously submitted to, or cited by, the Office in one of the following earlier applications that are relied on by the present application for an earlier effective filing date under 35 U.S.C. 120:

- U.S. Patent Application No.: 14/837,558, filed August 27, 2015, now U.S. Patent No.: 9,608,198, issued March 28, 2017;
- U.S. Patent Application No.: 13/767,290, filed February 14, 2013, now U.S. Patent No.: 9,123,463, issued September 1, 2015;
- U.S. Patent Application No.: 13/400,340, filed February 20, 2012, now U.S. Patent No.: 8,405,134, issued March 26, 2013;
- U.S. Patent Application No.: 12/923,643, filed September 30, 2010, now U.S. Patent No.: 8,319,263, issued November 27, 2012; and
- U.S. Patent Application No.: 10/591,947, filed September 8, 2006, now U.S. Patent No.: 7,884,403, issued February 8, 2011.

☒ 2. 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

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Page 191

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).*

☐ 3. 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:
  - ☐ $240 large entity or
  - ☐ $120 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.

☐ 4. 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:
  - ☐ $240 large entity or
  - ☐ $120 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.

☐ 5. 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).

☒ 6. 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.

☒ 7. 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:

By: Nicholas Trenkle
Registration No.: 54500

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Electronic Acknowledgement Receipt

EFS ID:	32158816
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Stephen John Weyer/Stacy Johnson
Filer Authorized By:	Stephen John Weyer
Attorney Docket Number:	P11338US02/NBT
Receipt Date:	26-MAR-2018
Filing Date:	09-FEB-2017
Time Stamp:	16:19:40
Application Type:	Utility under 35 USC 111(a)

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Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		P11338US02IDSLetter_List.pdf	1351068 ef7aca82863d4e7f453027907331c584d89382c6	yes	10

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Information Disclosure Statement (IDS) Form (SB08)	4	10
	Transmittal Letter	1	3
Warnings:			
Information:			
	Total Files Size (in bytes):	1351068	

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.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 06/01/2018

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	

ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
06/01/2018	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. 15/428,842	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 *2/23/18*.

☐ 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) *1-3,7-9 and 11-26* 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) *1-3,7-9 and 15-26* is/are rejected.

8)☒ Claim(s) *11 and 14* is/are objected to.

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

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

Application Papers

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

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

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

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

Priority under 35 U.S.C. § 119

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

Certified copies:

a)☒ All b)☐ Some** c)☐ None of the:

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

2.☒ Certified copies of the priority documents have been received in Application No. 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 *2/23/18,3/26/18*.

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 allowance or after an Office action under *Ex Parte Quayle*, 25 USPQ 74, 453 O.G. 213 (Comm'r Pat. 1935). 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, prosecution in this application has been reopened pursuant to 37 CFR 1.114. Applicant's submission filed on 2/23/18 has been entered.

Information Disclosure Statement

3. The information disclosure statement (IDS) submitted on 2/23/18 and 3/26/18 were filed after the mailing date of the Non-Final rejection on 5/25/18. The submission is in compliance with the provisions of 37 CFR 1.97. Accordingly, the information disclosure statement is being considered by the examiner.

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, 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 1-3 and 7-9 are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over Parkin (US 7,252,852) in view of Ohba et al. (US 2006/0125034).

With respect to Claims 1, Parkin discloses a first electrode comprising a first ferromagnetic material layer 119 that includes an amorphous Co, Fe, and B. A barrier layer 120' disposed over the first electrode, the barrier layer 120' comprising a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented. A second electrode disposed over the barrier layer and comprising a second ferromagnetic material layer 134 that includes an amorphous Co, Fe, and B. Each of the first and second ferromagnetic material layers is crystallized (see col. 15 lines 38-67, col. 16 lines 1-67, col. 18 lines 46-67, col. 19 and col. 32 lines 1-4; Figs. 2A-2C). Parkin fails explicitly disclose the first and second ferromagnetic material layers is entirely crystallized. However, Ohba discloses a first

and second ferromagnetic material layers should be crystalline material free from a defect in which a crystal structure is changed such as to be crystallized by annealing (see paragraph 74). Thus, Parkin and Ohba have substantially the same environment of a plurality of ferromagnetic layers attached to a barrier layer. Therefore, one skilled in the art at the time of invention would readily recognized to having the first and second ferromagnetic layers of Parkin-Ohba be entirely crystallized, since the annealing process of Ohba to one skilled in the art would allow the first and second ferrmomagnetic layers to be entirely crystallized based on the annealing process to create the desired result for the MTJ device.

With respect to Claim 2, Parkin discloses wherein the first ferromagnetic material layer is in direct contact, with the barrier layer, and wherein the second ferromagnetic material layer is in direct contact with the barrier layer (see Fig. 2B).

With respect to Claim 3, Parkin discloses the first ferromagnetic material layer is in direct contact with the MgO layer, and wherein the second ferromagnetic material layer is in direct contact with the MgO layer (see Fig. 2B).

With respect to Claims 7-9, Parkin discloses wherein each of the first and second ferromagnetic material layers (i.e. made of CoFeB) is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented (see col. 5 lines 60-62). In the other publications section of the Parkin. The (M. Klaua et al.) reference shoes a ferromagnetic material having a (001) crystal plane. Therefore, Parkin would discloses first and second ferromagnetic material made of CoFeB having a (001) crystal plane

since a (001) crystal plane is well known in the semiconductor industry as taught by the M. Klaua et al. reference.

Double Patenting

7. 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); *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.

8. Claims 15-22 are rejected under 35 U.S.C. 101 as claiming the same invention as that of claim 4 of prior U.S. Patent No. 8,405,134. This is a statutory double patenting rejection.

9. Claims 23-26 are rejected under 35 U.S.C. 101 as claiming the same invention as that of claim 3 of prior U.S. Patent No. 8,405,134. This is a statutory double patenting rejection.

Allowable Subject Matter

10. Claims 11-14 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.

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 wherein a barrier height @ of the barrier layer is in a range of .2 to .5 eV in claim 11.

A value of x in MgO_x for the MgO layer is greater than 0 and less than 1 in claim 13.

A value of x in MgO_x for the MgO layer is greater than .9 and less than 1 in claim 14.

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

Conclusion

15. 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 25, 2018

/Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Notice of References Cited	Application/Control No. 15/428,842	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	CPC Classification	US Classification
*	A	US-6,449,133 B1	09-2002	Makino; Eiji	B82Y10/00	360/324.11
*	B	US-2006/0125034 A1	06-2006	Ohba; Kazuhiro	B82Y10/00	257/421
	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	CPC Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

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

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in 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	105	257/$.ccls. and (fully entire$2) with ferromagnetic adj2 material	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/05/23 22:50
L2	6	(MTJ magnetic adj2 tunnel adj2 junction non adj2 volatile) and entire$2 same crystal$5 same ferromagnetic adj2 material	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/05/23 22:50
L3	28	257/$.ccls. and (fully entire$2) with crystal$5 same ferromagnetic	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/05/23 22:51
L4	322	(MTJ magnetic adj2 tunnel adj2 junction) and amorphous with crystal$5 with CoFeB and barrier	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/05/23 22:52
L5	597	257/$.ccls. and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB same MgO with barrier	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/05/23 22:53
L6	975	257/$.ccls. and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB and MgO with barrier	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/05/23 22:54
L7	967	L6 AND ((H01L43/08 OR H01L43/02 OR H01L43/10 OR H01L43/12 OR H01L27/222 OR G11C11/161 OR G11C11/16 OR G11C11/15 OR H01F10/3254 OR B82Y25/00 OR H01F10/132 OR H01L27/228 OR H01L27/11507).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/05/23 22:55

5/23/2018 10:57:58 PM

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

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
Sheet 1 of 1	Docket #	P11338US02/NBT

U.S. PATENT DOCUMENTS

Initial (*)	Document No. Number – Kind Code	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Corresponds to
	US-2006/003185	01-05-2006	PARKIN	
	US-7,252,852	08/07/2007	PARKIN	

FOREIGN PATENT DOCUMENTS

Initial (*)	Country-Number-Kind Code if known	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Trans-lation

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

Examiner Signature	/ALONZO CHAMBLISS/	Date Considered	05/23/2018

* *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:10004:427393:I:ALEXANDRIA

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /A.C/

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	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	06/25/2017	05/25/2018							
	1	✓	✓							
	2	✓	✓							
	3	✓	✓							
	4	✓								
	5	✓								
	6	✓								
	7	✓	✓							
	8	✓	✓							
	9	✓	✓							
	10	✓								
	11	✓	O							
	12	✓	O							
	13	✓	O							
	14	✓	O							
	15	✓	✓							
	16	✓	✓							
	17	✓	✓							
	18	✓	✓							
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	20	✓	✓							
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Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	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	06/25/2017	05/25/2018							
	37									
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Customized PTO/SB/08a+b (07-09)

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
Sheet 1 of 1	Docket #	P11338US02/NBT

U.S. PATENT DOCUMENTS

Initial (*)	Document No. Number – Kind Code	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Corresponds to
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2355LT:10004:415842:1:ALEXANDRIA

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /A.C/

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Initial (*)	Country-Number-Kind Code If known	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Trans-lation
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	JP 2003-304010	10/24/2003	Sony Corp	Abst
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	EP 1 391 942	5/24/2002	Nat. Inst. Of Adv. Ind. & Technol., et al.	Yes
	WO 2003/085750	10/16/2003	Sony Corp	Abst

2355LT:10004:415842:1:ALEXANDRIA

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /A.C/

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	EP 1 633 007	3/8/2006	Anelva Corporation	Yes
	EP 1 085 586	3/21/2001	Kabushiki Kaisha Toshiba	Yes
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	EP 0 145 403	06/19/1985	Energy Conversion Devices, Inc.	Yes
	EP 1 061 592	12/20/2000	Odagawa et al.	Yes
	EP 1 793 434	06/06/2007	Japan Science and Technology Agency	Yes
	JP 2002-359413	12/13/2002	Nat. Inst. Of Adv. Ind. & Technol., et al.	Abstr
	JP 2003-86863	03/20/2003	Nat. Inst. Of Adv. Ind. & Technol, et al.	Abst
	JP 2004-063592	02/26/2004	Sony Corp.	Abst
	JP 2004-128015	04/22/2004	Sony Corp.	
	JP 2004-153258	05/27/2004	Hewlett Packard Development Co.	Abst
	KR 2002-0042448	06/05/2002	Anelva Corp.	Abst
	KR 2003-0097904	12/31/2003	Nagahama et al.	Partial
	WO 01/056090	08/02/2001	Takahashi	Abst
	JP2004022599	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
	International Search Report of PCT/JP2005/004720 mailed June 21, 2005	Yes
	WOLF, S.A. et al., "Spintronics: A Spin-Based Electronics Vision for the Future", Science, Vol. 294, November 16, 2001, pp. 1488-1495.	Yes
	WULFHEKEL, W. et al., "Single-Crystal Magnetotunnel Junctions", Applied Physics Letters, Vol. 78, No. 4, January 22, 2001, pp. 509-511	Yes
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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /A.C/

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	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.	Yes
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	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.	Yes
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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /A.C/

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Examiner Signature	/ALONZO CHAMBLISS/ 05/23/2018	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:10004:415842:1:ALEXANDRIA

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /A.C/

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15428842	YUASA, SHINJI
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC- SEARCHED		
Symbol	Date	Examiner
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	6/25/17	AC
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	11/7/17	AC
H01F10/3254, 10/132: B82Y25/00: G11C11/15, 11/15, 11/161: H01L43/08, 43/02, 43/10, 43/12, 27/222, 27/228, 27/11507	5/25/18	AC

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner

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

SEARCH NOTES		
Search Notes	Date	Examiner
East text search only - see attached printout	6/25/17	AC
Updated prevous East text search only - see attached printout	11/7/17	AC
Updated prevous East text search only - see attached printout	5/28/18	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner
H01L	43/10, 43/08, 43/12, 43/02, 27/222	11/7/17	AC
G11C	11/161	11/7/17	AC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	**US Subclass / CPC Group**	**Date**	**Examiner**
US PGPUB text search only		11/7/17	AC

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 07/23/2018

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	

ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
07/23/2018	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

Applicant-Initiated Interview Summary	Application No.	Applicant(s)	
	15/428,842	YUASA, SHINJI	
	Examiner	Art Unit	
	ALONZO CHAMBLISS	2897	

All participants (applicant, applicant's representative, PTO personnel):

(1) *ALONZO CHAMBLISS*. (3)_____.

(2) *Nicholas B. Trenkle*. (4)_____.

Date of Interview: *13 July 2018*.

Type: ☒ Telephonic ☐ Video Conference
☐ Personal [copy given to: ☐ applicant ☐ applicant's representative]

Exhibit shown or demonstration conducted: ☐ Yes ☒ No.
If Yes, brief description: _____.

Issues Discussed ☐101 ☐112 ☐102 ☒103 ☐Others
(For each of the checked box(es) above, please describe below the issue and detailed description of the discussion)

Claim(s) discussed: *1 and 23*.

Identification of prior art discussed: *US 7,252,852 and US 8,405,134*.

Substance of Interview
(For each issue discussed, provide a detailed description and indicate if agreement was reached. Some topics may include: identification or clarification of a reference or a portion thereof, claim interpretation, proposed amendments, arguments of any applied references etc...)

Applicant's attorney called to discuss the agenda faxed to the examiner. The examiner agreed that the statutory double patenting rejection should be a non statutory rejection. In regards to the 103 rejection the examiner felt that the prior art read on the claimed invention. However, the examiner was not able to full review the prior art since the agenda was faxed over just hours before the interview. The examiner is waiting for a formal response by the attorney.

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

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

☐ Attachment

/ALONZO CHAMBLISS/ Primary Examiner, Art Unit 2897	

Summary of Record of Interview Requirements

Manual of Patent Examining Procedure (MPEP), Section 713.04, Substance of Interview Must be Made of Record
A complete written statement as to the substance of any face-to-face, video conference, or telephone interview with regard to an application must be made of record in the application whether or not an agreement with the examiner was reached at the interview.

Title 37 Code of Federal Regulations (CFR) § 1.133 Interviews
Paragraph (b)

In every instance where reconsideration is requested in view of an interview with an examiner, a complete written statement of the reasons presented at the interview as warranting favorable action must be filed by the applicant. An interview does not remove the necessity for reply to Office action as specified in §§ 1.111, 1.135. (35 U.S.C. 132)

37 CFR §1.2 Business to be transacted in writing.
All business with the Patent or Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office. No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt.

The action of the Patent and Trademark Office cannot be based exclusively on the written record in the Office if that record is itself incomplete through the failure to record the substance of interviews.

It is the responsibility of the applicant or the attorney or agent to make the substance of an interview of record in the application file, unless the examiner indicates he or she will do so. It is the examiner's responsibility to see that such a record is made and to correct material inaccuracies which bear directly on the question of patentability.

Examiners must complete an Interview Summary Form for each interview held where a matter of substance has been discussed during the interview by checking the appropriate boxes and filling in the blanks. Discussions regarding only procedural matters, directed solely to restriction requirements for which interview recordation is otherwise provided for in Section 812.01 of the Manual of Patent Examining Procedure, or pointing out typographical errors or unreadable script in Office actions or the like, are excluded from the interview recordation procedures below. Where the substance of an interview is completely recorded in an Examiners Amendment, no separate Interview Summary Record is required.

The Interview Summary Form shall be given an appropriate Paper No., placed in the right hand portion of the file, and listed on the "Contents" section of the file wrapper. In a personal interview, a duplicate of the Form is given to the applicant (or attorney or agent) at the conclusion of the interview. In the case of a telephone or video-conference interview, the copy is mailed to the applicant's correspondence address either with or prior to the next official communication. If additional correspondence from the examiner is not likely before an allowance or if other circumstances dictate, the Form should be mailed promptly after the interview rather than with the next official communication.

The Form provides for recordation of the following information:
- Application Number (Series Code and Serial Number)
- Name of applicant
- Name of examiner
- Date of interview
- Type of interview (telephonic, video-conference, or personal)
- Name of participant(s) (applicant, attorney or agent, examiner, other PTO personnel, etc.)
- An indication whether or not an exhibit was shown or a demonstration conducted
- An identification of the specific prior art discussed
- An indication whether an agreement was reached and if so, a description of the general nature of the agreement (may be by attachment of a copy of amendments or claims agreed as being allowable). Note: Agreement as to allowability is tentative and does not restrict further action by the examiner to the contrary.
- The signature of the examiner who conducted the interview (if Form is not an attachment to a signed Office action)

It is desirable that the examiner orally remind the applicant of his or her obligation to record the substance of the interview of each case. It should be noted, however, that the Interview Summary Form will not normally be considered a complete and proper recordation of the interview unless it includes, or is supplemented by the applicant or the examiner to include, all of the applicable items required below concerning the substance of the interview.

A complete and proper recordation of the substance of any interview should include at least the following applicable items:
1) A brief description of the nature of any exhibit shown or any demonstration conducted,
2) an identification of the claims discussed,
3) an identification of the specific prior art discussed,
4) an identification of the principal proposed amendments of a substantive nature discussed, unless these are already described on the Interview Summary Form completed by the Examiner,
5) a brief identification of the general thrust of the principal arguments presented to the examiner,
   (The identification of arguments need not be lengthy or elaborate. A verbatim or highly detailed description of the arguments is not required. The identification of the arguments is sufficient if the general nature or thrust of the principal arguments made to the examiner can be understood in the context of the application file. Of course, the applicant may desire to emphasize and fully describe those arguments which he or she feels were or might be persuasive to the examiner.)
6) a general indication of any other pertinent matters discussed, and
7) if appropriate, the general results or outcome of the interview unless already described in the Interview Summary Form completed by the examiner.

Examiners are expected to carefully review the applicant's record of the substance of an interview. If the record is not complete and accurate, the examiner will give the applicant an extendable one month time period to correct the record.

Examiner to Check for Accuracy

If the claims are allowable for other reasons of record, the examiner should send a letter setting forth the examiner's version of the statement attributed to him or her. If the record is complete and accurate, the examiner should place the indication, "Interview Record OK" on the paper recording the substance of the interview along with the date and the examiner's initials.

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

Substitute for Form 1449/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT**		
	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
Sheet 1 of 1	Docket #	P11338US02/NBT

U.S. PATENT DOCUMENTS

Initial (*)	Document No. Number – Kind Code	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Corresponds to

FOREIGN PATENT DOCUMENTS

Initial (*)	Country-Number-Kind Code if known	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Trans-lation
	JPA-2004-31605	01-29-2004	SONY CORPORATION	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

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.*

2355LT:10004:449926:1:ALEXANDRIA

(19) Japan Patent Office (JP) (12) Gazette for Japanese Published Unexamined Patent Applications (A) (11) Publication number

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(P2004-31605A)

(43) Date of publication of application January 29, 2004 (2004.1.29)

(51) Int. Cl.[7]	FI		Theme Code (Reference)
H01L 43/08	H01L 43/08	Z	5E049
G11C 11/15	H01L 43/08	M	5F083
HO1F 10/16	G11C 11/15	110	
H01L 27/105	H01F 10/16		
H01L 43/10	H01L 43/10		

Request for Examination Not yet Number of claims 24 OL

(21 pages in total) Continued to the last page

(21) Application number 2002-185164 (P2002-185164)

(22) Date of filing June 25, 2002 (2002.6.25)

(71) Applicant 000002185

Sony Corporation

7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

(74) Representative 100122884

TSUNODA Yoshisue Patent Attorney

(74) Representative 100113516

ISOYAMA Hironobu Patent Attorney

(72) Inventor HOSOMI Masanori

c/o Sony Corporation

7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

(72) Inventor MIZUGUCHI Tetsuya

c/o Sony Corporation

7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

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(54) Magnetoresistive Effect Element, Magnetic Memory Device, and Methods for manufacturing these

(57) Abstract

[Problem to be solved] To achieve excellent asteroid curve, high rate of change in resistance value, reduction in coercive force, and stabilization of magnetic characteristics.

[Solution] A magnetoresistive effect element includes a pair of ferromagnetic layers facing each other via an intermediate layer and is configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to the surfaces of the layers. At least one of the ferromagnetic layers is a crystalline ferromagnetic layer containing FeCoB or FeCoNiB.

The crystalline ferromagnetic layer is formed by crystallizing a sputtered film containing FeCoB or FeCoNiB.

[Selected Drawings] Fig. 1

CLAIMS

[Claim 1]

A magnetoresistive effect element comprising:

a pair of ferromagnetic layers facing each other via an intermediate layer and being configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to surfaces of the layers, wherein

at least one of the ferromagnetic layers is a crystalline ferromagnetic layer containing FeCoB or FeCoNiB.

[Claim 2]

The magnetoresistive effect element according to claim 1, wherein the at least one of the crystalline ferromagnetic layers is a ferromagnetic layer formed by crystallizing a sputtered film containing FeCoB or FeCoNiB.

[Claim 3]

The magnetoresistive effect element according to claim 1 or 2, wherein the at least one of the crystalline ferromagnetic layers has a composition represented by a compositional formula $Fe_xCo_yB_z$ (x, y, and z in the compositional formula represent each atomic %) where $5 \leq x \leq 45$, $35 \leq y \leq 85$, $10 \leq z \leq 30$, and $x+y+z=100$.

[Claim 4]

The magnetoresistive effect element according to claim 1 or 2, wherein the at

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least one of the crystalline ferromagnetic layers has a composition represented by a compositional formula $Fe_aCo_bNi_cB_d$ (a through d in the compositional formula represent each atomic %) where $5 \leq a \leq 45$, $35 \leq b \leq 85$, $0 < c \leq 35$, $10 \leq d \leq 30$, and $a+b+c+d=100$.

[Claim 5]

The magnetoresistive effect element according to claim 1, wherein the tunnel magnetoresistance element is a tunnel magnetoresistive effect element, of which the intermediate layer functions as a tunnel barrier layer.

[Claim 6]

The magnetoresistive effect element according to claim 1, wherein the magnetoresistive effect element is a spin-valve type magnetoresistive effect element in which one of the pair of the ferromagnetic layers is a magnetic fixed layer and the other of the pair of the ferromagnetic layers is an information recording layer.

[Claim 7]

The magnetoresistive effect element according to claim 1, wherein the ferromagnetic layers have each a laminated ferri structure.

[Claim 8]

A method for manufacturing a magnetoresistive effect element including a pair of ferromagnetic layers facing each other via an intermediate layer and being configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to surfaces of the layers, the method comprising the steps of:

depositing a ferromagnetic material layer, as at least one of the pair of the ferromagnetic layers, containing FeCoB or FeCoNiB and having an amorphous or microcrystalline structure; and

subsequently heat-treating the ferromagnetic material layer at a temperature equal to or higher than a crystallization temperature of the ferromagnetic material layer in a magnetic field and transforming the amorphous or microcrystalline structure to a crystalline structure.

[Claim 9]

The method for manufacturing a magnetoresistive effect element according to claim 8, wherein the ferromagnetic material layer with the amorphous or microcrystalline structure containing FeCoB or FeCoNiB is deposited by sputtering.

[Claim 10]

The method for manufacturing a magnetoresistive effect element according to claim 8 or 9, wherein the ferromagnetic material layer with the amorphous or

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microcrystalline structure has a composition represented by a compositional formula $Fe_xCo_yB_z$ (x, y, and z in the compositional formula represent each atomic %) where $5 \leq x \leq 45$, $35 \leq y \leq 85$, $10 \leq z \leq 30$, and $x+y+z=100$.

[Claim 11]

The method for manufacturing a magnetoresistive effect element according to claim 8 or 9, wherein the ferromagnetic material layer with the amorphous or microcrystalline structure has composition represented by a compositional formula $Fe_aCo_bNi_cB_d$ (a through d in the compositional formula represent each atomic %) where $5 \leq a \leq 45$, $35 \leq b \leq 85$, $0 < c \leq 35$, $10 \leq d \leq 30$, and $a+b+c+d=100$.

[Claim 12]

The method for manufacturing a magnetoresistive effect element according to claim 8, wherein a heat-treating temperature T [°C] in a magnetic field is set to satisfy: $280+2\times(\text{content of B [\%]}) \leq T \leq 400$.

[Claim 13]

A magnetic memory device comprising:

a magnetoresistive effect element including a pair of ferromagnetic layers facing each other via an intermediate layer and being configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to surfaces of the layers; and

a bit line and a word line which put the magnetoresistive effect element therebetween in the direction of thickness of the magnetoresistive effect element, wherein

at least one of the ferromagnetic layers is a crystalline ferromagnetic layer containing FeCoB or FeCoNiB.

[Claim 14]

The magnetic memory device according to claim 13, wherein the at least one of the crystalline ferromagnetic layers is a ferromagnetic layer formed by crystallizing a sputtered film containing FeCoB or FeCoNiB.

[Claim 15]

The magnetic memory device according to claim 13 or 14, wherein the at least one of the crystalline ferromagnetic layers has a composition represented by a compositional formula $Fe_xCo_yB_z$ (x, y, and z in the compositional formula represent each atomic %) where $5 \leq x \leq 45$, $35 \leq y \leq 85$, $10 \leq z \leq 30$, and $x+y+z=100$.

[Claim 16]

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The magnetic memory device according to claim 13 or 14, wherein the at least one of the crystalline ferromagnetic layers has a composition represented by a compositional formula $Fe_aCo_bNi_cB_d$ (a through d in the compositional formula represent each atomic %) where $5 \leq a \leq 45$, $35 \leq b \leq 85$, $0 < c \leq 35$, $10 \leq d \leq 30$, and $a+b+c+d=100$.

[Claim 17]

The magnetic memory device according to claim 13, wherein the magnetoresistive effect element is a tunnel magnetoresistive effect element, of which the intermediate layer functions as a tunnel barrier layer.

[Claim 18]

The magnetic memory device according to claim 13, wherein the magnetoresistive effect element is a spin-valve type tunnel magnetoresistance element in which one of the pair of the ferromagnetic layers is a magnetic fixed layer and the other of the pair of the ferromagnetic layers is an information recording layer.

[Claim 19]

The magnetic memory device according to claim 13, wherein the ferromagnetic layers have each a laminated ferri structure.

[Claim 20]

A method for manufacturing a magnetic memory device including a pair of ferromagnetic layers facing each other via an intermediate layer and being configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to surfaces of the layers; and a bit line and a word line which put the magnetoresistive effect element therebetween in the direction of thickness, the method comprising the steps of:

depositing a ferromagnetic material layer, as at least one of the pair of the ferromagnetic layers, containing FeCoB or FeCoNiB and having an amorphous or microcrystalline structure; and

subsequently heat-treating the ferromagnetic material layer at a temperature equal to or higher than a crystallization temperature of the ferromagnetic material layer in a magnetic field and transforming the amorphous or microcrystalline structure to a crystalline structure.

[Claim 21]

The method for manufacturing a magnetoresistive effect element according to claim 20, wherein the ferromagnetic material layer with an amorphous or microcrystalline structure containing FeCoB or FeCoNiB is deposited by sputtering.

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[Claim 22]

The method for manufacturing a magnetoresistive effect element according to claim 20 or 21, wherein the ferromagnetic material layer with an amorphous or microcrystalline structure has a composition represented by a compositional formula $Fe_xCo_yB_z$ (x, y, and z in the compositional formula represent each atomic %) where $5 \leq x \leq 45$, $35 \leq y \leq 85$, $10 \leq z \leq 30$, and $x+y+z=100$.

[Claim 23]

The method for manufacturing a magnetoresistive effect element according to claim 20 or 21, wherein the ferromagnetic material layer with an amorphous or microcrystalline structure has composition represented by a compositional formula $Fe_aCo_bNi_cB_d$ (a through d in the compositional formula represent each atomic %) where $5 \leq a \leq 45$, $35 \leq b \leq 85$, $0 < c \leq 35$, $10 \leq d \leq 30$, and $a+b+c+d=100$.

[Claim 24]

The method for manufacturing a magnetoresistive effect element according to claim 20, wherein the heat-treating temperature T [°C] in the magnetic field is set to satisfy:

$280+2\times(\text{content of B [\%]}) \leq T \leq 400$.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a magnetoresistive effect element, a magnetic memory device and methods for manufacturing these.

[0002]

[Description of the Prior Art]

With the rapid spread of information communication equipment, especially personal small equipment, such as a mobile terminal, elements which constitute the equipment, such as memories, logics, or the like, are required to have much more higher performance, for higher integration, higher speed, and lower power consumption, or the like. In particular, providing nonvolatile memories having higher density/higher capacity is becoming still more important as a technology which replaces hard discs and optical discs, which cannot be intrinsically miniaturized since they have movable parts.

[0003]

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Nonvolatile memories include flash memories using a semiconductor and FRAM (Ferro electric Random Access Memory) using a ferroelectric material, and so on.

Flash memories have a disadvantage that their write-in speed is on the order of μ seconds. On the other hand, as for FRAMs a problem is pointed out that their rewritability is poor.

[0004]

A nonvolatile memory that has attracted attention as being free of these disadvantages is a magnetic memory device called MRAM (Magnetic Random Access Memory) such as one described in, for example, "Wang et al., IEEE Trans. Magn. 33 (1997), 4498".

[0005]

This MRAM has features that it has a simple structure to enable high integration and it achieves storage by means of rotation of magnetic moment to enable it to have a very large maximum number of times of rewriting. Also, this MRAM is expected to have a considerably shortened access time and it has already been confirmed that operations on the order of nano seconds are possible.

[0006]

A magnetoresistive effect element for use in this MRAM is a tunnel magnetosensitive effect (Tunnel Magnetoresistance: TMR) element. The basic structure of this TMR element is a stacked structure of a ferromagnetic layer/a tunnel barrier layer/a ferromagnetic layer. In this TMR element, applying current to between a pair of ferromagnetic layers arranged through a tunnel barrier layer and applying external magnetic field in this state causes magnetoresistive effect depending on a relative angle between the magnetization directions of the two ferromagnetic layers. Then, if the magnetization directions of the ferromagnetic layers are antiparallel, the resistance value is maximal and if the magnetization directions of the ferromagnetic layers are parallel, the resistance value is minimal. Therefore, the TMR element can record information in terms of a change in resistance value by accomplishing the above-mentioned antiparallel and parallel states by means of an external magnetic field, so that it can function as a memory element.

[0007]

In a spin-valve type TMR element, one of the pair of ferromagnetic layers is provided with an antiferromagnetic layer adjacently to fix the direction of magnetization in constant direction by antiferromagnetic coupling with the antiferromagnetic layer, thereby making a magnetization fixed layer.

And the other of the ferromagnetic layers is made a magnetization free layer, which

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undergoes magnetization inversion with ease by means of external magnetic field or the like. In a magnetic memory device, this magnetization free layer is functioned as an information recording layer.

[0008]

The rate of change in resistance value of this spin-valve type TMR element is expressed by the following formula (1), assuming the spin polarizing coefficients of the pair of ferromagnetic layers are P1 and P2, respectively.

$$2P1P2/(1-P1P2) \qquad (1)$$

That is, the larger the spin polarizing coefficients P1 and P2 of the ferromagnetic layers, the larger the rate of change in resistance value of the TMR element. There have already been many reports on the relationship between the rate of change in resistance value and the material of the ferromagnetic layers for ferromagnetic elements of Fe group, such as Fe, Co, Ni and the like, and for alloys of these metals.

[0009]

Incidentally, the basic structure of MRAM comprises, as disclosed in Japanese Patent Application Laid-Open Publication No. H10-116490 (1998-116490), a plurality of bit write-in lines (so-called bit lines), a plurality of word write-in lines (so-called word lines) that intersect the bit lines at right angles, and TMR elements as magnetic memory elements arranged at grade separation parts of the bit lines and the word lines. Recording at the MRAM is achieved by selective writing to the TMR elements using the asteroid characteristics.

[0010]

That is, by applying necessary current to the bit lines and the word lines selectively, resultant inverted external field of induced magnetic fields mutually vertical to each other is generated. By applying the resultant inverted external field to a selected TMR element to cause the magnetization direction of its magnetization free layer, i.e., the information recording layer, to align parallel or antiparallel with the magnetization direction of its magnetization fixed layer, thus performing recording of "0" or "1", for example.

[0011]

For the bit lines and word lines to be used in the MRAM, conductor films of a wiring material such as Cu or Al, which is used in ordinary semiconductor devices, are used. Use of ordinary wiring material and achieving writing at a magnetic memory element having a inverted magnetic field Hc of, for example, 20 [Oe], through bit lines and word lines having line widths of 0.25 μm requires the current of about 2 mA applying. In case using

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of bit lines and word lines having thicknesses of 0.25 μm, which is as large as the line widths, reaches a current density of 3.2×10^6 A/cm^2, which is close to the disconnection threshold value due to electromigration.

To maintain the reliability of wiring, it is indispensable to reduce writing current. Also, from the viewpoints of the heat generation caused by the writing current and reduction of power consumption, it is necessary to reduce the writing current.

[0012]

Methods for achieving a reduction in the writing current at the MRAM include reducing the inverted magnetic field of the TMR element.

The inverted magnetic field Hc of the TMR element can be determined as appropriate depending on, for example, the size, shape, layer construction, and material of the layer of the TMR element. Use of smaller TMR element for the purpose of, for example, increasing the recording density of the MRAM causes a problem that the inverted magnetic field of the TMR element increases. To achieve both refining MRAM, i.e., high integration of MRAM and reduction in writing current simultaneously, it is necessary to achieve reduction of the inverted magnetic field of the TMR element by using appropriate materials.

[0013]

MRAM also has problems that TMR elements serving as memory elements have uneven magnetic characteristics from element to element and that occurrence of uneven magnetic characteristics among the TMR elements due to repeated use of one and the same element makes it difficult to perform selective writing using an asteroid characteristic.

This requires each TMR element to have magnetic characteristics sufficient for an ideal asteroid curve to be steadily depicted. To enable the ideal asteroid curve to be obtained, it is necessary that, R-H (resistance-magnetic field) curve obtained by TMR measuring is free of noises including, for example, Barkhausen noise or the like, the waveform of the R-H curve have a good squareness, and the magnetization state of the TMR element is stable and there is little unevenness of inverted magnetic field.

[0014]

Read-out of information from the TMR element is performed by detecting voltage difference at a constant bias voltage between in a state in which the magnetic moments of the information recording layer and the magnetization fixed layer arranged through the tunnel barrier layer align antiparallel to provide a high resistance value, i.e., for example, "1" and on the contrary in a state in which such magnetic moments align parallel to

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provide a low resistance value, i.e., for example, "0".

Therefore, if dispersion in resistance among the TMR elements is the same level, a memory device having a higher read-out speed, a higher degree of integration, and a lower error rate can be accomplished when the TMR ratio is high.

[0015]

It is known that, in the TMR element, a rate of change in resistance depends on a bias voltage and the TMR ratio decreases as the bias voltage increases.

When read-out is performed by current difference or voltage difference, it is known that the read-out signal takes a maximum value mostly at a voltage Vhalf at which the rate of resistance change in resistance decreases to half by the bias voltage dependence. This indicates that the lower the bias voltage dependence, the more effectively the read-out error reduces.

[0016]

[Problem to Be Solved by the Invention]

As stated above, the TMR element to be used in the MRAM must satisfy the above-mentioned write-in characteristics requirement and read-out characteristics requirement simultaneously.

However, for the material of the ferromagnetic layer of the TMR element, selection of the alloy composition that can increase the spin polarizing coefficients represented by P1 and P2 in the formula (1) from materials consisting of Co, Fe, and Ni, which are ferromagnetic transition metal elements, generally tends to increase inverted magnetic field Hc of the TMR element.

[0017]

Use of, for example, $Co_{75}Fe_{25}$ (at.%) alloy as the information recording layer enables the TMR element to have so high a spin polarizing coefficient as to achieve a TMR ratio as high as 40% or more, but with concomitant high inverted magnetic field Hc.

On the contrary, use of, for example, $Ni_{80}Fe_{20}$ (at. %) alloy called Permalloy, which is known as a soft magnetic material, as the information recording layer allows the inverted magnetic field Hc to decrease, but with a concomitant decrease in the spin polarizing coefficient as compared with the $Co_{75}Fe_{25}$ (at.%) alloy, thus decreasing the TMR ratio to about 33%.

Moreover, use of $Co_{90}Fe_{10}$ (at. %) enables the TMR element to have a TMR ratio of about 37% and a limited inverted magnetic field Hc on the order of between the inverted magnetic fields Hc of the $Co_{75}Fe_{25}$ (at.%) alloy and of the $Ni_{80}Fe_{20}$ (at. %) alloy, but with

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concomitant poor squareness of R-H curve, thus failing to obtain asteroid characteristics that are sufficient for writing. Also, the inverted magnetic fields of the information recording layers are unstable from element to element.

[0018]

The present invention is to provide a magnetoresistive effect element and a magnetic memory device that can improve the write-in characteristics and read-out characteristics simultaneously by using a specified material for the ferromagnetic layer and selecting conditions for forming it. The present invention also provides methods for manufacturing these.

[0019]

[Means for solving the problem]

The present invention provides a magnetoresistive effect element comprising: a pair of ferromagnetic layers facing each other via an intermediate layer and being configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to surfaces of the layers, wherein at least one of the ferromagnetic layers is a crystalline ferromagnetic layer containing FeCoB or FeCoNiB.

The crystalline ferromagnetic layer is preferably a ferromagnetic layer formed by crystallizing a sputtered film containing FeCoB or FeCoNiB.

[0020]

The present invention provides a method for manufacturing a magnetoresistive effect element including a pair of ferromagnetic layers facing each other via an intermediate layer and being configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to surfaces of the layers, the method comprising the steps of: depositing a ferromagnetic material layer, as at least one of the pair of the ferromagnetic layers, containing FeCoB or FeCoNiB and having an amorphous or microcrystalline structure; and subsequently heat-treating the ferromagnetic material layer at a temperature equal to or higher than a crystallization temperature of the ferromagnetic material layer in a magnetic field and transforming the amorphous or microcrystalline structure to a crystalline structure,.

[0021]

The ferromagnetic material layer with the amorphous or microcrystalline structure containing FeCoB or FeCoNiB is deposited preferably by sputtering.

Moreover, a heat-treating temperature T [°C] in the magnetic field is preferably set to satisfy:

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$280+2\times(\text{content of B [\%]})\leq T\leq 400$ (1)

[0022]

The present invention provides a magnetic memory device comprising: a magnetoresistive effect element including a pair of ferromagnetic layers facing each other via an intermediate layer and being configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to surfaces of the layers; and a bit line and a word line which put the magnetoresistive effect element therebetween in the direction of thickness, wherein at least one of the ferromagnetic layers is a crystalline ferromagnetic layer containing FeCoB or FeCoNiB.

The crystalline ferromagnetic layer is preferably a ferromagnetic layer formed by crystallizing a sputtered film containing FeCoB or FeCoNiB.

[0023]

The present invention provides a method for manufacturing a magnetic memory device including a pair of ferromagnetic layers facing each other via an intermediate layer and being configured to produce a change in magnetic resistance by applying an electric current in the direction vertical to surfaces of the layers; and a bit line and a word line which put the magnetoresistive effect element therebetween in the direction of thickness, the method comprising the steps of: depositing a ferromagnetic material layer, as at least one of the pair of the ferromagnetic layers, containing FeCoB or FeCoNiB and having an amorphous or microcrystalline structure; and subsequently heat-treating the ferromagnetic material layer at a temperature equal to or higher than a crystallization temperature of the ferromagnetic material layer in a magnetic field and transforming the amorphous or microcrystalline structure to a crystalline structure.

[0024]

The ferromagnetic material layer with the amorphous or microcrystalline structure is deposited by sputtering FeCoB or FeCoNiB to surely obtain an amorphous or microcrystalline structure for the ferromagnetic material layer.

[0025]

For the composition of FeCoB or FeCoNiB in each of the above-mentioned inventions, it is preferred that the FeCoB has a composition represented by a compositional formula $Fe_xCo_yB_z$ (x, y, and z in the compositional formula represent each atomic %), where $5\leq x\leq 45$, $35\leq y\leq 85$, $10\leq z\leq 30$, and $x+y+z=100$.

It is preferred that the FeCoNiB has a composition represented by a compositional formula $Fe_aCo_bNi_cB_d$ (a through d in the compositional formula represent each atomic %), where

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$5 \leq a \leq 45$, $35 \leq b \leq 85$, $0 < c \leq 35$, $10 \leq d \leq 30$, and $a+b+c+d=100$.

[0026]

For the each method for manufacturing according to present inventions, it is preferred that the heat-treating temperature T [°C] in the magnetic field is set to $280+2\times$(content of B[%]) $\leq T \leq 400$.

[0027]

The magnetoresistive effect element and the magnetic memory device with the magnetoresistive effect element according to the present invention provide a construction that at least one of the pair of ferromagnetic layers facing each other via an intermediate layer, which constitute the magnetoresistive effect element, comprises FeCoB or FeCoNiB. To make this construction, a magnetic material having this composition is deposited by sputtering to form a film with an amorphous or microcrystalline structure. The present invention is based on the finding that changing the structure of the deposited film to the crystalline structure enables, an increase in the magnetic resistance (MR ratio), improvement of the squareness of the R-H curve, i.e., improvement of asteroid characteristics, improvement of the bias voltage dependence of the MR ratio, and a reduction in unevenness of coercive force, that is, a reduction in unevenness of the inverted magnetic field to be achieved, of the magnetoresistive effect element.

[0028]

The method according to the present invention achieves this crystallization by heat-treating in the magnetic field to enable the increase in the MR ratio and the decrease in the unevenness of the inverted magnetic field and so on with reliability. It is seemed that the magnetic anisotropy of the crystallized ferromagnetic layer can be controlled to align in one direction through this treatment.

[0029]

It is noted that the above-mentioned ferromagnetic material can be deposited by various types of sputtering which includes sputtering method by causing ions from plasmas generated by various methods using discharge gas to collide with the target of a sputtering material, sputtering by causing an ion beam accelerated to have high energy to collide with a target as in so-called ion beam sputtering, or sputtering of the like.

[0030]

[Embodiments for carrying out the invention]

[Magnetoresistive effect element]

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One embodiment of the magnetoresistive effect element according to the present invention is a magnetoresistive effect element as a memory element of a magnetic memory device. However, the present invention is not limited to this embodiment.

The magnetoresistive effect element according to the present invention has a laminated structure constituted by a pair of ferromagnetic layers, specifically, a magnetization fixed layer and a magnetization free layer facing each other via an intermediate layer, which is configured to provide a change in magnetic resistance by applying an electric current in a direction vertical to the surface of the laminated structure, i.e., in the direction of thickness of the laminated structure.

At least the ferromagnetic layer that constitutes the magnetization free layer out of the pair of ferromagnetic layers is a ferromagnetic layer formed by crystallizing a sputtered film that contains at least Fe and Co together with B selected from ferromagnetic transition elements, i.e., a sputtered film of FeCoB or FeCoNiB.

[0031]

Because the intermediate layer is constructed with, for example, a tunnel barrier layer, this magnetoresistive element is referred to as a tunnel magnetoresistance effect (TMR) element.

Alternatively, the magnetoresistive effect element is referred to as a spin-valve type magnetoresistive effect element when the intermediate layer is constructed with a non-magnetic conductive layer.

The ferromagnetic layer may have a single layer structure or of a multi-layer structure. For example, the ferromagnetic layer that constitutes the magnetization fixed layer may have a laminated ferri structure.

[0032]

Fig. 1 is a schematic cross-sectional view showing an example of a spin-valve type TMR 1.

In this example, an under layer 3 is formed on the substrate 2, an antiferromagnetic layer 4 is formed on the under layer 3, and a pair of ferromagnetic layers 5 and 7 via an intermediate layer 6 are formed on the antiferromagnetic layer 4.

In this example, the ferromagnetic layer 5 that constitute a magnetization fixed layer 5 is formed on the antiferromagnetic layer 4, the intermediate layer 6 made of a tunnel barrier layer is formed on the magnetization fixed layer 5, and then the ferromagnetic layer 7 constituting a magnetization free layer is formed on the intermediate layer 6. This laminated structure forms a ferromagnetic tunneling junction (hereafter, referred to as

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"MTJ"). A protective layer 8, i.e., a so-called top-coating layer is deposited on the MTJ9.

[0033]

The underlayer 3 is made of, for example, a Ta film.

The antiferromagnetic layer 4, when antiferromagnetically coupled with the ferromagnetic layer 5, one of the ferromagnetic layers, i.e., with the magnetization fixed layer 5, undergoes no reversal of magnetization by externally applied signal magnetic field, for example, write-in magnetic field at a memory device and sets the direction of the magnetization of the magnetization fixed layer 5 to a fixed direction.

The antiferromagnetic layer 4 can be made of Mn alloy containing one or more of Fe, Ni, Pt, Ir, Rh, and the like, Co oxide, Ni oxide, or the like. For example, the antiferromagnetic layer 4 is made of PtMn.

[0034]

The tunnel barrier layer of the intermediate layer 6 can be made of an oxide or nitride film that is formed by oxidizing or nitriding a metal film, for example, a sputtered or vapor deposited film of Al. The tunnel barrier layer 6 can also be made by a CVD (Chemical Vapor Deposition) method using an organometal, oxygen, ozone, nitrogen, halogen, halide gas or the like.

[0035]

The magnetization fixed layer 5 and the magnetization free layer 7 laminated via this intermediate layer 6 are made of ferromagnetic layers containing FeCoB or FeCoNiB. The magnetization direction of the fixed layer 5 is fixed due to antiferromagnetic coupling with the antiferromagnetic layer 4 as described above.

[0036]

The both ferromagnetic layers that are arranged via the intermediate layer 6, in particular, for example the magnetization free layer that serves as an information recording layer, i.e., the ferromagnetic layer 7 is made of a ferromagnetic layer formed by crystallizing a sputtered film containing FeCoB or FeCoNiB.

[0037]

The magnetization free layer 7, for example, as the information recording layer preferably has a thickness of 1 nm to 10 nm to secure good magnetic characteristics.

The reason for this is that the magnetization free layer 7 with a thickness of less than 1 nm has magnetic characteristics for a magnetization free layer that are significantly deteriorated. On the other hand, the magnetization free layer 7 with a thickness more than 10 nm has too high coercive force to be practically unsuitable for use as, for example, a

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memory element of a magnetic memory device.

[0038]

The magnetization free layer 7 is not limited to one that has a single layer structure made of the above-mentioned FeCoB or FeCoNiB. It may also have a laminated structure constituted by, for example, a ferromagnetic layer having above-described composition and a NiFe layer having a smaller magnetization capacity than above-described composition. In the latter case, the total thickness of these layers may be larger than 10 nm.

[0039]

The magnetization fixed layer 5 made of FeCoB or FeCoNiB has a thickness selected to be, preferably, 0.5 nm to 6 nm.

The reason for this is that the magnetization fixed layer with a thickness of less than 0.5 nm has deteriorated magnetic characteristics for a magnetization fixed layer. On the other hand, the magnetization fixed layer 5 with a thickness more than 6 nm has insufficient exchange coupling magnetic field with an antiferromagnetic layer.

[0040]

In the example shown in Fig. 1, the magnetization fixed layer 5 has a single layer structure. As will be apparent from Fig. 2, which is a schematic cross-section of an example of such, the magnetization fixed layer 5 may have a ferromagnetic laminated ferri structure.

In this example, the antiferromagnetic layer 4 has formed thereon a first magnetization fixed layer 5a that is antiferromagnetically coupled with the antiferromagnetic layer 4 and a second magnetization fixed layer 5b laminated via a non-magnetic conductive layer 5c on this first magnetization fixed layer 5a.

The non-magnetic conductive layer 5c may be made of a metal film, for example, a film of Ru, Cu, Cr, Au, Ag or the like.

In Fig. 2, parts that correspond to those shown in Fig 1 are used the same signs and redundant explanations are omitted.

In the above-mentioned example, the intermediate layer 6 is a tunnel barrier layer, thus constituting a TMR element. The intermediate layer 6 may also be adopted in a spin-valve type magnetoresistive effect element having a so-called CPP (Current Perpendicular to Plane) structure, in which the intermediate layer 6 is made of a non-magnetic conductive layer and current is applied in the direction of its thickness.

[0041]

[Manufacturing method for magnetoresistive effect element]

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Manufacture of magnetoresistive effect element shown in Fig. 1 is illustrated as an embodiment of the method of manufacturing a magnetoresistive effect element according to the present invention. However, the present invention is not limited to this embodiment.

In this embodiment, deposition, on the substrate, of the underlayer 3, the antiferromagnetic layer 4, the magnetization fixed layer 5, the intermediate layer 6, the magnetization free layer 7, and the protective layer 8 can be achieved by using, for example, a multi-chamber type sputtering apparatus.

[0042]

In this case, first the substrate 2 made of, for example, Si is arranged in one chamber. On this substrate are sequentially formed by continuous sputtering the underlayer 3 made of, for example, Ta, the antiferromagnetic layer 4 made of PtMn, the magnetization fixed layer 5 made of FeCoB or FeCoNiB, which is a lower side one of the pair of the ferromagnetic layer, and the intermediate layer 6 made of, for example, an Al metal film.

[0043]

Subsequently, the substrate 2 having deposited hereon these layers is transferred into another chamber, where the surface of the Al metal film that constitutes the intermediate layer 6 is oxidized to form a tunnel barrier layer. Thereafter, the substrate 2 is brought in, for example, the previous chamber again where the magnetization free layer 7 made of FeCoB or FeCoNiB as an upper layer side one of the pair of the ferromagnetic layers is deposited by sputtering on the intermediate layer 6. On this intermediate layer 6 is further formed the protective layer 8 made of, for example, Ta by continuous sputtering.

[0044]

These sputtering methods include, as described above, various types of sputtering, for example, sputtering by causing ions from plasmas generated by various methods using discharge gas to collide with the target of a sputtering material and sputtering by causing an ion beam accelerated to have high energy to collide with a target as in so-called ion beam sputtering, or the like.

[0045]

Each of laminaed layers thus formed, in particular the magnetization fixed layer 5 and the magnetization free layer 7 made of FeCoB or FeCoNiB are formed as layers with an amorphous or microcrystalline structure.

[0046]

Then, the substrate 2 having the laminated film is heat-treated in a magnetic field.

The heat-treating in a magnetic field is carried out by a field heat-treating apparatus, like

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as shown in Fig. 3 illustrating the schematic cross-sectional view, which includes for example a vacuum chamber 131 and on the outer periphery of which a heating means 132 such as heaters and a magnetic field applying means 133 such as a magnet are arranged.

[0047]

The substrate 2 having the laminated film is arranged on a rack 134 in the vacuum chamber 131 and is heated by the heating means 132 in a state in which a magnetic field is applied by the magnetic field applying means 133 in a predetermined direction along the surface of the laminated film as indicated by an arrow 135. By this heat-treating, the magnetization fixed layer 5 and the magnetization free layer 7 that are formed to have an amorphous or microcrystalline structure are crystallized.

This heat-treating in a magnetic field simultaneously make the antiferromagnetic layer 4 order, that is, the antiferromagnetic layer 4 is magnetized in a predetermined direction. This enables the magnetization of the magnetization fixed layer 5, the ferromagnetic layer that is formed on the antiferromagnetic layer 4 and is antiferromagnetically coupled with the antiferromagnetic layer 4, to be fixed to one direction.

[0048]

This heat-treating in a magnetic field is performed in a magnetic field of 500 kOe or higher at a temperature that is equal to or higher than the crystallization temperature of the ferromagnetic materials of the ferromagnetic layers, i.e., the ferromagnetic layers 5 and 7 as a magnetization fixed layer and a magnetization free layer, respectively. Specifically, the heat-treating temperature T [°C] in a magnetic field is set to satisfy: $280+2\times$(content of B [%])$\leq T \leq 400$, which is explained in detail later.

[0049]

[Magnetic memory device and a method of manufacturing the same]

The magnetic memory device according to the present invention includes memory elements, which constitute its memory cells, made of magnetoresistive effect elements having various structures according to the present invention, for example, TMR elements. The magnetic memory device may have a crosspoint type MRAM array structure as shown in, for example, Fig. 4 illustrating a schematic cross-sectional view of one example of the device and in Fig. 5 illustrating a schematic cross-sectional view of one memory cell 11 of the device.

[0050]

This MRAM includes a plurality of word lines WL in parallel arrangement and a plurality of bit lines BL in parallel arrangement so that these can cross the word lines WL at grade

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separation. The respective crossing parts between the word lines WL and the bit lines BL are provided with the magnetoresistive effect elements according to the present invention, for example, TMR elements 1 as the memory cells 11.

Fig. 4 shows a part of the magnetic memory device where 3×3 memory cells 11 are arranged in a matrix state.

[0051]

Each memory cell 11 includes, as shown in Fig. 5. On the semiconductor substrate 2 made of, for example, a silicon substrate, i.e., on a semiconductor wafer, a transistor 13 for switching.

The transistor 13 comprises, for example, a MOS transistor (insulated gate type field effect transistor). In this case, an insulated gate part is formed, which includes the semiconductor substrate 2, the gate insulation layer 14 formed on the semiconductor substrate 2, and the gate electrode 15 deposited on the gate insulation layer 14.

The semiconductor substrate 2 is formed of a source region 16 and a drain region 17 on both sides of the insulated gate part. In this structure, the gate electrode 15 constitutes a read-out word line WL1.

[0052]

On the semiconductor substrate 2 with the transistor 13 formed thereon is formed a first interlayer insulation layer 31 so as to cover the gate electrode 15. The first interlayer insulation layer 31 is provided with contact holes 18 extending therethrough above the source region 16 and the drain region 17, respectively. Each of the contact holes 18 is filled with an conductive plug 19.

On the firs interlayer insulation layer 31 is deposited a wire layer 20 for the source region 16 such that the wire layer 20 deposited so as to mount on the conductive plug 19 that contacts the source region 16.

[0053]

Further, a second interlayer insulation layer 32 is formed on the first interlayer insulation layer 31 so as to cover the wire layer 20.

The second interlayer insulation layer 32 is provided with a contact hole 18 therethrough above the conductive plug 19 that contacts the drain region 17 and the conductive plug 19 is filled therein.

[0054]

On the second interlayer insulation layer 32 is formed a write-in word line WL2 that corresponds to the word line WL in Fig. 4 extending, for example, in the direction in

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which the read-out word line WL1 extends.

On the second interlayer insulation layer 32 is also formed a third interlayer insulation layer 33 made of, for example, silicon oxide to cover the write-in word line WL2. Also, the third interlayer insulation layer 33 is provided with a contact hole 18 therethrough above the conductive plug 19 that contacts the drain region 17 and the conductive plug 19 is filled therein.

[0055]

Then, the third interlayer insulation layer 33 is formed thereon of an underlayer 3 made of, for example, Ta, shown in Fig. 1 or 2 so as to contact the conductive plug 19 that is penetrating the third interlayer insulation layer 33 and on this underlayer 3 is formed a magnetoresistive effect element, for example, the TMR element 1.

[0056]

Further, a fourth interlayer insulation layer 34 is formed so as to cover the underlayer 3 and the TMR element 1, and on the fourth interlayer insulation layer 34, a bit line BL is formed crossing over the write-in word line WL.

[0057]

On the bit line BL, a surface insulation layer is formed as necessary, which is non-illustrated.

[0058]

The structure and the manufacturing method of the TMR element 1 as the magnetoresistive effect element are comprises, as described above, forming the structure shown in Fig. 2 or 3 by using the constituent materials and the film forming method, specifically by forming the antiferromagnetic layer 4, the magnetization fixed layer having a single layer or laminated ferri structure, and the intermediate layer 6 by sputtering, and then performing oxidizing or nitriding treatment of the intermediate layer 6, and subsequently forming the magnetization free layer 7 and the protective layer 8 by sputtering.

[0059]

In this case too, the ferromagnetic layer 5 as the magnetization fixed layer and the ferromagnetic layer 7 as the magnetization free layer, i.e., the information recording layer are formed as an amorphous or microcrystalline layer comprising FeCoB or FeCoNiB. These memory cells 11 are arranged in a matrix state on the common semiconductor substrate 2, i.e., semiconductor wafer as shown in Fig. 4.

[0060]

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The semiconductor substrate 2 is likewise heat-treated in a magnetic field by using the field heat-treating apparatus as illustrated in Fig. 3 and then, the ferromagnetic layers 5 and 7 of the magnetization fixed layer and the magnetization free layer, both formed as an amorphous or microcrystalline structure, are transformed to crystalline structure in the TMR element 1 of the magnetoresistive effect element.

This heat-treating in a magnetic field simultaneously make the antiferromagnetic layer 4 order, that is, magnetizes the antiferromagnetic layer 4 in a predetermined direction. This enables the magnetization of the magnetization fixed layer 5, which is formed in contact with the antiferromagnetic layer 4 and is antiferromagnetically coupled with the antiferromagnetic layer 4, to be fixed to one direction.

[0061]

The magnetic memory device having this structure includes bit lines BL and write-in word lines WL (WL1) , which, upon applying a necessary current, apply a necessary magnetic field obtained by the synthesis of magnetic fields generated by both the bit line BL and the word line WL to the magnetization free layer of the magnetoresistive effect element, for example, the TMR element 1 of the memory cell 11 arranged at the selected crossing part, thereby reversing he magnetization of the magnetization free layer to perform recording of information as described above.

[0062]

Rea-out of the information is achieved by applying a necessary on-voltage to the gate electrode 15 of the transistor 13 engaged with the memory cell that performs selected read-out to bring the transistor 13 into on-state to allow read-out current to pass between the bit line BL and the wire layer 20 in the source region 16 of the transistor 13.

[0063]

As mentioned-above, the magnetoresistive effect element according to the present invention achieves an increase in inverted magnetic field by including the ferromagnetic layers 5 and 7 constituting the magnetization fixed layer and the magnetization free layer, respectively, particularly the ferromagnetic layer 7 that constitutes the magnetization free layer, made of FeCoB or FeCoNiB, containing Fe and Co from among ferromagnetic transition metal elements together with B.

Common TMR element that uses only ferromagnetic transition metal elements in the ferromagnetic layers has a disadvantage that does not satisfy an increase in spin polarizing coefficient and a decrease in inverted magnetic field simultaneously.

In contrast, use of the above-mentioned FeCoB or FeCoNiB enables both an increase in

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spin polarizing coefficient and a decrease in coercive force, i.e., inverted magnetic field. The increased spin polarizing coefficient provides a high rate of change in resistance, which corresponds to a high TMR ratio for the TMR element, according to the formula (1) above. In the magnetic memory device, the decrease in the inverted magnetic field enables a decrease in write-in magnetic field that is applied to the magnetoresistive effect element serving as the memory element, in other words a decrease in write-in current.

[0064]

Particularly, in the present invention, the ferromagnetic layer having the specified composition having an amorphous or microcrystalline structure is subjected to heat-treating in a magnetic field to control magnetic anisotropy represented by presence of an axis of easy magnetization and an axis of difficult magnetization in the magnetic layer, increase the squareness in the R-H curve, and stabilize the inverted magnetic field of the magnetization free layer, i.e., the information recording layer.

Moreover, including B (boron) reduces the bias voltage dependence.

[0065]

A TMR element according to the present invention whose information recording layer contains $Co_{72}Fe_8B_{20}$ (at. %) and a TMR element whose information recording layer contains $Co_{90}Fe_{10}$ (at. %) were fabricated. These were measured for a change rate in tunnel resistance value with respect to the change in external magnetic field. Fig. 6 shows the results of measurement in terms of TMR [%] - external magnetic field [Oe] curve. In Fig. 6, a curve 61 represents a TMR - external magnetic field curve for the TMR element whose information recording layer comprises $Co_{72}Fe_8B_{20}$ (at. %), and a curve 62 represents a TMR - external magnetic field curve for the TMR element whose information recording layer comprises $Co_{90}Fe_{10}$ (at. %).

[0066]

Comparison of the curves 61 and 62 with each other clearly indicates that in the TMR element whose information recording layer comprises Fe, Co, and B maintained a higher TMR ratio than the TMR element whose information recording layer comprises only Fe and Co and still achieved a reduced coercive force Hc.

The comparison also indicates that the squareness in the TMR - magnetic field loop of these TMR elements was increased and the Barkhausen noise was reduced.

[0067]

Therefore, the memory element in the magnetic memory device that uses a magnetoresistive effect element according to the present invention not only achieves a

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decrease in write-in current but also improves the shape of the asteroid curve. This improves the write-in characteristics and unevenness in the characteristics, thereby reducing the write-in errors.

[0068]

Although the cause of the occurrence of such effects is unclear, it is believed that those phenomena are specific to ferromagnetic layers containing B. This improvement of the characteristics is not always achieved by the ferromagnetic layers with an amorphous or microcrystalline structure. It is believed that such effects come to be when the ferromagnetic layer is crystallized by heat-treating in a magnetic field at a temperature equal to or higher than the above-mentioned crystallization temperature under controlling so that it can have magnetic anisotropy.

[0069]

In the magnetic memory device, which includes a very large number of memory elements, i.e. magnetoresistive effect elements on the same substrate, decreasing in write-in current provides a very large profit. In addition, it is very important that an excellent asteroid curve can be obtained, that is, stabilization of magnetic characteristics can be achieved.

[0070]

The alloy composition of FeCoB or FeCoNiB that the ferromagnetic layer contains has a preferred range. The magnetoresistive effect element and memory element using he ferromagnetic layers made of FeCoB and FeCoNiB, respectively, have already been proposed in Japanese Patent Application No. 2002-106926 filed by the applicant of the present application.

[0071]

The alloy composition of Fe, Co, and B that the ferromagnetic layer contains, exclusive of unavoidable impurity elements, is represented by a compositional formula $Fe_xCo_yB_z$ (x, y, and z in the compositional formula represent atomic %) where x, y, and z preferably satisfy $5 \leq x \leq 45$, $35 \leq y \leq 85$, and $10 \leq z \leq 30$ provided that $x+y+z=100$.

[0072]

First, the content of B is explained. With the content of B of less than 10 atomic %, the magnetic characteristic of the Fe-Co alloy, which is a base composition, is largely reflected so that only mild improvement effect is observed. With the content of B of more than 10 atomic %, the TMR ratio increases considerably as compared with the alloy that contains Fe, Co and so on in the same ratios and the squareness in the resistance - magnetic field curve (R-H curve) is improved. Also, the bias current dependence of TMR

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ratio is improved. Further, the magnetization state of the information recording layer is stable, which makes the unevenness of coercive force small and widely reduces the noise appearing on the R-H curve.

[0073]

The content of B is preferably equal to 30 atomic % or less. The reason for this is that with the content of B of more than 30 atomic %, the ferromagnetic characteristics as the information recording layer and the fixed magnetic field as the magnetization fixed layer deteriorate. As a result, there might be a decrease in TMR ratio, deterioration of the squareness in the R-H curve, and a decrease in coercive force. To secure the effects to be obtained by the addition of B, it is preferred that at least one of the ferromagnetic layers, specifically he ferromagnetic layer 7 that constitutes the information recording layer has a composition containing B of 10 atomic % or more and 30 atomic % or less although this may vary to some extent depending on the composition of the Fe-Co alloy.

[0074]

Next, the Fe-Co alloy that forms a base is explained.

The alloy composition including B requires at least 35 atomic % of Co to enhance the effect to be obtained by the addition of B and in addition, to keep ferromagnetic characteristics. In addition to this, adding Fe shows, like the changes occurring in the Co-Fe based alloy, effects of an increase in TMR ratio and an enhancement of coercive force. On the other hand, with the content of Fe of more than 45 atomic %, the coercive force increases excessively for the size of actual size of the element, and it is unsuitable for a TMR element. With the content of Fe of less than 5 atomic % , the spin polarizing coefficient decreases, which will make it difficult to provide a TMR ratio that is sufficient for the element to act as a magnetoresistive effect element. Accordingly, the content of Fe is preferably 5 atomic % or more and 45 atomic % or less.

[0075]

The ferromagnetic layer may comprise Ni in addition to Fe, Co, and B. The ferromagnetic layer with this composition including Ni causes an acceptable TMR ratio to be maintained while preventing enhancement of the coercive force and enables the squareness in the R-H curve to be improved. In this case, for a preferred range of the content of Ni, 35 atomic % or less of Ni is preferred. The reason for this is that with the content of Ni of more than 35 atomic %, it is likely that the coercive force will decrease too much to control the operation of the TMR element. That is, the ferromagnetic layer made of FeCoNiB has a composition that is represented, exclusive of unavoidable impurity elements, by a

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compositional formula $Fe_aCo_bNi_cB_d$ (a through d in the compositional formula representing each atomic %) where $5 \leq a \leq 45$, $35 \leq b \leq 85$, $0 < c \leq 35$, and $10 \leq d \leq 30$, provided that $a+b+c+d=100$.

[0076]

In the present invention, FeCoB or FeCoNiB alloy with an amorphous or microcrystalline structure is heat-treated in a magnetic field at a temperature equal to or higher than the crystallization temperature to convert the structure into a crystalline structure having a controlled magnetic anisotropy. This makes uniform the inverted magnetic field of the information recording layer, to reduce write-in errors, and creates a state in which an MRAM of gigabit grade can operate correctly.

The field heat-treating, as described above, is performed in a magnetic field at 500 kOe or higher. The heat-treating temperature T [°C] is set, as described above, to satisfy: $280+2\times(\text{content of B [\%]}) \leq T \leq 400$. This heat-treating temperature is explained below.

[0077]

The crystallization temperature of the amorphous phase depends on a heat-treating time, which is controlled in a wide range. In manufacturing an MRAM, mutual diffusion of constituent elements of respective layers of the MTJ 9 of the MRAM occurs at an interface between any two adjacent layers. This, for example, may affect the characteristics of the MTJ 9. This suggests as a realistic time, a heat-treating time, that is, a temperature retention time, of 2 hours. Under this condition, the crystallization temperatures for the FeCoB alloy and the FeCoNiB alloy depend on the content of B. With the content of B of 10 atomic %, the crystallization temperature was 290°C. With the content of B of 20 atomic %, the crystallization temperature was 300°C. Then, with the content of B of 30 atomic %, the crystallization temperature was 310°C. That is, the crystallization temperature depends on the content of B. From these relationships between the content of B and the crystallization temperature, an approximation of the crystallization temperature is given by $280+2\times(\text{content of B [\%]})$.

Consequently, the heat-treating temperature for crystallization is set to a temperature equal to or higher than $280+2\times(\text{content of B [\%]})$.

On the other hand, the heat-treating must be carried out at a temperature at which the MTJ 9 has no deteriorated characteristics of the tunnel magnetoresistance effect. This suggests a heat-treating temperature of 400°C or lower.

From these, the heat-treating temperature T [°C] in the magnetic field is set to the

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temperature represented by the formula (2) above, i.e., $280+2\times(\text{content of B [\%]})\leq T\leq 400$.

[0078]

With respect to a cooling rate after the heat-treating, if this cooling rate is too low, fine precipitates containing a large amount of B, which deteriorates the characteristics are generated. Therefore, it is desirable that the cooling rate after the heat-treating is adjusted properly. Specifically, it was confirmed that the cooling rate from the heat-treating temperature down to 280°C is desirably 2°C per minute or higher.

On the other hand, the temperature elevation rate in the heat-treating depends on the performance of the heat-treating apparatus used. It is desirable to use a high temperature elevation rate as high as possible within the range where no so-called overshooting occurs, in which the controlled temperature becomes higher than the desired temperature.

[0079]

The strength of magnetic field during the heat-treating must be 5 kOe or higher.

It is necessary to continue applying the magnetic field during the heat-treating. Specifically, it is desirable to continue applying the magnetic field over a temperature range of from the heat-treating temperature down to 70°C during the cooling.

[0080]

In the process of manufacturing an MRAM, the heat-treating according to the present invention may also be carried out immediately after a MTJ is formed. However, it is possible that film depositing of an interlayer insulation layer, for example, in case depositing a silicon oxide layer by plasma CVD, because this deposition is performed at a temperature of 300°C or higher, it is desirable that the heat-treating according to the present invention, that is performed after MTJ forming, is performed after this plasma CVD.

[0081]

[Evaluation of characteristics]

An element for evaluating characteristics (hereafter, referred to as "TEG" (Test Element Group) that corresponds to an embodiment of the magnetoresistive effect element and the MRAM using the magnetoresistive effect element as a memory element, these are according to the present invention, was prepared, and characteristics of the structure according to the present invention was evaluated. The evaluation of characteristics and the results are explained below.

As illustrated in Fig. 5, the MRAM includes the transistor 13 for switching besides the

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TMR element as a memory element. For the TEG, formation of the transistor 13 for switching on the semiconductor substrate 2, that is, on the semiconductor wafer was omitted.

[0082]

As shown in Fig. 7 presenting a schematic plan view and in Fig. 8 presenting a schematic cross-sectional view along the A-A line of Fig. 7, a 0.6 mm-thick semiconductor substrate (semiconductor wafer) 2 having formed on the surface thereof an insulation layer 12 made of a 2 μm-thick thermal oxide film was provided.

On this semiconductor substrate 2 was formed a metal film for constituting a word line, and then subjecting pattern etching by photolithography to form a word line WL that extends in one direction.

At the etched part other than the part where the word line WL was formed, the oxide film on the surface of the semiconductor substrate 2, i.e., the insulation layer 12 was etched to a depth of 5 nm.

[0083]

On a portion of the word line WL was fabricated a TMR element 1. The TMR element 1 was fabricated such as, forming from the side of the semiconductor substrate 2, an underlayer 3 made of a 3 nm-thick Ta layer and a 100 nm-thick Cu layer, an antiferromagnetic layer 4 made of a 2 nm-thick PtMn layer, a magnetization fixed layer 5 comprising a non-magnetic conductive layer having a 3 nm-thick CoFe layer and a 0.8 nm-thick Ru layer and a ferrimagnetic layer made of a 2.5 nm-thick CoFe layer, an intermediate layer 6 obtained by oxidizing 1 nm-thick Al, a magnetization free layer 7 made of a 5 nm-thick FeCoB layer, and a protective layer 8 made of a 5 nm-thick Ta layer.

[0084]

Thus, a portion of the laminated film constitutes the TMR element 1. For this purpose, the part of the laminated film where the TMR element 1 was formed is provided thereon with a mask layer (not shown) made of a photoresist layer by photolithography.

This mask layer was used as an etching mask for performing etching, for example, dry etching the laminated film is performed to form the TMR element with the laminated film having a necessary pattern.

Further, to cover the mask layer of the photoresist layer and periphery of the TMR element 1, Al_2O_3 of around 100 nm was sputtered. Thereafter, the mask layer was removed and the insulation layer on the TMR element 1 was removed, that is, lifted off, to expose the surface of the TMR element 1.

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[0085]

In contact with the exposed TMR element 1 and extending across it was formed a metal film. This was subjected to pattern etching by photolithography to form a bit line BL.

[0086]

This bit line BL and the word line WL, each of which was made of a Cu layer, were formed to have a pattern in which these extend in mutually crossing directions.

[0087]

The composition of FeCoB of the ferromagnetic layer 7 that constitutes the magnetization free layer, i.e., the information recording layer, was selected to be $Fe_8Co_{72}B_{20}$ [atomic %].

The composition of CoFe of the ferromagnetic layer 5 that constitutes the magnetization fixed layer was selected to be $Co_{75}Fe_{25}$ [atomic %].

The tunnel barrier layer of the intermediate layer 6 was formed by first depositing an Al film to a thickness of 1 nm by DC sputtering and subsequently plasma oxidizing the metal Al film by ICP (Inductive Coupled Plasma) at a flow ratio of oxygen to argon being 1:1 with the gas pressure of the chamber being set to 0.1 mTorr. This oxidation time depended on the ICP plasma output. In this example, the oxidation was performed for 30 seconds.

Film forming of layers other than the intermediate layer 6 was achieved by using a DC magnetron sputtering method. The TMR element 1 was made to have an elliptical pattern with a short axis of 0.5 μm and a long axis of 1.0 μm.

[0088]

The word lines WL and the bit lines BL were respectively fabricated by forming a metal film and patterning this by Ar plasma etching using photolithography.

The both ends of the word line WL and of the bit line BL extended and were each provided with a terminal pad as shown in Fig. 7.

A plurality of such TEGs was formed on the common substrate 2.

The thus-fabricated sample TEGs were measured for their crystallization temperature, which showed 300°C.

[0089]

The thus-fabricated TEGs were heated in a magnetic field by using a field heat-treating apparatus. This heat-treating can also serve as ordering heat-treating for the antiferromagnetic layer 4 made of PtMn. Thus, a ferromagnetic tunnel junction MTJ was formed.

This heat-treating in a magnetic field was performed at a magnetic field strength of 10 kOe for a heat-treating time of 2 hours.

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[0090]

The thus-fabricated TEGs, which were fabricated at various heat-treating temperatures, were measured for their TMR ratio, dispersion of inverted magnetic field Hc, and bias voltage dependence. These were measured as follows.

[0091]

[Measurement of TMR ratio]

Recording of information to the memory element of the MRAM is achieved by use of induction magnetic field generated by applying current to the bit line and the word line. In the measurement of TMR ratios, the magnetization inversion of the information recording layer, i.e., the magnetization free layer 7 of the TEG was achieved by applying an external magnetic field.

This measurement was performed by first applying an external magnetic field for causing the magnetization inversion of the information recording layer of the TMR element so that it in a direction parallel to its axis of easy magnetization.

The strength of the magnetic field was set to 500 [Oe].

[0092]

Next, the strength of the magnetic field was swept form -500 [Oe] to +500 [Oe] as seen from one of the axes of easy magnetization of the information recording layer and at the same time the bias voltage applied to the terminal pad 23 of the word line and the terminal pad 24 of the bit line BL was adjusted to 100 mV, in this state, tunnel current was flowed to the ferromagnetic tunnel junction (MTJ). Values of resistance against respective external magnetic fields were measured.

[0093]

A ratio of; a difference between a resistance value R_H at a state in which the magnetization of the magnetization fixed layer 5 and the magnetization of the magnetization free layer 7 are in antiparallel and the resistance is high and a resistance value R_L at a state in which the magnetization of the magnetization fixed layer 5 and the magnetization of the magnetization free layer 7 are in parallel and the resistance is low, to R_L; i.e., $\{(R_H - R_L)/R_L\} \times 100$ was defined to be a TMR ratio. This TMR ratio is preferably 45% or higher to achieve satisfactory read-out characteristics.

[0094]

[Measurement of inverted magnetic field and dispersion thereof]

The inverted magnetic field Hc was determined based on the R-H curve obtained by the above-mentioned method of measuring TMR ratios. R-H was measured for element by

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element on the wafer and an average value and standard deviation σ of inverted magnetic field Hc were obtained. A dispersion value was calculated as an average value of σ/Hc. The dispersion of inverted magnetic field Hc is preferably 10% or less to improve the write-in characteristics.

[0095]

[Measurement of bias voltage dependence]

The R-H curve was obtained by varying the bias voltage from 100 mV to 1,000 mV at intervals of 10 mV and TMR ratios were obtained based on the curve. The TMR ratios against the bias voltages were plotted. Based on this graph, a TMR ratio at 0 mV was obtained by extrapolating and then a bias voltage at which the TMR ratio was half the TMR ratio at 0 mV was obtained, and it was named Vhalf.

Vhalf is preferably 550 mV or higher.

[0096]

Fig. 9 shows results of measurements regarding the relationship between the heat-treating temperature and the TMR ratio (average value). Fig. 10 shows results of measurements regarding the relationship between the heat-treating temperature and the inverted magnetic field Hc. Fig. 11 shows results of measurements regarding the relationship between the heat-treating temperature and the deviation of the inverted magnetic field Hc. Fig. 12 shows results of measurements regarding the relationship between the heat-treating temperature and the bias voltage (average value).

[0097]

Figs. 9 to 12 indicate that the heat-treating in a magnetic field at a temperature equal to or higher than the crystallization temperature of 300°C and equal to or lower than 400°C enables the TMR ratio, the inverted magnetic field Hc, the dispersion of the inverted magnetic field Hc, and the bias voltage to be within preferred characteristics ranges, respectively.

[0098]

Fig. 11 indicates that the heat-treating in a magnetic field at a temperature equal to or higher than the crystallization temperature and equal to or lower than 400°C clearly reduces the dispersion of the inverted magnetic field among the TMR elements formed on the same wafer to improve the write-in characteristics directly and widely.

Fig. 12 indicates that the bias voltage dependence of TMR ratio is clearly reduced to give satisfactory effects on the write-in characteristics and the read-out characteristics directly.

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[0099]

Also, Figs. 9 and 10 indicate that the heat-treating in a magnetic field at a temperature in arrange from the crystallization temperature to 400°C enables improvement of TMR ratio and maintenance of proper inverted magnetic field, which enables the element to have well-balanced satisfactory characteristics.

[0100]

It is evident from these results that the write-in characteristics and the read-out characteristics for MRAM are improved and further the error rates of these are widely improved.

[0101]

As described above, the present invention has a construction that at least a magnetization free layer, i.e., a ferromagnetic layer as an information recording layer of the memory element in a magnetic memory device, comprises FeCoB or FeCoNiB containing B in an amount of, preferably 10 atomic % or more and 30 atomic % or less. Further, the present invention has a construction that for a sputtered film of the above feature, a ferromagnetic layer deposited as a layer with an amorphous or microcrystalline structure is heat-treated in a magnetic field to crystallize it. These enable stable enhancement of TMR ratio, improvement of inverted magnetic field, reduction in dispersion of the inverted magnetic field, improvement of asteroid characteristic by improvement of squareness in R-H characteristic.

[0102]

In the above-mentioned example, explanation has been made mainly on the structure in which the intermediate layer 6 sandwiched by the pair of the ferromagnetic layers 5 and 7 is made of a tunnel barrier layer, thus forming a TMR element. However, the magnetoresistive effect element may be possible to be a so-called GMR element of a spin-valve type having the intermediate layer 6 made of a non-magnetic conductive layer.

[0103]

Effects of the invention

As described above, the magnetoresistive effect element according to the present invention can achieve improvement of MR ratio, reduction in bias voltage dependence of MR ratio, decrease in inverted magnetic field, and decrease in dispersion of the inverted magnetic field, and improvement of asteroid characteristics.

With these improvements, the magnetic memory device, which includes this magnetoresistive effect element as a memory element, is particularly excellent in write-in

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characteristics and read-out characteristics and can achieve improvement of error rates, stability and high reliability, and decrease in the power consumption.

[Brief explanation of the drawings]

Fig. 1 is a schematic cross-sectional view of an example of the magnetoresistive effect element according to the present invention;

Fig. 2 is a schematic cross-sectional view of another example of the magnetoresistive effect element according to the present invention;

Fig. 3 is a schematic cross-sectional view of an example of a field heat-treating apparatus for use in the manufacturing method according to the present invention;

Fig. 4 is a schematic perspective view of an example of the magnetic memory device according to the present invention;

Fig. 5 is a schematic cross-sectional view of a memory cell in an example of the magnetic memory device according to the present invention;

Fig. 6 is a diagram illustrating TMR measurement curves against external magnetic field of the TMR element according to the present invention and of the conventional TMR element;

Fig. 7 is a schematic plan view of a characteristics evaluation element;

Fig. 8 is a schematic cross-sectional view of a characteristics evaluation element;

Fig. 9 is a diagram illustrating a change in TMR ratio by heat-treating temperature;

Fig. 10 is a diagram illustrating a change in inverted magnetic field by heat-treating temperature;

Fig. 11 is a diagram illustrating a change in a dispersion from element to element of inverted magnetic field by heat-treating temperature; and

Fig. 12 is a diagram illustrating a change in bias voltage Vhalf by heat-treating temperature.

[Explanation of signs]

1…magnetoresistive effect element (TMR element), 2…substrate, 3…underlayer, 4…antiferromagnetic layer, 5…ferromagnetic layer (magnetization fixed layer), 5a…first magnetization fixed layer, 5b…second magnetization fixed layer, 5c…non-magnetic conductive layer, 6…intermediate layer (tunnel barrier layer), 7…ferromagnetic layer (magnetization free layer), 8…protective layer, 9…ferromagnetic tunnel junction, 11…memory cell, 12…insulation layer, 13…transistor, 14…gate insulation layer, 15…gate electrode, 16…source region, 17…drain region, 18…contact hole, 19…conductive plug, 20…wire layer, 3, 4…terminal pads, 30…insulation layer, 31 to

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34…first to fourth interlayer insulation layers, 131…vacuum chamber, 132…heating means, 133…magnetic field applying means, 134…rack, WL…word line, BL…bit line

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(72) Inventor BESSHO Kazuhiro
c/o Sony Corporation
7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

(72) Inventor OHBA Kazuhiro
c/o Sony Corporation
7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

(72) Inventor HIGO Yutaka
c/o Sony Corporation
7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

(72) Inventor YAMAMOTO Tetsuya
c/o Sony Corporation
7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

(72) Inventor SONE Takeyuki
c/o Sony Corporation
7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

(72) Inventor KANO Hiroshi
c/o Sony Corporation
7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo

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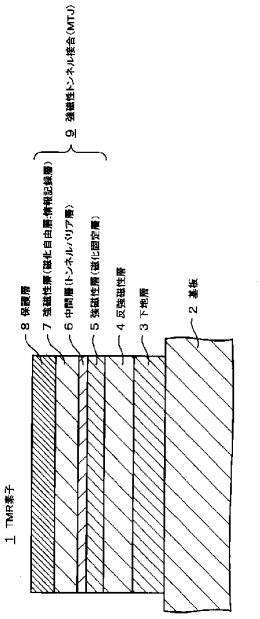
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(71)出願人　000002185
ソニー株式会社
東京都品川区北品川６丁目７番３５号
(74)代理人　100122884
弁理士　角田　芳末
(74)代理人　100113516
弁理士　磯山　弘信
(72)発明者　細見　政功
東京都品川区北品川６丁目７番３５号　ソニー株式会社内
(72)発明者　水口　徹也
東京都品川区北品川６丁目７番３５号　ソニー株式会社内

最終頁に続く

(54)【発明の名称】磁気抵抗効果素子および磁気メモリ装置とこれらの製造方法

(57)【要約】
【課題】すぐれたアステロイド曲線と、高い抵抗変化率および保磁力の低減、磁気特性の安定化を図ることができるようにする。
【解決手段】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、その強磁性層のうちの少なくとも一方が、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有する結晶質の強磁性層を有する構成とする。
結晶質の強磁性層は、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するスパッタ膜の結晶質化強磁性層による。
【選択図】　図１



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【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の少なくとも一方が、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有する結晶質の強磁性層を有することを特徴とする磁気抵抗効果素子。
【請求項２】
上記少なくとも一方の結晶質の強磁性層が、上記ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するスパッタ膜の結晶質化強磁性層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３】
上記少なくとも一方の結晶質の強磁性層を、組成式Fe_x Co_y B_z（組成式中、ｘ、ｙ、ｚは、原子％を表す）を有し、５≦ｘ≦４５、３５≦ｙ≦８５、１０≦ｚ≦３０、ｘ＋ｙ＋ｚ＝１００による構成とすることを特徴とする請求項１または２に記載の磁気抵抗効果素子。
【請求項４】
上記少なくとも一方の結晶質の強磁性層を、組成式ＦｅａＣｏｂＮｉｃＢｄ（組成式中、ａ～ｄは原子％を表す）を有し、５≦ａ≦４５、３５≦ｂ≦８５、０＜ｃ≦３５、１０≦ｄ≦３０、ａ＋ｂ＋ｃ＋ｄ＝１００による構成とすることを特徴とする請求項１または２に記載の磁気抵抗効果素子。
【請求項５】
上記磁気抵抗効果素子が、上記中間層をトンネルバリア層とする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６】
上記対の強磁性層の一方が、磁化固定層であり、他方が情報記録層であるスピンバルブ型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７】
上記強磁性層が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８】
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の製造方法であって、
上記強磁性層のうちの少なくとも一方の強磁性層を、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するアモルファスないしは微結晶組織の強磁性材料層の成膜工程と、その後、該強磁性材料層の結晶化温度以上の温度で、磁場中熱処理し、上記アモルファスないしは微結晶組織を結晶質に構造変更する工程とを経て形成することを特徴とする磁気抵抗効果素子の製造方法。
【請求項９】
上記ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するアモルファスないしは微結晶組織の強磁性材料層を、スパッタによって成膜することを特徴とする請求項８に記載の磁気抵抗効果素子の製造方法。
【請求項１０】
上記アモルファスないしは微結晶組織の強磁性材料層を、組成式Fe_x Co_y B_z（組成式中、ｘ、ｙ、ｚは、原子％を表す）を有し、５≦ｘ≦４５、３５≦ｙ≦８５、１０≦ｚ≦３０、ｘ＋ｙ＋ｚ＝１００による構成とすることを特徴とする請求項８または９に記載の磁気抵抗効果素子の製造方法。
【請求項１１】
上記アモルファスないしは微結晶組織の強磁性材料層を、組成式ＦｅａＣｏｂＮｉｃＢｄ（組成式中、ａ～ｄは原子％を表す）を有し、５≦ａ≦４５、３５≦ｂ≦８５、０＜ｃ≦３５、１０≦ｄ≦３０、ａ＋ｂ＋ｃ＋ｄ＝１００による構成とすることを特徴とする請求

項８または９に記載の磁気抵抗効果素子の製造方法。
【請求項１２】
上記磁場中熱処理温度Ｔ〔℃〕を、
２８０＋２×（Ｂ含有量〔％〕）≦Ｔ≦４００
とすることを特徴とする請求項８に記載の磁気抵抗効果素子の製造方法。
【請求項１３】
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、
該磁気抵抗効果素子を厚さ方向に挟むワード線およびビット線とを備え、
上記強磁性層のうちの少なくとも一方が、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有する結晶質の強磁性層を有することを特徴とする磁気メモリ装置。
【請求項１４】
上記少なくとも一方の結晶質の強磁性層が、上記ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するスパッタ膜の結晶質化強磁性層であることを特徴とする請求項１３に記載の磁気メモリ装置。
【請求項１５】
上記少なくとも一方の結晶質の強磁性層を、組成式Fe_x Co_y B_z（組成式中、ｘ、ｙ、ｚは、原子％を表す）を有し、５≦ｘ≦４５、３５≦ｙ≦８５、１０≦ｚ≦３０、ｘ＋ｙ＋ｚ＝１００による構成とすることを特徴とする請求項１３または１４に記載の磁気メモリ装置。
【請求項１６】
上記少なくとも一方の結晶質の強磁性層を、組成式ＦｅａＣｏｂＮｉｃＢｄ（組成式中、ａ～ｄは原子％を表す）を有し、５≦ａ≦４５、３５≦ｂ≦８５、０＜ｃ≦３５、１０≦ｄ≦３０、ａ＋ｂ＋ｃ＋ｄ＝１００による構成とすることを特徴とする請求項１３または１４に記載の磁気メモリ装置。
【請求項１７】
上記磁気抵抗効果素子が、上記中間層をトンネルバリア層とする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１３に記載の磁気メモリ装置。
【請求項１８】
上記対の強磁性層の一方が、磁化固定層であり、他方が情報記録層であるスピンバルブ型磁気抵抗効果素子であることを特徴とする請求項１３に記載の磁気メモリ装置。
【請求項１９】
上記強磁性層が積層フェリ構造を有することを特徴とする請求項１３に記載の磁気メモリ装置。
【請求項２０】
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、該磁気抵抗効果素子を厚さ方向に挟むワード線およびビット線とを備える磁気メモリ装置の製造方法であって、
上記強磁性層のうちの少なくとも一方を、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するアモルファスないしは微結晶組織の強磁性材料層を成膜し、その後、該強磁性材料層の結晶化温度以上の温度で、磁場中熱処理し、上記アモルファスないしは微結晶組織を結晶質に構造変更することを特徴とする磁気メモリ装置の製造方法。
【請求項２１】
上記少なくとも一方のＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するアモルファスないしは微結晶組織の強磁性材料層をスパッタによって成膜することを特徴とする請求項２０に記載の磁気メモリ装置の製造方法。
【請求項２２】
上記アモルファスないしは微結晶組織の強磁性材料層が、組成式Fe_x Co_y B_z（組成式中、ｘ、ｙ、ｚは、原子％を表す）を有し、５≦ｘ≦４５、３５≦ｙ≦８５、１０≦ｚ≦３０、ｘ＋ｙ＋ｚ＝１００による構成とすることを特徴とする請求項２０または

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２１に記載の磁気メモリ装置の製造方法。
【請求項２３】
上記アモルファスないしは微結晶組織の強磁性材料層が、組成式ＦｅａＣｏｂＮｉｃＢｄ（組成式中、ａ～ｄは原子％を表す）を有し、５≦ａ≦４５、３５≦ｂ≦８５、０＜ｃ≦３５、１０≦ｄ≦３０、ａ＋ｂ＋ｃ＋ｄ＝１００による構成とすることを特徴とする請求項２０または２１に記載の磁気メモリ装置の製造方法。
【請求項２４】
上記磁場中熱処理温度Ｔ〔℃〕を、
２８０＋２×（Ｂ含有量〔％〕）≦Ｔ≦４００
とすることを特徴とする請求項２０に記載の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、磁気抵抗効果素子および磁気メモリ装置とこれらの製造方法に関わる。
【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などの素子には、高集積化、高速化、低電力化など、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 ；強誘電体メモリ）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秒オーダーであるという欠点がある。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装置である。
【０００５】
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る記憶がなされることから、書換え可能回数がきわめて大きいという特徴がある。また、このＭＲＡＭは、アクセス時間をかなり高速化することができると予想されていて、既に、ナノ秒台での動作が可能であることの確認がなされている。
【０００６】
このＭＲＡＭのメモリ素子を構成する磁気抵抗効果素子として、トンネル磁気抵抗効果（Ｔｕｎｎｅｌ Ｍａｇｎｅｔｏｒｅｓｉｓｔａｎｃｅ：ＴＭＲ）素子がある。このＴＭＲ素子の基本的構造は、強磁性層／トンネルバリア層／強磁性層の積層構造による。
このＴＭＲ素子にあっては、そのトンネルバリア層を介して配置された対の強磁性層間に一定の電流を通電した状態で、外部磁場を印加することによって、両強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。このとき、両強磁性層の互い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。したがって、このＴＭＲ素子は、外部磁場により上述した反平行と平行の状態を作り出すことによって、抵抗値変化として、情報の記録を行うことができ、メモリ素子として機能させることができる。
【０００７】

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特にスピンバルブ型のＴＭＲ素子においては、対の強磁性層の一方の強磁性層は、これに反強磁性層を隣接配置して、この反強磁性層との反強磁性結合によって磁化の向きを一定の向きに固定させることによって固定磁化層とするものである。
そして、他方の強磁性層を、外部磁場等によって容易に磁化反転する磁化自由層とし、この磁化自由層をもって磁気メモリ装置においては、情報記録層とするものである。

【０００８】

このスピンバルブ型のＴＭＲ素子における抵抗値の変化率は、その対の強磁性層のそれぞれのスピン分極率をＰ１　，Ｐ２　とすると、下記の式（１）で表される。

２Ｐ１　Ｐ２　／（１－Ｐ１　Ｐ２　）　　（１）

つまり、両強磁性層のスピン分極率Ｐ１　，Ｐ２　が大きい程、抵抗変化率が大きくなる。この抵抗変化率と強磁性層の材料との関係については、すでに、Ｆｅ、Ｃｏ、Ｎｉ等のＦｅ族の強磁性元素や、それらのこれら金属の合金についての報告がなされている。

【０００９】

ところで、ＭＲＡＭの基本的構成は、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、これらビット線とワード線との立体的交叉部に磁気メモリ素子としてのＴＭＲ素子が配置される。このＭＲＡＭでの記録は、アステロイド特性を利用したＴＭＲ素子に対する選択書き込みによる。

【００１０】

すなわち、ビット線およびワード線に選択的に所要の通電がなされて、これによって発生する互いに直交する方向の誘導磁界の合成による反転外部磁界を、選択されたＴＭＲ素子に印加して、その磁化自由層すなわち情報記録層の磁化の向きを上述した磁化固定層の磁化の向きと平行もしくは反平行として、例えば“０”，“１”の記録を行う。

【００１１】

このＭＲＡＭに使用されるビット線およびワード線には、通常の半導体装置における配線材料のＣｕや、ＡＩ等の導体薄膜が使用される。このような通常の配線材料を用い、かつ線幅０．２５μｍのビット線およびワード線によって例えば反転磁界Ｈｃが２０〔Ｏｅ〕である磁気メモリ素子に対して、書き込みを行うには、約２ｍＡの電流が必要となる。ビット線およびワード線の厚さが、線幅と同じ０．２５μｍである場合、このときの電流密度は、エレクトロマイグレーションによる断線限界値に近い３．２×10^6　Ａ／ｃｍ^2　である。
したがって、配線の信頼性を維持するためには、書き込み電流の低減が不可欠である。
また、書き込み電流による発熱の問題や、消費電力の低減の観点からも、書き込み電流を低減させる必要がある。

【００１２】

ＭＲＡＭにおける書き込み電流の低減を実現する手法として、ＴＭＲ素子の反転磁界を低減させることが挙げられる。
ＴＭＲ素子の反転磁界Ｈｃは、ＴＭＲ素子の大きさ、形状、層構成、材料の選択等によって適宜決定されるものである。しかしながら、例えばＭＲＡＭの記録密度の向上を目的としてＴＭＲ素子を微細化した場合には、ＴＭＲ素子の反転磁界が上昇するという不都合が生じる。したがって、ＭＲＡＭの微細化すなわち高集積化と、書き込み電流の低減とを同時に達成するためには、材料面からＴＭＲ素子の反転磁界の低減化を達成する必要がある。

【００１３】

また、ＭＲＡＭにおいて、各メモリ素子となるＴＭＲ素子の磁気特性が素子毎にばらついたり、同一素子についての繰り返し使用で、磁気特性にばらつきが生じると、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がある。
したがって、各ＴＭＲ素子において、安定して理想的なアステロイド曲線を描かせるに必要な磁気特性が求められる。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）曲線においてバルクハウゼンノイズ等のノイズがない

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こと、波形の角形性が良いこと、磁化状態が安定しており、反転磁界のばらつきが少ないことが必要である。

【００１４】

ＴＭＲ素子の情報読み出しは、上述したトンネルバリア層を介して配置された情報記録層と磁化固定層との磁気モーメントが反平行で抵抗値が高い状態の、例えば“１”、その逆に、互いの磁気モーメントが平行で抵抗値が低い状態の、例えば“０”を、例えば一定バイアス電圧での差電圧の検出により行う。

したがって、素子間の抵抗のばらつきが同じである場合には、ＴＭＲ比が高いほど、高速で集積度が高く、エラーレートの低いメモリ装置が実現できる。

【００１５】

また、ＴＭＲ素子には抵抗変化率のバイアス電圧依存性が存在し、バイアス電圧が上昇するにつれて、ＴＭＲ比が減少していくことが知られている。

そして、差電流または差電圧で読み出しを行う場合に、多くの場合、抵抗変化率が、バイアス電圧依存性により半減する電圧Ｖｈａｌｆで読み出し信号の最大値をとることがが知られているので、バイアス電圧依存性が小さいほど読み出しエラーの低減において有効である。

【００１６】

【発明が解決しようとする課題】

上述したように、ＭＲＡＭに用いられるＴＭＲ素子には、上述の書き込み特性要件と、読み出し特性要件とを同時に満足することが必要である。

しかしながら、ＴＭＲ素子の強磁性層の材料を選択する場合に、式（１）のＰ１　およびＰ２　で示されるスピン分極率が大きくなるような合金組成をＣｏ、Ｆｅ、Ｎｉの強磁性遷移金属元素のみを成分とする材料から選択すると、一般的にＴＭＲ素子の反転磁界Ｈｃが増大する傾向にある。

【００１７】

例えば$Co_{75}Fe_{25}$（原子％）合金等を情報記録層に用いた場合は、スピン分極率が大きく４０％以上の高いＴＭＲ比を確保できるが、反転磁界Ｈｃも高くなる。

これに対して、軟磁性材料として知られているパーマロイと呼称される$Ni_{80}Fe_{20}$（原子％）合金等を用いた場合には、反転磁界Ｈｃの低減は可能ではあるものの、上述の$Co_{75}Fe_{25}$（原子％）合金と比較してスピン分極率が小さくなることから、ＴＭＲ比が３３％程度まで低下してしまう。

また、$Co_{90}Fe_{10}$（原子％）は、約３７％のＴＭＲ比が得られるとともに、反転磁界Ｈｃを上述の$Co_{75}Fe_{25}$（原子％）合金と$Ni_{80}Fe_{20}$（原子％）合金との中間程度に抑えられるが、Ｒ－Ｈ曲線の角形比が劣り、書き込みを可能とするアステロイド特性が得られない。また、素子毎の情報記録層の反転磁界が安定しないという問題も発生する。

【００１８】

本発明は、特定材料による強磁性層と、その形成条件の選定によって上述した書き込み特性と、読み出し特性とを同時に向上することができる磁気抵抗効果素子および磁気メモリ装置、さらにこれらの製造方法を提供するものである。

【００１９】

【課題を解決するための手段】

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、その強磁性層のうちの少なくとも一方が、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有する結晶質の強磁性層を有する構成とする。

結晶質の強磁性層は、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するスパッタ膜の結晶質化強磁性層によることが望ましい。

【００２０】

本発明による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、

その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の製造方法であって、その強磁性層のうちの少なくとも一方を、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するアモルファスないしは微結晶組織の強磁性材料層を成膜し、その後、この強磁性材料層の結晶化温度以上の温度で、磁場中熱処理し、アモルファスないしは微結晶組織を結晶質に構造変更することによって磁気抵抗効果素子を得るものである。

【００２１】

そのアモルファスないしは微結晶組織の強磁性材料層の成膜は、スパッタによって行うことが望ましい。

また、磁場中熱処理の熱処理温度Ｔ〔℃〕は、

２８０＋２×（Ｂ含有量〔％〕）≦Ｔ≦４００　　・・・（１）

とすることが望ましいものである。

【００２２】

また、本発明によるメモリ装置は、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、この磁気抵抗効果素子を厚さ方向に挟むワード線およびビット線とを備え、対の強磁性層のうちの少なくとも一方が、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有する結晶質の強磁性層を有する構成とするものである。

そして、その結晶質の強磁性層は、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するスパッタ膜の結晶質化強磁性層によることが望ましい。

【００２３】

更に、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、この磁気抵抗効果素子を厚さ方向に挟むワード線およびビット線とを備える磁気メモリ装置の製造方法であって、強磁性層のうちの少なくとも一方を、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するアモルファスないしは微結晶組織の強磁性材料層を成膜し、その後、この強磁性材料層の結晶化温度以上の温度で、磁場中熱処理し、そのアモルファスないしは微結晶組織を結晶質に構造変更する。

【００２４】

そのアモルファスないしは微結晶組織の強磁性材料層の成膜は、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢのスパッタによって行うことによって、確実にアモルファスないしは微結晶組織の強磁性材料層としての成膜がなされる。

【００２５】

また、上述した各本発明におけるＦｅＣｏＢあるいはＦｅＣｏＮｉＢの各組成は、ＦｅＣｏＢについては、組成式Fe_x Co_y B_z（組成式中、ｘ、ｙ、ｚは、原子％を表す）を有し、５≦ｘ≦４５、３５≦ｙ≦８５、１０≦ｚ≦３０、ｘ＋ｙ＋ｚ＝１００とすることが望ましい。

また、ＦｅＣｏＮｉＢについては、組成式ＦｅａＣｏｂＮｉｃＢｄ（組成式中、ａ～ｄは原子％を表す）を有し、５≦ａ≦４５、３５≦ｂ≦８５、０＜ｃ≦３５、１０≦ｄ≦３０、ａ＋ｂ＋ｃ＋ｄ＝１００とすることが望ましい。

【００２６】

また、本発明による各製造方法における磁場中熱処理の熱処理温度Ｔ〔℃〕は、２８０＋２×（Ｂ含有量〔％〕）≦Ｔ≦４００とすることが望ましいものである。

【００２７】

本発明による磁気抵抗効果素子およびこの磁気抵抗効果素子を具備する磁気メモリ装置においては、その磁気抵抗効果素子を構成する、中間層を介して対向する対の強磁性層の少なくとも一方を、ＦｅＣｏＢ、あるいはＦｅＣｏＮｉＢによって構成するものであるが、この構成において、この組成の磁性材料をスパッタによって成膜するとき、アモルファスないしは微結晶組織の成膜がなされるが、本発明においては、この成膜を結晶質に構造変更することによって、磁気抵抗効果素子の磁気抵抗（ＭＲ比）の向上、Ｒ－Ｈ曲線の角形

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比の改善、したがって、ステロイド特性の改善、ＭＲ比のバイアス電圧依存性の改善、保磁力のばらつきすなわち反転磁界のばらつきの改善を図ることができることを見出したものである。

【００２８】

そして、本発明方法においては、その結晶質化を、磁場中熱処理によって行うことによって、上述したＭＲ比の向上、反転磁界のばらつきの低減化等を確実に行うことができるものである。これは、この処理によって強磁性層の結晶磁気異方性が一方向に制御されることによると思われる。

【００２９】

尚、上述した強磁性材料のスパッタは、放電ガスを用いて、各種方法によって発生させたプラズマからのイオンを、スパッタ材ターゲットに衝突させてスパッスパッタリングする方法、あるいはいわゆるイオンビームスパッタにおけるように、高エネルギーに加速させたイオンビームをターゲットに衝撃させるスパッタ等、各種のスパッタによることができる。

【００３０】

【発明の実施の形態】

〔磁気抵抗効果素子〕

本発明による磁気抵抗効果素子の一実施形態は、磁気メモリ装置のメモリ素子としての磁気抵抗効果素子であるが、この実施形態に限られるものではない。

本発明による磁気抵抗効果素子は、対の強磁性層、具体的には、磁化固定層と磁化自由層とが、中間層を介して対向された積層構造部を有し、その積層面に垂直、すなわち厚さ方向に電流を流すことによって磁気抵抗変化を得る構成による。

そして、対の強磁性層の少なくとも磁化自由層を構成する強磁性層は、強磁性遷移金属元素の少なくともＦｅおよびＣｏと共にＢを含有する、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢのスパッタ膜を結晶質化した強磁性層によって構成する。

【００３１】

この磁気抵抗効果素子は、その中間層を、例えばトンネルバリア層によって構成することにより、トンネル磁気抵抗効果（ＴＭＲ）素子とされる。

あるいは、その中間層を非磁性導電層によって構成してスピンバルブ型磁気抵抗効果素子とする。

強磁性層は、単層構造とすることもできるが、多層構造とすることができる。例えば磁化固定層を構成する強磁性層を、積層フェリ構造とすることができる。

【００３２】

図１は、この磁気抵抗効果素子、例えばスピンバルブ型のＴＭＲ１の一例の概略断面図を示す。

この例では、基板２例えばＳｉ基板上に、下地層３が形成され、この下地層３を介して反強磁性層４が形成され、この上に、中間層６を介して対の強磁性層５および７が形成された積層構造とされる。

この例では、反強磁性層４上に、磁化固定層を構成する強磁性層５が形成され、この上に、トンネルバリア層による中間層６が形成され、更にこの上に、情報記録層となる磁化自由層を構成する強磁性層７が形成されて、この積層構造によって強磁性トンネル接合（以下ＭＴＪという）が構成される。そして、このＭＴＪ９上に保護層８いわゆるトップコート層が被着形成される。

【００３３】

下地層３は、例えばＴａ膜によって構成される。

反強磁性層４は、一方の強磁性層５による磁化固定層５と反強磁性的に結合することにより、外部から印加される信号磁界、例えばメモリ装置における書き込み磁界によっても磁化が反転することなく、常に、磁化固定層５の磁化の向きを一定の向きに設定するものである。

この反強磁性層４は、Ｆｅ、Ｎｉ、Ｐｔ、Ｉｒ、Ｒｈ等を含むＭｎ合金、Ｃｏ酸化物、Ｎ

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ｉ酸化物等によって構成することができるものであり、この反強磁性層４は、例えばＰｔＭｎによって構成する。

【００３４】

中間層６のトンネルバリア層は、金属膜例えばＡｌのスパッタ膜あるいは蒸着膜を、酸化した酸化膜あるいは窒化した窒化膜によって形成することができる。そのほか、このトンネルバリア層６は、有機金属と、酸素、オゾン、窒素、ハロゲン、ハロゲン化ガス等を用いたＣＶＤ（Ｃｈｅｍｉｃａｌ Ｖａｐｏｒ Ｄｅｐｏｓｉｔｉｏｎ） 法による成膜によって構成することもできる。

【００３５】

そして、この中間層６を介して積層される磁化固定層５および磁化自由層７は、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有する強磁性層によって構成される。磁化固定層５は、上述したように、反強磁性層４との反強磁性結合によって磁化の向きが一定に固定される。

【００３６】

そして、中間層６を介して配置される両強磁性層、特に、例えば情報記録層となる磁化自由層、すなわち強磁性層７は、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢを含有するスパッタ膜を結晶質化した強磁性層によって構成される。

【００３７】

例えば情報記録層としての磁化自由層７は、膜厚１ｎｍ～１０ｎｍとすることが、良好な磁気特性を確保する上で望ましい。

すなわち、この磁化自由層７の膜厚が、１ｎｍ未満である場合は、磁化自由層としての磁気特性が大幅に損なわれ、また、１０ｎｍを超えると保磁力が大きくなり過ぎ、例えば磁気メモリ装置のメモリ素子として用いる場合、実用上不適当となるおそれがあることに因る。

【００３８】

磁化自由層７は、上述したＦｅＣｏＢあるいはＦｅＣｏＮｉＢによる単層構造とするに限られるものではなく、例えばこの組成の強磁性層と、これに比し磁化量の小さいＮｉＦｅ層との積層構造とすることができ、この場合は、これら層の総厚が１０ｎｍを超える構成とすることもできる。

【００３９】

また、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢによって磁化固定層５を構成する場合、その膜厚は、０．５ｎｍ～６ｎｍに選定することが望ましい。

これは、磁化固定層５の膜厚が、０．５未満である場合には、磁化固定層としての磁気特性が損なわれ、また６ｎｍを超えると反強磁性層との交換結合磁界が十分に得られなくなることに因る。

【００４０】

また、図１で示した例では、磁化固定層５を単層構造とした場合であるが、図２にその一例の概略断面図を示すように、その磁化固定層５を、強磁性積層フェリ構造とすることができる。

この例では、反強磁性層４上に、この反強磁性層４と反強磁性結合する第１の磁化固定層５ａが成膜され、この上に非磁性導電層５ｃを介して第２の磁化固定層５ｂが積層されている。

非磁性導電層５ｃは、例えばＲｕ、Ｃｕ、Ｃｒ、Ａｕ、Ａｇ等の金属膜によって構成することができる。

尚、図２において、図１と対応する部分には同一符号を付して重複説明を省略する。

また、上述した例では、中間層６が、トンネルバリア層であってＴＭＲ素子構成とした場合であるが、中間層６が、非磁性導電層によって構成され、膜厚方向に通電がなされるいわゆるＣＰＰ（Ｃｕｒｒｅｎｔ Ｐｅｒｐｅｄｉｃｕｌａｒ ｔｏ Ｐｌａｎｅ） 構成のスピンバルブ型磁気抵抗効果素子に適用することもできる。

【００４１】

〔磁気抵抗効果素子の製造方法〕

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本発明による磁気抵抗効果素子の製造方法の一実施形態として、図１で示した磁気抵抗効果素子を製造する場合を例示する。しかしながら、本発明は、この実施形態に限定されるものではない。
この実施の形態においては、上述した基板２上への、下地層３、反強磁性層４、磁化固定層５、中間層６、磁化自由層７、保護層８の成膜は、例えばマルチチャンバー型のスパッタリング装置によって行うことができる。
【００４２】
この場合、先ず、１つのチャンバー内に、例えばＳｉよりなる基板２を配置して、この上に、順次例えばＴａによる下地層３、ＰｔＭｎによる反強磁性層４、対となる強磁性層の下層側のＦｅＣｏＢあるいはＦｅＣｏＮｉＢによる磁化固定層５、例えばＡＩ金属膜による中間層６を、連続的にスパッタリングによって形成する。
【００４３】
その後、他のチャンバー内に、これら成膜を施した基板２を移行し、このチャンバー内において、中間層６を構成するＡＩ金属膜の表面を酸化してトンネルバリア層を形成する。その後、再び基板２を、例えば先のチャンバー内に持ち来し、中間層６上に、上述した対となる上層側の強磁性層として、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢによる磁化自由層７をスパッタリングし、更に、この上に、例えばＴａによる保護層８を、連続スパッタリングによって形成する。
【００４４】
これらスパッタリングは、前述したように、放電ガスを用いて、各種方法によって発生させたプラズマからのイオンを、スパッタ材のターゲットに衝突させてスパッタリングする方法、あるいはいわゆるイオンビームスパッタにおけるように、高エネルギーに加速させたイオンビームをターゲットに衝撃させるスパッタ等、各種のスパッタリングによることができる。
【００４５】
このようにして、形成された各積層膜、特にＦｅＣｏＢあるいはＦｅＣｏＮｉＢによる磁化固定層５および磁化自由層７は、アモルファスないしは微結晶組織の層として成膜される。
【００４６】
次に、この積層膜を有する基板２を、磁場中熱処理する。
この磁場中熱処理を行う磁場中熱処理装置は、図３にその一例の概略断面図を示すように、例えば真空チャンバー１３１を有し、その外周には例えばヒーターによる加熱手段１３２と、例えば電磁石による磁場印加手段１３３が配置された構成を有する。
【００４７】
この真空チャンバー１３１内のラック１３４に、上述した積層膜を有する基板２を配置し、磁場印加手段１３３によって矢印１３５に示すように、積層膜の膜面方向に沿う、所定の向きの磁場を印加した状態で加熱手段１３２によって加熱する。この熱処理によって、アモルファスないしは微結晶組織として形成された磁化固定層５および磁化自由層７を結晶質化する。
このとき、この磁場中熱処理によって、同時に、反強磁性層４の規則化すなわち所定の向きに磁化し、これによってこの反強磁性層４上に接して形成され、反強磁性層４と反強磁性結合された強磁性層による磁化固定層５の磁化を一方向に固定することができる。
【００４８】
この磁場中熱処理は、５００ｋＯｅ以上の磁場中で、強磁性層、すなわち磁化固定層および磁化自由層としての強磁性層５および７の強磁性材料の結晶化温度以上の温度で行う。具体的には、この磁場中熱処理温度Ｔ〔℃〕は、後に詳述する２８０＋２×（Ｂ含有量〔％〕）≦Ｔ≦４００とする。
【００４９】
〔磁気メモリ装置とその製造方法〕
本発明による磁気メモリ装置は、そのメモリセルを構成するメモリ素子が、上述した本発

明の各構成による磁気抵抗効果素子、例えばＴＭＲ素子によって構成される。
この磁気メモリ装置は、例えば図４に、その一例の要部の概略構成の斜視図を示し、図５に、その１つのメモリセル１１の概略断面図を示すように、クロスポイント型のＭＲＡＭアレイ構造とすることができる。
【００５０】
すなわち、このＭＲＡＭにおいては、並置配列された複数のワード線ＷＬと、これらワード線ＷＬとそれぞれ立体的に交叉するように並置配列された複数のビット線ＢＬとを有し、これらワード線ＷＬとビット線ＢＬとの間の立体的交叉部に、それぞれメモリセル１１として、本発明による磁気抵抗効果素子、例えばＴＭＲ素子１が配置される。
図４においては、磁気メモリ装置における３×３のメモリセル１１がマトリクス状に配置された部分を示している。
【００５１】
各メモリセル１１は、図５に示すように、例えばシリコン基板より成る半導体基板２上すなわち半導体ウエハ上に、スイッチング用のトランジスタ１３が形成される。
このトランジスタ１３は、例えばＭＯＳトランジスタ（絶縁ゲート電界効果型トランジスタ）より成る。この場合、半導体基板２上にゲート絶縁層１４が形成され、この上にゲート電極１５が被着された絶縁ゲート部が構成される。
また、半導体基板２に、絶縁ゲート部を挟んでその両側にソース領域１６とドレイン領域１７とが形成される。この構成において、ゲート電極１５は、読み出し用のワード線ＷＬ１　を構成している。
【００５２】
このトランジスタ１３が形成された半導体基板２上には、ゲート電極１５を覆って第１の層間絶縁層３１が形成され、この第１の層間絶縁層３１の、各ソース領域１６およびドレイン領域１７上に、層間絶縁層３１を貫通してコンタクトホール１８が穿設され、各コンタクトホール１８に、導電性プラグ１９が充填される。
そして、第１の層間絶縁層３１上に、ソース領域１６に対する配線層２０が、ソース領域１６にコンタクトされた導電性プラグ１９上に跨がって被着形成される。
【００５３】
更に、配線層２０を覆って第１の層間絶縁層３１上に第２の層間絶縁層３２が形成される。
この第２の層間絶縁層３２には、ドレイン領域１７にコンタクトされた導電性プラグ１９上に、コンタクトホール１８が貫通穿設され、これに導電性プラグ１９が充填される。
【００５４】
第２の層間絶縁層３２上には、例えば読み出し用ワード線ＷＬ１　の延長方向に延長して図４のワード線ＷＬに相当する書き込み用ワード線ＷＬ２　が形成される。
また、この書き込み用ワード線ＷＬ２　を覆って、第２の層間絶縁層３２上に、例えば酸化シリコンより成る第３の層間絶縁層３３が形成される。この第３の層間絶縁層３３においても、ドレイン領域１７にコンタクトされた導電性プラグ１９上に、コンタクトホール１８が貫通穿設され、これに導電性プラグ１９が充填される。
【００５５】
そして、この第３の層間絶縁層３３を貫通する導電プラグ１９にコンタクトして、第３の層間絶縁層３３上に、図１あるいは図２で示した導電性の例えばＴａより成る下地層３を形成し、この下地層３上に、磁気抵抗効果素子例えばＴＭＲ素子１を形成する。
【００５６】
更に、この下地層３とこの上のＴＭＲ素子１を覆って第４の層間絶縁層３４が形成され、この上に、書き込み用ワード線ＷＬ上を横切って、ビット線ＢＬを形成する。
【００５７】
ビット線ＢＬ上には、図示しないが表面絶縁層が必要に応じて形成される。
上述した第１～第４の各層間絶縁層や表面絶縁層等は、例えばプラズマＣＶＤによって形成することができる。

【００５８】
磁気抵抗効果素子のＴＭＲ素子１の構造および製造方法は、前述したように、図２あるいは図３の構造を、本発明製造方法で説明した構成材料および成膜方法によって、反強磁性層４、単層あるいは積層フェリ構造による磁化固定層５、中間層６をスパッタリングによって形成し、中間層６に対する酸化処理もしくは窒化処理を行い、続いて、磁化自由層７、保護層８のスパッタリングを行うことによって形成することができる。
【００５９】
したがって、この場合においても、磁化固定層の強磁性層５、および磁化自由層すなわち情報記録層の強磁性層７は、ＦｅＣｏＢあるいはＦｅＣｏＮｉＢのアモルファスないしは微結晶組織層として形成される。
これら、メモリセル１１は、共通の半導体基板２すなわち半導体ウエハ上に、図４で示すように、マトリックス状に配列される。
【００６０】
次に、この半導体基板２を、図３で説明した磁場中熱処理装置によって、同様に、磁場中熱処理して、磁気抵抗効果素子のＴＭＲ素子１の、アモルファスないしは微結晶組織として形成された磁化固定層および磁化自由層の強磁性層５および７を結晶質化する。
このとき、この磁場中熱処理によって、同時に、反強磁性層４の規則化すなわち反強磁性層４を所定の向きに磁化し、これによってこの反強磁性層４上に接して形成されこれと反強磁性結合された強磁性層による磁化固定層５の磁化を一方向に固定することができる。
【００６１】
この構成による磁気メモリ装置は、ビット線ＢＬと書き込みワード線ＷＬ（ＷＬ１　）とに所要の電流を通電することによって、選択された交叉部のメモリセル１１の磁気抵抗効果素子例えばＴＭＲ素子１の磁化自由層に、両ビット線ＢＬと書き込みワード線ＷＬによる発生磁界の合成による所要の書き込み磁界を印加して、前述したように、磁化自由層の磁化を反転させて、情報の記録を行う。
【００６２】
この情報の読み出しは、選択された読み出しを行うメモリセルに関わるトランジスタ１３のゲート電極１５すなわち読み出しワード線ＷＬ１　に所要のオン電圧を印加してトランジスタ１３をオン状態とし、ビット線ＢＬとトランジスタ１３のソース領域１６の配線層２０との間に、読み出し電流を通電することによってその読み出しを行う。
【００６３】
上述したように、本発明による磁気抵抗効果素子は、磁化固定層および磁化自由層を構成する強磁性層５および７、特に磁化自由層を構成する強磁性層７が強磁性遷移金属元素であるＦｅ、Ｃｏと共にＢを含有するＦｅＣｏＢ、ＦｅＣｏＮｉＢによって構成することにより反転磁界の増大化が図られる。
すなわち、強磁性遷移金属元素のみで強磁性層を構成する従来通常のＴＭＲ素子では、スピン分極率の向上と反転磁界の低減化とが相容れないという不都合がある。
これに比し、上述したＦｅＣｏＢ、ＦｅＣｏＮｉＢによるときは、スピン分極率の向上と共に保磁力すなわち反転磁界の低減が実現される。すなわち、スピン分極率が高められることによって、前記（１）式から高い抵抗変化率、すなわちＴＭＲ素子においては、高いＴＭＲ比が得られる。また、反転磁界の低減によって、磁気メモリ装置において、そのメモリ素子としての磁気抵抗効果素子に対する書き込み磁界、すなわち書き込み電流の低減を図ることができる。
【００６４】
そして、特に本発明においては、アモルファスないしは微結晶組織として形成された、この組成の強磁性層を、磁場中熱処理することによって磁性層の磁気的困難軸と容易軸とで示される磁気異方性が制御され、Ｒ－Ｈ曲線の角形性が高められ、磁化自由層すなわち情報記録層の反転磁界が安定する。
また、Ｂ（ボロン）を含有することによってバイアス電圧依存性が改善される。
【００６５】

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ここで、情報記録層が$Co_{72}Fe_8B_{20}$〔原子%〕を含有する本発明によるＴＭＲ素子と、情報記録層が$Co_{90}Fe_{10}$〔原子%〕を含有するＴＭＲ素子とを作製し、これらに付いて外部磁場の変化に対するトンネル抵抗値の変化率を測定した。このＴＭＲ〔%〕－外部磁場〔Ｏｅ〕曲線の測定結果を、図６に示す。図６においては、曲線６１は、情報記録層が$Co_{72}Fe_{80}B_{20}$のＴＭＲ素子の場合のＴＭＲ－外部磁場曲線であり、曲線６２は、情報記録層が$Co_{90}Fe_{10}$のＴＭＲ素子のＴＭＲ－外部磁場曲線である。

【００６６】

曲線６１と６２を比較して明らかなように、情報記録層がＦｅ、Ｃｏ、Ｂを含有するＴＭＲは、Ｆｅ、Ｃｏのみを含有するＴＭＲ素子に比してＴＭＲ比を高く維持しつつ、保磁力Ｈｃを低減することが可能であった。

また、ＴＭＲ－磁場ループの角形性が向上すると共に、バルクハウゼンノイズも改善されていることが分かる。

【００６７】

したがって、本発明による磁気抵抗効果素子による磁気メモリ装置のメモリ素子は、書き込み電流の低減が図られるばかりでなく、アステロイド曲線の形状も改善されることによって、書き込み特性が向上し、特性のばらつきが改善され、て、書き込みエラーの低減が図られる。

【００６８】

このような効果が現れる原因は明確でないが、Ｂを含有する強磁性層特有の現象と考えられ、また、この特性の改善は、強磁性層がアモルファスないしは微結晶状態において必ずしも得られるものではない。すなわち、上述した結晶化温度以上で、かつ磁場中熱処理によって結晶質化され、かつ磁気異方性を有するように制御されることによって生じると思われる。

【００６９】

そして、磁気メモリ装置においては、同一基板上に、極めて多数のメモリ素子、すなわち磁気抵抗効果素子が形成されることから、上述した書き込み電流の低減は、きわめて大きな利益をもたらすものであり、また、すぐれたアステロイド曲線を得ることができること、つまり安定した磁気的特性の安定化が図られことは、極めて重要な点である。

【００７０】

尚、強磁性層が含有するＦｅＣｏＢ、ＦｅＣｏＮｉＢの合金組成には、好ましい範囲が存在するものである。これらＦｅＣｏＢ、ＦｅＣｏＮｉＢによる強磁性層による磁気抵抗効果素子、メモリ素子については、本出願人による特許願２００２－１０６９２６号ですでに提案しているところである。

【００７１】

すなわち、強磁性層が含有するＦｅ、Ｃｏ、Ｂの合金組成については、不可避な不純物元素を除いて、組成式$Fe_xCo_yB_z$（組成式中、ｘ、ｙ、ｚは、原子%を表す）から構成され、５≦ｘ≦４５、３５≦ｙ≦８５、１０≦ｚ≦３０であることが好ましい。このとき、ｘ＋ｙ＋ｚ＝１００である。これら組成の特定について以下説明する。

【００７２】

まず、Ｂの添加量について説明する。このＢの添加量が１０原子%未満であると、ベースとなるＦｅ－Ｃｏ合金の磁気特性が大きく反映され、緩やかな改善　効果が認められるのみである。したがって、１０原子%以上のＢを含有することにより、Ｆｅ、Ｃｏ等を同じ比率で含む合金と比較して、ＴＭＲ比が顕著に増大すると共に、抵抗－磁場曲線（Ｒ－Ｈ曲線）の角形性が改善される。また、ＴＭＲ比のバイアス依存性も改善され、更に、情報記録層の磁化状態が安定しているため、保磁力のばらつきが小さく、Ｒ－Ｈ曲線上に見られるノイズも大幅に低減する。

【００７３】

また、Ｂの添加量は、３０原子%以下であることが好ましい。これは、Ｂの添加量が３０原子%を超えると、例えば情報記録層としての強磁性的な特性および磁化固定層としての

固定磁界が損なわれてくる。その結果、ＴＭＲ比の低下、Ｒ－Ｈ曲線の角形性の劣化および保磁力の減少を来すおそれが生じる。したがって、Ｂを添加することによる効果を確実に得るためには、Ｆｅ－Ｃｏ合金の組成によって若干変化するが、少なくとも一方の強磁性層の、情報記録層を構成する強磁性層７は、１０原子％以上、３０原子％以下のＢが含有する組成とすることが望ましい。

【００７４】

次に、ベースとなるＦｅ－Ｃｏ合金について説明する。

Ｂを含めた合金組成で少なくとも３５原子％のＣｏが必要である。Ｂが添加された場合の効果を促進し、しかも強磁性的な性質を保持するためである。その上で、Ｆｅが添加されると、Ｃｏ－Ｆｅベース合金での変化と同様に、ＴＭＲ比の向上および保磁力の増大効果が認められる。しかし、Ｆｅの含有量が、４５原子％を超えると実際の素子寸法では、保磁力が過剰に増大し、ＴＭＲ素子として不適当となる。また、Ｆｅの含有量が５原子％未満であると、強磁性層のスピン分極率が小さくなり、磁気抵抗効果素子として動作するに十分なＴＭＲ比が得られなくなるおそれがある。したがって、Ｆｅの含有量は、５原子％以上、４５原子％以下とすることが好ましい。

【００７５】

また、強磁性層としては、上述したように、Ｆｅ、Ｃｏ、ＢのほかにＮｉを含有する組成とすることができる。このＮｉを含有する場合でも、保磁力の増大を抑えつつ良好なＴＭＲ比を維持し、Ｒ－Ｈ曲線の角形性の改善効果を得ることができる。この場合、Ｎｉ含有量の好ましい範囲が存在する。すなわちＮｉは、３５原子％以下であることが好ましい。これは、Ｎｉの含有量が、３５原子％を超えると保磁力が小さくなり過ぎて、ＴＭＲ素子の動作の制御が困難となるおそれがあることに因る。すなわち、ＦｅＣｏＮｉＢの強磁性層においては、不可避な不純物元素を除いて、組成式ＦｅａＣｏｂＮｉｃＢｄ（組成式中、ａ～ｄは原子％を表す）から構成され、５≦ａ≦４５、３５≦ｂ≦８５、０＜ｃ≦３５、１０≦ｄ≦３０であるとが好ましい。そして、このとき、ａ＋ｂ＋ｃ＋ｄ＝１００である。

【００７６】

本発明は、上述した組成のＦｅＣｏＢおよびＦｅＣｏＮｉＢ合金に対し、アモルファスないしはＢ結晶組織を磁場中で結晶化温度以上の温度で熱処理し、磁気異方性が制御された結晶質に変化させることにより、情報記録層の反転磁界が均一化し、書き込みエラーが抑制され、ギガビット級のＭＲＡＭが正しく動作し得る状態を作るものである。

この磁場中熱処理は、前述したように、５００ｋＯｅ以上とし、熱処理温度は、Ｔ〔℃〕は、前述したように、２８０＋２×（Ｂ含有量〔％〕）≦Ｔ≦４００とするものであるが、この熱処理温度について説明する。

【００７７】

すなわち、アモルファス相の結晶化温度は、熱処理時間に依存し、その制御範囲は広い。ＭＲＡＭを製造する場合を考慮したとき、例えばそのＭＴＪ９における各層の界面における各層の構成元素の相互拡散の発生等による特性への影響から、現実的な時間として、その熱処理時間すなわち温度保持時間を２時間として考えると、ＦｅＣｏＢ合金およびＦｅＣｏＢ合金の結晶化温度は、Ｂ含有量に依存する。Ｂ含有量が１０原子％のとき、結晶化温度は２９０℃、Ｂ含有量が２０原子％のとき、結晶化温度は３００℃、Ｂ含有量が３０原子％のとき、結晶化温度は３１０℃であった。つまり、この結晶化温度は、Ｂの含有量に依存する。この結晶化温度の関係は、これらＢの含有量と結晶化温度の関係から、結晶化温度の近似式は、２８０＋２×（Ｂ含有量（％））で与えられる。

したがって、結晶化の熱処理温度は、２８０＋２×（Ｂ含有量（％））以上とする。

一方、この熱処理において、上述のＭＴＪ９において、そのトンネル磁気抵抗効果の特性が損なわれることがない温度とすることが必要であり、したがって、この熱処理温度は、４００℃以下となる。

これらのことから、磁場中熱処理の、熱処理温度Ｔ〔℃〕は、前記（２）式の、２８０＋２×（Ｂ含有量（％））≦Ｔ≦４００となる。

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【００７８】
尚、熱処理後の冷却時の冷却速度については、この冷却速度が余り遅いと、Ｂを多く含む微細析出物が生じ、特性の低下をもたらす。したがって、熱処理後の冷却速度にも考慮が望まれる。具体的には、熱処理温度から２８０℃に冷却するまでは、その冷却速度は毎分２℃以上とすることが望ましいことが確認された。
一方、加熱処理における昇温速度については、熱処理装置の性能に依存し、制御温度が、所望温度より高くなるいわゆるオーバーシュートが発生しない範囲でなるべく速い方が望ましい。
【００７９】
また、熱処理中の磁場強度に関して、磁場強度は、５ｋＯｅ以上必要である。
また、熱処理中にも磁場を印加し続けることが必要である。具体的に磁場を印加する温度域としては、熱処理温度から冷却中において、その温度７０℃に達するまで印加することが望ましい。
【００８０】
また、上述したＭＲＡＭの作製工程で、本発明における上述した熱処理は、ＭＴＪの形成直後に行うこともできるものの、積層構造部、すなわちＭＴＪを形成して後に、層間絶縁層例えば酸化シリコンをプラズマＣＶＤによって成膜する場合、この成膜において、３００℃以上に温度上昇することが考えられることから、本発明における熱処理は、ＭＴＪの形成後になされるこのプラズマＣＶＤの後に行うことが望ましい。
【００８１】
〔特性評価〕
次に、本発明による磁気抵抗効果素子と、これをメモリ素子として用いたＭＲＡＭの実施例に対応する特性評価用素子（以下ＴＥＧ（Ｔｅｓｔ　Ｅｌｅｍｅｎｔ　Ｇｒｏｕｐ）という）を作製して、これによって本発明構成の特性評価を行った。この特性評価とその結果について説明する。
この場合、図５において説明したように、ＭＲＡＭにおいては、メモリ素子としてのＴＭＲ素子以外に、スイッチング用のトランジスタ１３が形成されるものであるが、このＴＥＧにおいては、半導体基板２すなわち半導体ウエハには上述したスイッチング用トランジスタ１３の形成を省略した。
【００８２】
図７に概略平面図を示し、図８に、図７のＡ－Ａ線の概略断面図を示すように、表面に厚さ２μｍの熱酸化膜による絶縁層１２が形成された、厚さ０．６ｍｍの半導体基板（半導体ウエハ）２を用意した。
この半導体基板２上に、ワード線を構成する金属膜の形成、およびフォトリソグラフィによるパターンエッチングを行って、一方向に延長するワード線ＷＬを形成した。
このとき、ワード線ＷＬの形成部以外のエッチング部においては、半導体基板２の表面の酸化膜すなわち絶縁層１２が深さ５ｎｍまでエッチングされた。
【００８３】
ワード線ＷＬ上の一部に、ＴＭＲ素子１を作製した。このＴＭＲ素子１の形成は、先ず、半導体基板２側から、それぞれ全面的に、順次、厚さ３ｎｍのＴａ層と厚さ１００ｎｍのＣｕ層とによる下地層３、厚さ２ｎｍのＰｔＭｎ層による反強磁性層４、厚さ３ｎｍのＣｏＦｅ層と厚さ０．８ｎｍのＲｕ層による非磁性導電層と厚さ２．５ｎｍのＣｏＦｅ層とのフェリ磁性層による磁化固定層５、厚さ１ｎｍのＡＩを酸化処理した中間層６、厚さ５ｎｍのＦｅＣｏＢ層による磁化自由層７、厚さ５ｎｍのＴａ層より成る保護層８を形成した。
【００８４】
このようにして、形成した積層膜の一部によってＴＭＲ素子１を構成するものであり、このために積層膜のＴＭＲ素子１の形成部上に、フォトレジスト層によるマスク層（図示せず）をフォトリソグラフィによって形成する。
このマスク層を、エッチングマスクとして、上述の積層膜に対するエッチング例えばドラ

イエッチングを行って、上述した積層膜による所要のパターンのＴＭＲ素子１を形成する。
更に、フォトレジスト層によるマスク層上から、ＴＭＲ素子１の周囲を覆って厚さ１００ｎｍ程度に、Al_2O_3をスパッタし、その後、マスク層の除去を行って、ＴＭＲ素子１上の絶縁層の除去、すなわちリフトオフを行ってＴＭＲ１の表面を露出する。
【００８５】
この露出したＴＭＲ素子１上にコンタクトして全面的に金属膜の形成を成膜し、この金属膜をフォトリソグラフィによってパターンエッチングしてビット線ＢＬを形成する。
【００８６】
このビット線ＢＬと上述したワード線ＷＬとは、それぞれＣｕ層によって形成し、相互に交叉する方向に延長するパターンに形成する。
【００８７】
磁化自由層すなわち情報記録層を構成する強磁性層７のＦｅＣｏＢの組成は、$Fe_8Co_{72}B_{20}$〔原子％〕とした。
また、磁化固定層を構成する強磁性層５のＣｏＦｅの組成は、$Co_{75}Fe_{25}$〔原子％〕とした。
中間層６のトンネルバリア層は、先ずＡＩ膜をＤＣスパッタ法により厚さ１ｎｍに堆積し、その後に、酸素とアルゴンの流量比は、１：１とし、チャンバーのガス圧を０．１ｍＴｏｒｒとし、ＩＣＰ（Ｉｎｄｕｃｔｉｖｅ Ｃｏｕｐｌｅｄ Ｐｌａｓｍａ：誘導結合型プラズマ）により金属ＡＩ膜をプラズマ酸化することによって形成した。
この酸化時間は、ＩＣＰプラズマ出力に依存するが、この例では３０秒の酸化処理を行った。
この中間層６以外の成膜は、ＤＣマグネトロンスパッタ法を用いて成膜した。ＴＭＲ素子１は、短軸０．５μｍ、長軸１．０μｍの楕円形パターンに形成した。
【００８８】
ワード線ＷＬおよびビット線ＢＬは、それぞれ金属膜を形成し、これをフォトリソグラフィを用いたＡｒプラズマエッチングによってパターン化して形成するした。
ワード線ＷＬおよびビット線ＢＬの両端には、図７に示すように、それぞれ端子パッドを２３および２４を延長形成した。
このＴＥＧは、共通の基板２上に、多数個配列形成した。
このようにして作製したサンプルのＴＥＧにおける結晶化温度を測定したところ３００℃であった。
【００８９】
このようにして作製したＴＥＧを上述した磁場中熱処理装置よって、磁場中熱処理した。この熱処理は、ＰｔＭｎによる反強磁性層４の規則化熱処理も兼ねることができ、これによって強磁性トンネル接合ＭＴＪを構成した。
この磁場中熱処理は、磁場強度１０ｋＯｅ、熱処理時間（具体的には加熱保持時間）は、２時間とした。
【００９０】
上述のようにして作製されたＴＥＧについて、その熱処理温度を変化させて、ＴＭＲ比、反転磁界Ｈｃのばらつき、バイアス電圧依存性を測定した。これらは、次のように測定した。
【００９１】
〔ＴＭＲ比の測定〕
ＭＲＡＭのメモリ素子への情報記録は、ビット線、ワード線への通電による誘導磁界によって行うが、この場合の測定においては、ＴＥＧの情報記録層すなわち磁化自由層７の磁化反転を、外部磁界の印加によって行い、ＴＭＲ比の測定を行った。
この測定は、先ず、ＴＭＲ素子１の情報記録層を磁化反転させるための外部磁界を、情報記録層の磁化容易軸に対して平行になるように印加した。
この磁界の大きさは、５００〔Ｏｅ〕とした。

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【００９２】
次に、情報記録層の磁化容易軸の一方からみて、－５００〔Ｏｅ〕から＋５００〔Ｏｅ〕まで掃引するのと同時に、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となるように調整して、強磁性トンネル接合（ＭＴＪ）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た。
【００９３】
そして、磁化固定層５と情報記録層７との磁化が反平行の状態であって抵抗が高い状態の抵抗値R_Hと、磁化固定層５と情報記録層７と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R_Lとの差と、R_Lとの比、｛（R_H－R_L）／R_L｝×１００を、ＴＭＲ比とした。そして、このＴＭＲ比は、良好な読み出し特性を得るという観点から、４５％以上であることが望ましい。
【００９４】
〔反転磁界Ｈｃとばらつきの測定〕
反転磁界Ｈｃは、前記ＴＭＲ比の測定法から求められるＲ－Ｈ曲線から求めた。そして、ウエハ内の素子毎にＲ－Ｈを測定し、反転磁界Ｈｃの平均値と、標準偏差σを求めた。ばらつき値は、σ／Ｈｃ平均値として算出した。この反転磁界Ｈｃのばらつきは、書き込み特性の向上を図るという観点から、１０％以下が望ましい。
【００９５】
〔バイアス電圧依存性の測定〕
バイアス電圧を１００ｍＶから１０００ｍＶまで１０ｍＶ刻みに変化させながらＲ－Ｈ曲線の測定を行い、ＴＭＲを求め、バイアス電圧に対してプロットした。そして、これから外挿された０ｍＶでのＴＭＲ比に対して、半分になるバイアス電圧を求め、これをＶｈａｌｆとした。
Ｖｈａｌｆは、５５０ｍＶ以上であることが望ましい。
【００９６】
図９は、熱処理温度とＴＭＲ比（平均値）との関係の測定結果を示し、図１０は、熱処理温度と反転磁界Ｈｃとの関係の測定結果を示し、図１１は、熱処理温度と反転磁界Ｈｃのばらつきとの関係の測定結果を示し、図１２は、熱処理温度とバイアス電圧（平均値）との関係の測定結果を示した。
【００９７】
図９～図１２によれば、３００℃の結晶化温度以上、かつ４００℃以下で磁場中熱処理することにより、ＴＭＲ比、反転磁界Ｈｃ、反転磁界Ｈｃのばらつき、バイアス電圧において、望ましい特性範囲を満足している。
【００９８】
そして、図１１から、結晶化温度以上４００℃以下で磁場中で熱処理することにより、明らかに同一ウエハのＴＭＲ素子間での反転磁界のばらつきが抑制され、書き込み特性が直接大きく改善されることが分かる。
また、図１２から、同様に、ＴＭＲ比のバイアス依存性が明確に改善されており、読み込み特性ならびに書き込み特性に直接良好な効果をもたらすことが分かる。
【００９９】
更に、図９および図１０においても、結晶化温度から４００℃の間で、磁場中熱処理によって、ＴＭＲ比の改善と適正な反転磁界が維持されており、バランスに優れた良好な特性を備えていることが分かる。
【０１００】
これらの結果から、ＭＲＡＭとして、書き込み特性および読み込み特性、更にはいずれもエラーレートが大きく改善されることが明らかとなった。
【０１０１】
このように、少なくとも磁化自由層、すなわち磁気メモリ装置におけるメモリ素子の情報記録層としての強磁性層が、ボロンＢを、好ましくは１０原子％以上３０％以下で含有させたＦｅＣｏＢあるいはＦｅＣｏＮｉＢによって構成したことによって、更に、この組成

によるスパッタ膜において、アモルファスないは微結晶組織を有する膜として成膜された強磁性層を磁場中熱処理して結晶化するという構成によって、より安定してＴＭＲ比の増大、反転磁界の改善、そのばらつきの改善、Ｒ－Ｈ曲線の角形性の改善によるアステロイド特性の改善がはかられるものである。

【０１０２】

尚、上述した例では、主として、対の強磁性層５および７間の中間層６が、トンネルバリア層でＴＭＲ素子を構成する場合について説明したが、磁気抵抗効果素子として、中間層６が非磁性導電層によって構成したスピンバルブ型のいわゆるＧＭＲ素子とすることもできる。

【０１０３】

【発明の効果】

上述したように、本発明による磁気抵抗効果素子は、ＭＲ比の向上、ＭＲ比のバイアス電圧依存性の改善、反転磁界の低減およびばらつきの低減、アステロイド特性の改善が図られる。

また、これらの改善によって、この磁気抵抗効果素子をメモリ素子とする本発明による磁気メモリ装置は、書き込み特性および読み出し特性にすぐれ、エラーレートの改善、安定した信頼性の高い、また消費電力の低減化等を図ることができるものである。

【図面の簡単な説明】

【図１】本発明による磁気抵抗効果素子の一例の概略断面図である。

【図２】本発明による磁気抵抗効果素子の他の例の概略断面図である。

【図３】本発明製造方法に用いる磁場中熱処理装置の一例の概略断面図である。

【図４】本発明による磁気メモリ装置の一例の概略構成の斜視図である。

【図５】本発明による磁気メモリ装置の一例のメモリセルの概略断面図である。

【図６】本発明および従来のＴＭＲ素子の外部磁場に対するＴＭＲ測定曲線を示す図である。

【図７】特性評価素子の概略平面図である。

【図８】特性評価素子の概略断面図である。

【図９】ＴＭＲ比の熱処理温度による変化を示す図である。

【図１０】反転磁界の熱処理温度による変化を示す図である。

【図１１】反転磁界の素子間の熱処理温度による変化を示す図である。

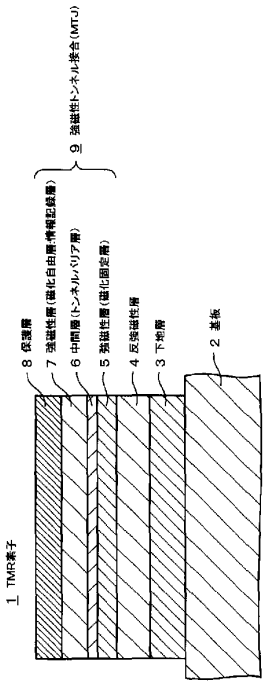
【図１２】バイアス電圧Ｖｈａｌｆ熱処理温度による変化を示す図である。

【符号の説明】

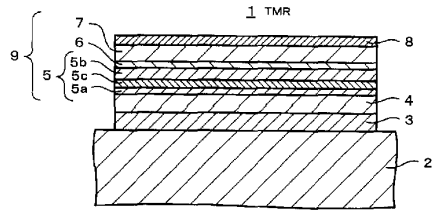
１・・・磁気抵抗効果素子（ＴＭＲ素子）、２・・・基板、３・・・下地層、４・・・反強磁性層、５・・・強磁性層（磁化固定層）、５ａ・・・第１の磁化固定層、５ｂ・・・第２の磁化固定層、５ｃ・・・非磁性導電層、６・・・中間層（トンネルバリア層）、７・・・強磁性層（磁化自由層）、８・・・保護層、９・・・強磁性トンネル接合、１１・・・メモリセル、１２・・・絶縁層、１３・・・トランジスタ、１４・・・ゲート絶縁層、１５・・・ゲート電極、１６・・・ソース領域、１７・・・ドレイン領域、１８・・・コンタクトホール、１９・・・導電性プラグ、２０・・・配線層、２３，２４・・・端子パッド、３０・・・絶縁層、３１～３４・・・第１～第４の層間絶縁層、１３１・・・真空チャンバー、１３２・・・加熱手段、１３３・・・磁場印加手段、１３４・・・ラック、ＷＬ・・・ワード線、ＢＬ・・・ビット線

WD EX1012
Western Digital v IP Bridge
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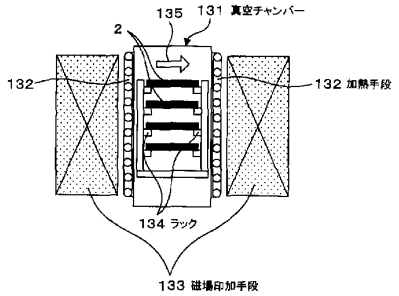
【図１】


9 強磁性トンネル接合(MTJ)
8 保護層
7 強磁性層(磁化自由層/情報記録層)
6 中間層(トンネル/バリア層)
5 強磁性層(磁化固定層)
4 反強磁性層
3 下地層
2 基板
1 TMR素子

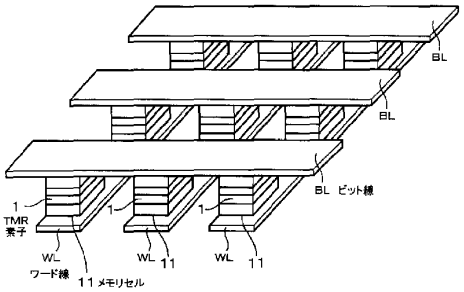
【図２】


1 TMR
9
5
7
6
5b
5c
5a
8
4
3
2

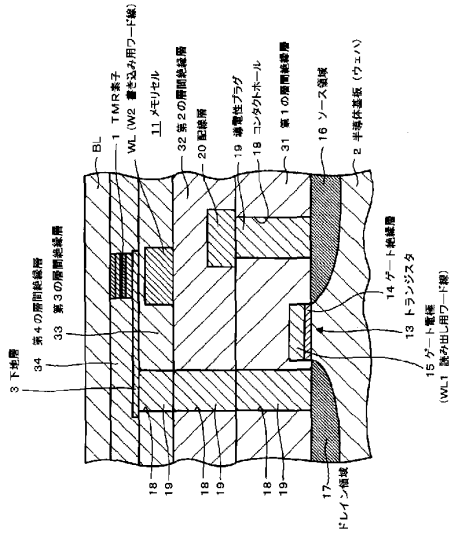
【図３】


135
131 真空チャンバー
2
132
132 加熱手段
134 ラック
133 磁場印加手段

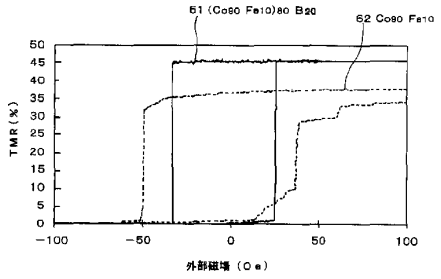
【図４】


BL
BL
BL ビット線
1
TMR
素子
WL
ワード線
11 メモリセル
WL
11
WL
11

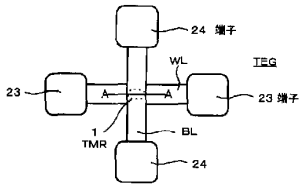
【図５】


BL
1 TMR素子
WL (W2 書き込み用ワード線)
11 メモリセル
32 第2の層間絶縁膜
20 配線層
19 導電性プラグ
18 コンタクトホール
31 第1の層間絶縁膜
16 ソース領域
2 半導体基板 (ウェハ)
第4の層間絶縁膜
第3の層間絶縁膜
33
34
3 下地層
14 ゲート絶縁膜
13 トランジスタ
15 ゲート電極
(WL1 読み出し用ワード線)
18
19
18
19
18
19
17
ドレイン領域

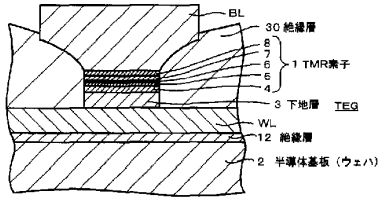
【図６】



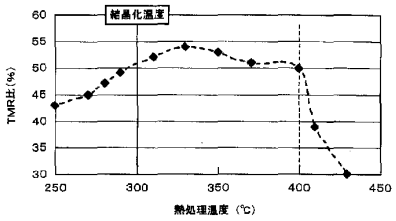
【図７】



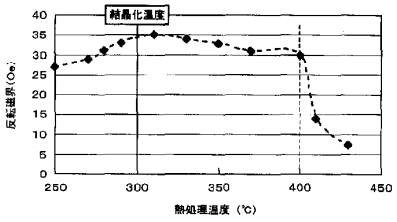
【図８】



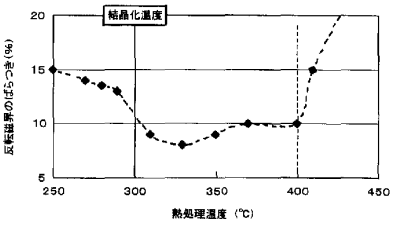
【図９】



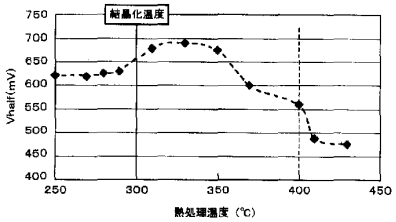
【図１０】



【図１１】



【図１２】



フロントページの続き

(51)Int.Cl.[7]	F I	テーマコード（参考）
Ｈ０１Ｌ 43/12	Ｈ０１Ｌ 43/12	
	Ｈ０１Ｌ 27/10 ４４７	

(72)発明者 別所 和宏
東京都品川区北品川６丁目７番３５号 ソニー株式会社内
(72)発明者 大場 和博
東京都品川区北品川６丁目７番３５号 ソニー株式会社内
(72)発明者 肥後 豊
東京都品川区北品川６丁目７番３５号 ソニー株式会社内
(72)発明者 山元 哲也
東京都品川区北品川６丁目７番３５号 ソニー株式会社内
(72)発明者 曽根 威之
東京都品川区北品川６丁目７番３５号 ソニー株式会社内
(72)発明者 鹿野 博司
東京都品川区北品川６丁目７番３５号 ソニー株式会社内

Ｆターム(参考) 5E049 AA04 AC05 BA06
5F083 FZ10 GA11 GA15 GA27 JA37 JA38 JA60 LA12 LA16 MA06
MA19 PR21 PR22

Electronic Patent Application Fee Transmittal

Application Number:	15428842
Filing Date:	09-Feb-2017
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Stephen John Weyer/Stacy Johnson
Attorney Docket Number:	P11338US02/NBT

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($)
Miscellaneous:				
SUBMISSION- INFORMATION DISCLOSURE STMT	1806	1	240	240
		Total in USD ($)		**240**

Electronic Acknowledgement Receipt	
EFS ID:	33718331
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Stephen John Weyer/Stacy Johnson
Filer Authorized By:	Stephen John Weyer
Attorney Docket Number:	P11338US02/NBT
Receipt Date:	13-SEP-2018
Filing Date:	09-FEB-2017
Time Stamp:	19:06:16
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$240
RAM confirmation Number	091418INTEFSW19063500
Deposit Account	
Authorized User	
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		P11338US02IDSLetter_List.pdf	354928 ec6e97a8d615c52a7940a05dfe1d9724fb24c709	yes	3
	Multipart Description/PDF files in .zip description				
	Document Description		**Start**	**End**	
	Transmittal Letter		1	2	
	Information Disclosure Statement (IDS) Form (SB08)		3	3	
Warnings:					
Information:					
2	Foreign Reference	P11338US02_JPA_2004031605.pdf	726286 e41074a4996488c22b3b2775500138c918c39cba	no	54
Warnings:					
Information:					
3	Fee Worksheet (SB06)	fee-info.pdf	30765 13a5e0d8cfe43299a90b6b6a93d6d5dabef52c26	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	1111979		

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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.

INFORMATION DISCLOSURE STATEMENT		
	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
	Docket #	P11338US02/NBT

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:
☒ $240 large entity or
☐ $120 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.

☐ **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: September 13, 2018

/B. Aaron Schulman/
By: B. Aaron Schulman
Registration No.: 31,877

STITES & HARBISON PLLC ◆ 1800 Diagonal Road ◆ Suite 325 ◆ Alexandria, VA 22314
TEL: 703-739-4900 ◆ FAX: 703-739-9577 ◆ CUSTOMER NO. 881

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	**Confirmation No. 9576**
YUASA	)	
	)	**Art Unit 2897**
Application Number: 15/428,842	)	
	)	**Examiner**
Filed: February 9, 2017	)	**Alonzo Chambliss**
	)	
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
ATTORNEY DOCKET NO. P11338US02/NBT	)	

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 June 1, 2018, the period of response to which is set to expire on October 1, 2018, 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, 7-9, and 11-33 are pending in this application, wherein claims 27-33 are being newly added, as follows:

1. (Previously Presented) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode comprising a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed over the first electrode, the barrier layer comprising a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented; and

a second electrode disposed over the barrier layer and comprising a second ferromagnetic material layer that includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is entirely crystallized.

2. (Previously Presented) The MTJ device of claim 1, wherein the first ferromagnetic material layer is in direct contact with the barrier layer, and wherein the second ferromagnetic material layer is in direct contact with the barrier layer.

3. (Previously Presented) The MTJ device of claim 1, wherein the first ferromagnetic material layer is in direct contact with the MgO layer, and wherein the second ferromagnetic material layer is in direct contact with the MgO layer.

4-6. (Canceled).

7. (Original) The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

8. (Previously Presented) The MTJ device of claim 2, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

9. (Previously Presented) The MTJ device of claim 3, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

10. (Canceled).

11. (Original) The MTJ device of claim 1, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

12. (Previously Presented) The MTJ device of claim 11, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device to an equation (1):

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

where J is a tunnel current density flowing through the 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 Planck's constant, Δs is an effective thickness of the barrier layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer.

13. (Previously Presented) The MTJ device of claim 1, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1.

14. (Previously Presented) The MTJ device of claim 1, wherein a value of x in MgO_x for the MgO layer is greater than 0.9 and less than 1.

15. (Previously Presented) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode made of a first CoFeB layer;

a barrier layer made of a magnesium oxide (MgO) layer that is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented; and

a second electrode made of a second CoFeB layer, and

wherein the barrier layer is located between the first electrode and the second electrode, and

wherein both the first and second CoFeB layers are entirely crystallized.

16. (Previously Presented) The MTJ device of claim 15, wherein the first CoFeB layer is in direct contact with the MgO layer, and wherein the second CoFeB layer is in direct contact with the MgO layer.

17. (Previously Presented) The MTJ device of claim 15, wherein the MgO layer and the first CoFeB layer form a first interface of the MTJ, and wherein the MgO layer and the second CoFeB layer form a second interface of the MTJ.

18. (Original) The MTJ device of claim 15, wherein each of the first and second CoFeB layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

19. (Original) The MTJ device of claim 15, wherein a barrier height φ of the MgO layer is in a range of 0.2 to 0.5 eV.

20. (Previously Presented) The MTJ device of claim 19, wherein the barrier height φ of the MgO layer is obtained by fitting J-V characteristics of the MTJ device 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 MgO 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 Planck's constant, Δs is an effective thickness of the MgO layer that is equivalent to ($t_{MgO}-0.5$ nm), and t_{MgO} is an actual thickness of the MgO layer.

21. (Previously Presented) The MTJ device of claim 15, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1.

22. (Previously Presented) The MTJ device of claim 19, wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1.

23. (Previously Presented) A magnetic tunnel junction (MTJ) device, comprising:

a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed on the first ferromagnetic material layer, the barrier layer comprising a magnesium oxide (MgO) layer that is a poly-crystalline MgO in which (001) crystal plane is preferentially oriented; and

a second ferromagnetic material layer that is disposed on the barrier layer and includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is entirely crystallized.

24. (Previously Presented) The MTJ device of claim 23, wherein a value of x in MgOx for the MgO layer is greater than 0 and less than 1.

25. (Previously Presented) The MTJ device of claim 23, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

26. (Previously Presented) The MTJ device of claim 25, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device to an equation (1):

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

where J is a tunnel current density flowing through the 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 Planck's constant, Δs is an effective thickness of the barrier layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer.

27. (New) The MTJ device of claim 1, wherein each of the first and second ferromagnetic material layers has a Body-Centered Cubic (BCC) structure.

28. (New) The MTJ device of claim 7, wherein each of the first and second ferromagnetic material layers has a BCC structure.

29. (New) The MTJ device of claim 15, wherein each of the first and second CoFeB layers has a BCC structure.

30. (New) The MTJ device of claim 18, wherein each of the first and second CoFeB layers has a BCC structure.

31. (New) The MTJ device of claim 23, wherein each of the first and second ferromagnetic material layers has a BCC structure.

32. (New) The MTJ device of claim 23, wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented.

33. (New) The MTJ device of claim 32, wherein each of the first and second ferromagnetic material layers has a BCC structure.

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 June 1, 2018 (U.S. Patent Office Paper No. 20180523). 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, 7-9, and 11-33 stand for consideration in this application, wherein claims 27-33 are being newly added. All amendments to the application are fully supported therein.

In particular, Applicants note that, with reference to the USPTO publication of the present application as originally filed (U.S. Patent Application Pub. No. 2017/0155042), the specification of the present application describes exemplary embodiments of the present invention that provide "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." (Para. [0012]). To this point, paragraph [0028] explains that, "in the context of the present specification, BCC structure, which the crystalline structure of ferromagnetic electrode layer, means body-centered cubic lattice structure."

With reference to Figures 2(A)-2(D), the present application further discloses an embodiment of "[a] 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')" in which "Fe(001) refers to a ferromagnetic material with the BCC structure." (Para. [0035]). The present application further describes that "[a]lthough 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." (Para. [0045]).

In this regard, with reference to Figure 11, the present application further describes "a MTJ device according to a variation of the embodiments" disclosed therein in which "the MTJ device

of the variation is characterized in that, as in the MTJ device of the [other] embodiments [disclosed therein], 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." (Para. [0049]). With further reference to this embodiment, the present application discloses that, "[a]s 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." (Para. [0050]).

With reference to the cited disclosure discussed above, as well as the additional disclosure otherwise provided in paragraphs [0028-50] of the present application, Applicants further note that paragraph [0051] of the present application specifically states that, "[w]hile 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." Accordingly, Applicants hereby submit that no new matter is being introduced into the application through the submission of this response.

Allowable Subject Matter

The Examiner indicated that claims 11-14 would each be allowable if rewritten to include all the limitations of the base claim and any intervening claims from which it depends.

Examiner Interview Summary

A telephonic interview was held with Examiner Chambliss on July 13, 2018, relating to the present application. The interview was held to discuss the rejections of claims 15-22 under 35 U.S.C. §101 as being unpatentable over claim 4 of U.S. Patent Application No. 13/400,340 (U.S. Patent No. 8,405,134; "the '134 patent"), claims 23-26 as being unpatentable over claim 3 of the '134 patent on grounds of double patenting, and claims 1-3 and 7-9 under 35 U.S.C. §103(a) as being unpatentable over Parkin (U.S. Patent No. 7,252,852) and in view of Ohba (U.S. Patent

Application Pub. No. 2006/0125034), which were issued in the Office Action mailed on June 1, 2018.

During the interview, with respect to the double patenting rejections issued under 35 U.S.C. §101, Applicants' representative presented arguments that claims 23-26 of the present application are substantively different from and not identical to claim 3 of the '134 patent and that claims 15-22 of the present application are likewise substantively different from and not identical to claim 4 of the '134 patent. In view of these arguments, an agreement was reached that the statutory-type double patenting rejections of claims 15-26 would be withdrawn.

With respect to the claim rejections issued under 35 U.S.C. §103(a), Applicants' representative presented arguments that the cited references fail to teach, suggest, or otherwise render obvious the limitation required by independent claim 1 of "a second electrode…comprising a second ferromagnetic material layer that includes Co, Fe, and B." In reply, the Examiner replied by expressing that these arguments would receive consideration upon being presented in a formal response to the Office Action.

Applicants respectfully thank Examiner Chambliss for his consideration in conducting the above-discussed interview of July 13, 2018 with Applicants' representative.

Applicants further note that an earlier telephonic interview was also held with Examiner Chambliss on May 16, 2018, relating to the present application. The interview was held to discuss the two references that were listed in the Information Disclosure Statement (IDS) submitted on February 23, 2018, U.S. Patent Application Pub. No. 2006/003185 ("the Parkin '185 reference") and U.S. Patent No. 7,252,852 ("the Parkin '852 reference"). In the discussion held during this interview, Applicants' representative provided an explanation of the distinctions between the different embodiments disclosed in the two Parkin references and the claims of the present application as presented in the Amendment that was submitted with the IDS on February 23, 2018.

In reply to the remarks, the Examiner acknowledged the distinctions between the disclosures of the two Parkin references and the claims of the present application noted by Applicants' representative. Nevertheless, the Examiner also indicated he would be conducting a further search of the prior art in view of the embodiment of a magnetic tunnel junction disclosed in the Parkin '185 reference with reference to Figure 11. More specifically, the Examiner expressed that he would be searching for the existence of one or more additional reference

teachings that may potentially be used in conjunction with the embodiment of Figure 11 of Parkin '185 to conduct an obviousness analysis of the claims of the present application.

Applicants respectfully thank Examiner Chambliss for his consideration in conducting the above-discussed interview of May 16, 2018 with Applicants' representative.

Double Patenting Rejections

The Examiner rejected claims 15-22 under 35 U.S.C. §101 as being unpatentable over claim 4 of U.S. Patent Application No. 13/400,340 (U.S. Patent No. 8,405,134; "the '134 patent") and claims 23-26 as being unpatentable over claim 3 of the '134 patent on grounds of double patenting. As discussed above, the Examiner has indicated that the statutory-type double patenting rejections will be withdrawn in view of the discussion that was held during the Examiner Interview conducted on July 13, 2018.

Prior Art Rejections

The Examiner rejected claims 1-3 and 7-9 under 35 U.S.C. §103(a) as being unpatentable over Parkin (U.S. Patent No. 7,252,852) and in view of Ohba (U.S. Patent Application Pub. No. 2006/0125034). Applicants have reviewed the above-noted rejections, and hereby respectfully traverse.

A proper obviousness rejection under 35 U.S.C. §103 requires a determination that the claimed invention "as a whole" would have been obvious to person of ordinary skill in the art when the invention was unknown and just before it was made. MPEP §2142. Accordingly, "[a]ll words in a claim must be considered in judging the patentability of that claim against the prior art." *In re Wilson*, 424 F.2d 1382, 1385 (C.C.P.A. 1970). When considering obviousness of a combination of prior art elements, the operative question is whether "the improvement is more than the predictable use of prior art elements according to their established functions." *KSR Int'l Co. v. Teleflex, Inc.*, 550 U.S. 398, 418 (U.S. 2007). To properly support a conclusion that a claimed invention is directed to obvious subject matter, "either the references must expressly or impliedly suggest the claimed invention or the examiner must present a convincing line of reasoning as to why the artisan would have found the claimed invention to have been obvious in light of the teachings of the references." *Ex parte Clapp*, 227 USPQ 972, 973 (Bd. Pat. App. &

Inter. 1985). In this respect, "[t]he key to supporting any rejection under 35 U.S.C. 103 is the clear articulation of the reason(s) why the claimed invention would have been obvious." MPEP §2141.

As outlined above, claims 1-3, 7-9, and 11-33 remain of record. Accordingly, Applicants respectfully submit that Parkin, either alone or in combination with Ohba, fails to teach, suggest, or disclose each and every limitation of claims 1-3 and 7-9. For example, neither Parkin nor Ohba teaches or suggests "a second electrode…comprising **a second ferromagnetic material layer that includes Co, Fe, and B**, and…is **entirely crystallized**" as required by independent claim 1. In this regard, on page 3 of the Office Action, the Examiner cites the free ferromagnetic layer 134 disclosed in Parkin with respect to the embodiments of a magnetic tunnel junction illustrated in Figures 2A-2C as teaching the second electrode required by claim 1. The Examiner, however, further notes that "Parkin fails [to] explicitly disclose the…second ferromagnetic material layer[] is entirely crystalized." (Office Action, p. 3). Nevertheless, the Examiner further asserts, citing paragraph [0074] of Ohba, that "Ohba discloses a…second ferromagnetic material layers should be crystalline material free from a defect in which a crystal structure is changed such as to be crystallized by annealing." (Office Action, p. 3-4). Applicants respectfully disagree with these assertions.

In particular, with respect to the assertion that the free ferromagnetic layer 134 disclosed in Parkin with respect to the embodiments of a magnetic tunnel junction illustrated in Figures 2A-2C teaches "a second electrode…comprising a second ferromagnetic material layer that includes Co, Fe, and B" as required by claim 1, Applicants note that Parkin, in contrast to claim 1, merely describes the ferromagnetic layers 119 and 134 of the magnetic tunnel junction disclosed therein that are being cited by the Examiner as respectively disclosing the first and second electrodes required by claim 1 as including cobalt and iron, not also boron as is specifically required by claim 1. For example, at column 19, lines 20-23, Parkin describes that "**the ferromagnetic layer 134**, which acts as the counter electrode of the MTJ for the samples used in collecting the data shown in FIG. 4, **was formed from a 100 Å thick** $\underline{Co_{84}Fe_{16}}$." (Emphasis added). As another example, at column 16, lines 25-29, Parkin describes that "FIG. 3 shows the detailed dependence of resistance and TMR on the thickness of the Mg layer 122 for a series of otherwise nominally identical MTJs with a structure formed from 75 Å Ta/250 Å $Ir_{26}Mn_{74}$/**8 Å $Co_{84}Fe_{16}$/18 Å Fe**/t Mg/18 Å MgO/**200 Å $Co_{84}Fe_{16}$**/100 Å Ta." (Emphasis added). In terms of the embodiments of

a magnetic tunnel junction described in Parkin with reference to Figures 2A-2C, this example shows that the lower ferromagnetic electrode is formed from the bilayer 115 of 8 Å $Co_{84}Fe_{16}$ (layer 118) and 18 Å Fe (layer 119), and that the upper ferromagnetic electrode is formed from 200 Å $Co_{84}Fe_{16}$ (layer 134). In other words, Parkin shows magnetic tunnel junctions in which the ferromagnetic electrodes are formed from CoFe or CoFe/Fe layers.

In this regard, Applicants note that while Parkin also remarks that the method for forming a tunnel barrier disclosed therein can "also be used for the formation of improved $[Mg_{1-x}Zn_x]O$ tunnel barriers on a wide variety of underlayers ranging from crystalline layers prepared on crystalline substrates…to **amorphous underlayers** (such as CoFeB)" (cols. 31-32, ll. 66-4) (emphasis added), the term "underlayer" is specifically used in Parkin to reference the layers that are under the tunnel barrier layer 120 or 120' of the embodiments of a magnetic tunnel junction disclosed therein, such as the ferromagnetic layer 119, as opposed to the ferromagnetic layer 134 that is being cited by the Examiner as disclosing the second electrode required by claim 1.

To this point, Applicants note that, throughout the disclosure of Parkin, the ferromagnetic layer 134 is specifically described therein as being an "overlayer" as opposed to an "underlayer." For example, with reference to the embodiment of a magnetic tunnel junction illustrated in Figure 16, Parkin describes that "**the free ferromagnetic layer 134 and the spacer layer 225 comprise an overlayer**. **Generally, the magnetic tunnel junction will include an overlayer formed on top of the $[Mg_{1-x}Zn_x]O$ tunnel barrier 120'** which may be comprised of one or more ferromagnetic layers with or without a non-magnetic spacer layer, or, more generally, from a multiplicity of ferromagnetic and non-ferromagnetic, non-ferrimagnetic layers. **Similarly, the magnetic tunnel junction will include an underlayer beneath the $[Mg_{1-x}Zn_x]O$ tunnel barrier 120'** which may be comprised of one or more ferromagnetic layers with or without a non-magnetic spacer layer (e.g., spacer layer 226), or, more generally, from a multiplicity of ferromagnetic and non-ferromagnetic, non-ferrimagnetic layers." (Col. 31, ll. 48-62) (emphasis added).

Therefore, as Parkin clearly fails to include any teaching or suggestion to modify the ferromagnetic layer 134 of the magnetic tunnel junction disclosed therein to further include boron in addition to cobalt and iron, it is readily apparent that Parkin, in addition to failing to teach or suggest a second ferromagnetic material layers being entirely crystallized as required by claim 1,

also fails to teach or suggest a second electrode…comprising a second ferromagnetic material layer that includes Co, Fe, and B" as required by claim 1.

Furthermore, with respect to the assertion on pages 3-4 of the Office Action that "Ohba discloses a…second ferromagnetic material layer[] should be crystalline material free from a defect in which a crystal structure is changed such as to be crystallized by annealing," Applicants note that the disclosure of Ohba, in contrast to claim 1, is specifically directed to a magnetoresistive device that "has an arrangement including a pair of ferromagnetic layers (magnetization fixed layer 5 and magnetization free layer 7) being opposed to each other through an intermediate layer 6," with "the pair of ferromagnetic layers 5, 7 composed of the magnetization fixed layer 5 made of a crystalline ferromagnetic layer provided under the intermediate layer 6 and **the magnetization free layer 7 being made of an amorphous ferromagnetic layer being provided above the intermediate layer 6**." (Abstract) (emphasis added).

To this point, Applicants note that this description in Ohba of the magnetization free layer that is provided above the intermediate layer of the magnetoresistive device disclosed therein being made of an *amorphous* ferromagnetic layer is repeated numerous times throughout the disclosure of Ohba. For example, Ohba specifically describes this magnetization free layer as being made of an *amorphous* ferromagnetic layer, for example, in each of paragraphs [0027], [0028], [0029], [0040], [0043], [0058], [0062], [0066], [0067], [0069], [0071], and [0072]. Moreover, claim 1 of Ohba explicitly recites "a magnetization free layer being made of **an amorphous ferromagnetic layer being provided above said intermediate layer**." (Emphasis added).

In this regard, Applicants note that while paragraph [0074] of Ohba, as cited by the Examiner, inconsistently states that "it is desired that the ferromagnetic layer formed on the tunnel barrier layer should be made of a crystalline ferromagnetic material," it is readily apparent that the term "on" used in the phrase "formed on" in this statement is a typographical error that occurred during the translation of the original Japanese text of the corresponding international patent application, WIPO Patent Application No. PCT/JP03/09824 (published as WIPO Publication WO 2004/015791), from which Ohba is a national stage entry, into the English language, rather than an intent to contradict the entirety of the disclosure provided in Ohba.

To this point, Applicants note that, in the Japanese text of the corresponding international patent application, the Kanji character that corresponds to the term "on" in paragraph [0074] specifically translates to the English term "under" in a manner that, in a correct translation, would

result in paragraph [0074] of Ohba being consistent with the entirety of the remainder of the disclosure of Ohba, confirming that the term "on" used in the phrase "formed on" in paragraph [0074] is a typographical error that occurred during the translation process. In other words, paragraph [0074] of Ohba is intended to be a description of the magnetization fixed layer 5 that is made of a crystalline ferromagnetic layer and provided under the intermediate layer 6, not the magnetization free layer 7 that is made of an amorphous ferromagnetic layer and provided above the intermediate layer 6.

This proper interpretation of the disclosure of Ohba is further supported by the immediately subsequent paragraph [0075], which specifically states that "[a]s the amorphous ferromagnetic material for use with the magnetization free layer 7, there can be used amorphous alloys," as well as paragraph [0076], which again describes that "the TMR device 1 has the arrangement in which the magnetization free layer 7 (adjoining the upper surface of the tunnel barrier layer) disposed on the tunnel barrier layer 6 is made of the amorphous ferromagnetic material."

Accordingly, it is clear that Ohba, as with Parkin, fails to teach or suggest "a second electrode…comprising a second ferromagnetic material layer that includes Co, Fe, and B, and…is entirely crystallized" as required by claim 1. For this reason alone, claim 1 is patentable over the cited references.

For at least these reasons, Applicants respectfully submit that Parkin, either alone or in combination with Ohba, fails to teach, disclose, or suggest each and every limitation of claim 1 and, therefore, that claim 1 is now in condition for allowance. Where an independent claim is nonobvious under 35 U.S.C. §103, then any claim depending therefrom is nonobvious. *In re Fine*, 5 U.P.S.Q.2d 1596, 1598 (Fed. Cir. 1988). Because claims 2, 3, and 7-9 depend either directly or indirectly from claim 1, Applicants respectfully submit that Parkin, either alone or in combination with Ohba, does not render obvious claims 2, 3, and 7-9 for at least the reasons set forth above that it does not render obvious claim 1 and, therefore, that claims 2, 3, and 7-9 are also now in condition for allowance.

Therefore, 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 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,

__/NicholasBTrenkle/_____
Nicholas B. Trenkle
Registration Number 54,500

STITES & HARBISON PLLC
1800 Diagonal Road
Suite 325
Alexandria, VA 22314
(703) 739-4900 Voice
(703) 739-9577 Fax
Customer No. 00881
September 21, 2018

2355LT:10004:448711:1

Electronic Patent Application Fee Transmittal

Application Number:	15428842
Filing Date:	09-Feb-2017
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Stephen John Weyer/Stacy Johnson
Attorney Docket Number:	P11338US02/NBT

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:				
CLAIMS IN EXCESS OF 20	1202	4	100	400
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Extension - 1 month with $0 paid	1251	1	200	200
Miscellaneous:				
		Total in USD ($)		**600**

Electronic Acknowledgement Receipt	
EFS ID:	33796766
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Customer Number:	881
Filer:	Stephen John Weyer/Stacy Johnson
Filer Authorized By:	Stephen John Weyer
Attorney Docket Number:	P11338US02/NBT
Receipt Date:	21-SEP-2018
Filing Date:	09-FEB-2017
Time Stamp:	18:02:24
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$600
RAM confirmation Number	092418INTEFSW18025200
Deposit Account	
Authorized User	
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		P11338US02Transmittal_Response.pdf	519323 125d202fb644b45ff7bca4d78910dba62024a2ef	yes	16

Multipart Description/PDF files in .zip description

Document Description	Start	End
Transmittal Letter	1	1
Amendment/Req. Reconsideration-After Non-Final Reject	2	2
Claims	3	7
Applicant Arguments/Remarks Made in an Amendment	8	16

Warnings:

Information:

2	Fee Worksheet (SB06)	fee-info.pdf	32621 bcb576d68df1118c19fd1e90ad63999735e18fd7	no	2

Warnings:

Information:

Total Files Size (in bytes):	551944

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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.

Doc Code: TRAN.LET
Document Description: Transmittal Letter *Customized PTO/SB/21 (07-09)*

TRANSMITTAL FORM *(for all correspondence after initial filing)*		
	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2897
	Examiner	Chambliss, Alonzo
Total number of pages in this submission =	Docket #	P11338US02/NBT

ENCLOSURES *(check all that apply)*

☒ **Fees** calculated below	☐ Reply to **Missing Parts**/Incomplete Application
☒ including **Extension of Time Fee**	☐ **I**nformation **D**isclosure **S**tatement
☒ **Amendment/Reply**	☐
☒ including **Attachment**(s)	☐
☐ **After Final** Amendment/Reply	☐
☐ including **Attachment**(s)	

FEES CALCULATION: For claims if required and/or other fees as shown below:

STATUS of Applicant is:		☐ MICRO	☐ SMALL	☒ LARGE	**FEE DUE**
FEE FOR	**CALCULATION**	**$**	**$**	**$**	**$**
☒ TOTAL CLAIMS	29 - 25 = 4 (extra)	× 25 =	× 50 =	× 100 =	400
☒ INDEP. CLAIMS	3 - 3 = 0 (extra)	× 115 =	× 230 =	× 460 =	0
☒ Extension of Time for ONE month(s) *(serving as constructive EOT Petition)* =					200
☐ Other fee for					
				TOTAL	600

☒ **Payment** of **$** 600 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 21, 2018 /B. Aaron Schulman/

Signed By Name: B. Aaron Schulman
Attorney of Record Registration No.: 31,877

STITES & HARBISON PLLC ◆ 1800 Diagonal Road. ◆ Suite 325 ◆ Alexandria, VA 22314
TEL: 703-739-4900 ◆ FAX: 703-739-9577 ◆ Customer No. 881

2355LT:10004:450656:1:ALEXANDRIA

PTO/SB/06 (09-11)
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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 15/428,842	Filing Date 02/09/2017	☐ 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 $80 =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*		x $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).				
☐ 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	09/21/2018	(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))	* 29	Minus	** 25	= 4		x $100 =	400
	Independent (37 CFR 1.16(h))	* 3	Minus	*** 3	= 0		x $460 =	0
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	400

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 $0 =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=		x $0 =	
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.	LIE
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".	Renee Hawkins
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".	
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.	

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

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

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 12/03/2018

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER
CHAMBLISS, ALONZO

ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
12/03/2018	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. 15/428,842	Applicant(s) YUASA, Shinji	
	Examiner ALONZO CHAMBLISS	Art Unit 2897	AIA 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 9/21/18.

☐ 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) 1-3,7-9 and 11-33 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) 1-3,7-9,15-18,23 and 27-33 is/are rejected.

8) ☑ Claim(s) 11-14,19-22 and 24-26 is/are objected to.

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

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

Application Papers

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

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

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

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

Priority under 35 U.S.C. § 119

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

Certified copies:

a)☑ All b)☐ Some** c)☐ None of the:

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

2.☑ Certified copies of the priority documents have been received in Application No. 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 9/13/18.

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

4) ☐ Other: _____.

Notice of Pre-AIA or AIA Status

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

2. The amendment filed on 9/21/18 have been fully considered and made of record in this application.

Response to Arguments

3. Applicant's arguments with respect to claims 1-3, 7-9, and 11-33 have been considered but are moot because the arguments do not apply to any of the references being used in the current rejection.

Information Disclosure Statement

4. The information disclosure statement (IDS) submitted on 9/13/18 was filed before the mailing date of the Non-Final rejection on 11/27/18. The submission is in compliance with the provisions of 37 CFR 1.97. Accordingly, the information disclosure statement is being considered by the examiner.

Claim Rejections - 35 USC § 103

5. 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, 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.

6. 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.

7. Claims 1-3, 7-9, 15-18, 23, and 27-33 are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over Sony Corporation (JP 2004-31605) in view of Nashimoto (US 5,514,484) and Parkin (US 2006/0003185).

With respect to Claims 1, 15, 18, 23, and 32, Sony discloses a first electrode comprising a first ferromagnetic material layer 5 that includes Co, Fe, and B. A barrier layer 6 disposed over the first electrode. A second electrode 7 disposed over the barrier layer and comprising a second ferromagnetic material layer that includes Co, Fe, and B. Each of the first and second ferromagnetic material layers is entirely crystallized when the temperature higher than the crystallization temperature of the ferromagnectic material layer as state in claim 8 (see paragraphs 35, 36, 39, 40, 43, and 45; Fig. 2). Sony fails to explicitly disclose a barrier layer comprises a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented. However, Nashimoto discloses a barrier layer comprises a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented (see col. 2 lines 55-62, col. 5 lines 1-7, col. 6 lines

5-14, and col. 8 lines 57-62; Fig. 2). However, Sony and Nashimoto have substantially the same environment of barrier layer made of a material is between to two ferromagnetic materials. Therefore, one skilled in the art at the time of invention would readily recognize to substitute the poly-crystalline Mg0 which has a (001) crystal plane for the barrier material of Nashimoto, since the poly-crystalline MgO as a material for the barrier layer would improve the polarization state of the ferroelectric substance in the device as taught by Nashimoto.

With respect to Claims 2 and 16, Sony discloses wherein the first ferromagnetic material layer is in direct contact with the barrier layer. The second ferromagnetic material layer is in direct contact with the barrier layer (see Fig. 2).

With respect to Claims 3 and 17, Sony discloses wherein the first ferromagnetic material layer is in direct contact with the MgO layer, and wherein the second ferromagnetic material layer is in direct contact with the MgO layer (see Figs. 2).

With respect to Claims 7-9, Sony discloses wherein each of the first and second ferromagnetic material layers is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented (see col. 2 lines 55-62, col. 5 lines 1-7, col. 6 lines 5-14, and col. 8 lines 57-62).

With respect to Claims 27-33, it is well known in the semiconductor industry wherein each of the first and second ferromagnetic material layers has a Body-Centered Cubic (BCC) structure as evident by Parkin (see paragraph 26).

Double Patenting

8. 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 conflicting claims 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); *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 nonstatutory double patenting provided the reference application or patent either is shown to be commonly owned with the examined application, or claims an invention made as a result of activities undertaken within the scope of a joint research agreement. See MPEP § 717.02 for applications subject to examination under the first inventor to file provisions of the AIA as explained in MPEP § 2159. See MPEP §§ 706.02(l)(1) - 706.02(l)(3) for applications not subject to examination under the first inventor to file provisions of the AIA. A terminal disclaimer must be signed in compliance with 37 CFR 1.321(b).

The USPTO Internet website contains terminal disclaimer forms which may be used. Please visit www.uspto.gov/patent/patents-forms. The filing date of the application in which the form is filed determines what form (e.g., PTO/SB/25, PTO/SB/26, PTO/AIA/25, or PTO/AIA/26) 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 www.uspto.gov/patents/process/file/efs/guidance/eTD-info-I.jsp.

9. Claims 1-3, 7-9, and 11-33 are rejected on the ground of nonstatutory double patenting as being unpatentable over claim 4 of U.S. Patent No. 8,405,134. 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 first electrode comprising a first ferromagnetic material layer that includes Co, Fe, and B. A barrier layer disposed over the first electrode, the barrier layer comprising a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented; and a second electrode disposed over the barrier layer and comprising a second ferromagnetic material layer that includes Co, Fe, and B, and wherein each of the first and second ferromagnetic material layers is entirely crystallized.

Allowable Subject Matter

10. Claims 11-14, 19-22, 24-26 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.

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 barrier height x of the barrier layer is in a range of 0.2 to 0.5 eV. in claims 11, 19, and 25.

A value of x in MgOx for the MgO layer is greater than 0 and less than 1 in claims 13, 21, and 24 .

A value of x in MgOx for the MgO layer is greater than 0.9 and less than 1in claims 14 and 22.

Conclusion

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

Applicant's submission of an information disclosure statement under 37 CFR 1.97(c) with the fee set forth in 37 CFR 1.17(p) on 9/13/18 prompted the new ground(s) of rejection presented in this Office action. Accordingly, **THIS ACTION IS MADE FINAL**. See MPEP § 609.04(b). 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.

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/November 27, 2018 /Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Notice of References Cited	Application/Control No. 15/428,842	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	CPC Classification	US Classification
*	A	US-5514484-A	05-1996	Nashimoto; Keiichi	C04B35/462	117/948
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					

FOREIGN PATENT DOCUMENTS

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

NON-PATENT DOCUMENTS

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

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

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	ALONZO CHAMBLISS	2897

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

CLAIMS

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

CLAIM		DATE								
Final	Original	06/25/2017	05/25/2018	11/27/2018						
	1	✓	✓	✓						
	2	✓	✓	✓						
	3	✓	✓	✓						
	4	✓								
	5	✓								
	6	✓								
	7	✓	✓	✓						
	8	✓	✓	✓						
	9	✓	✓	✓						
	10	✓								
	11	✓	O	O						
	12	✓	O	O						
	13	✓	O	O						
	14	✓	O	O						
	15	✓	✓	✓						
	16	✓	✓	✓						
	17	✓	✓	✓						
	18	✓	✓	✓						
	19	✓	✓	O						
	20	✓	✓	O						
	21	✓	✓	O						
	22	✓	✓	O						
	23		✓	✓						
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CLAIM		DATE								
Final	Original	06/25/2017	05/25/2018	11/27/2018						
	43									
	44									
	45									
	46									
	47									
	48									

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CPC - Searched*		
Symbol	**Date**	**Examiner**
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	6/25/17	AC
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	11/7/17	AC
H01F10/3254, 10/132: B82Y25/00: G11C11/15, 11/15, 11/161: H01L43/08, 43/02, 43/10, 43/12, 27/222, 27/228, 27/11507	5/25/18	AC
H01F10/3254, 10/132: B82Y25/00: G11C11/15, 11/15, 11/161: H01L43/08, 43/02, 43/10, 43/12, 27/222, 27/228, 27/11507	11/27/2018	AC

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

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

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

Search Notes		
Search Notes	**Date**	**Examiner**
East text search only - see attached printout	6/25/17	AC
Updated prevous East text search only - see attached printout	11/7/17	AC
Updated previous East text search only - see attached printout	5/28/18	AC
Updated previous East text search only - see attached printout	11/27/2018	AC

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Interference Search			
US Class/CPC Symbol	**US Subclass/CPC Group**	**Date**	**Examiner**
H01L	43/10, 43/08, 43/12, 43/02, 27/222	11/7/17	AC
G11C	11/161	11/7/17	AC
US PGPUB text search only		11/7/17	AC

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EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	1	("7252852").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2018/11/27 16:36
L2	0	257/$.ccls. and tunnel adj2 barrier same poly adj2 crystalline with MgO and ferro adj2 magnetic$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 16:40
L3	14	tunnel adj2 barrier same poly adj2 crystalline with MgO and (MTJ magnetic adj2 tunnel adj2 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 16:42
L4	1	("20060003185").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2018/11/27 16:42
L5	1	("6449133").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2018/11/27 16:43
L6	1	("20060125034").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2018/11/27 16:45
L7	1	("7252852").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2018/11/27 16:45
L8	14	tunnel adj2 barrier same poly near4 crystalline same MgO and (MTJ magnetic adj2 tunnel adj2 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 17:04
L9	15	tunnel adj2 barrier same poly near4 crystalline same magnesium adj2 oxide and (MTJ magnetic adj2 tunnel adj2 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 17:06
L10	1	("5759265").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2018/11/27 17:10
L11	15	barrier same poly near4 crystalline same magnesium adj2 oxide and (MTJ magnetic adj2 tunnel adj2 junction)	US-PGPUB; USPAT; USOCR;	OR	ON	2018/11/27 17:33

			FPRS; EPO; JPO; DERWENT; IBM_TDB			
L12	16	poly near4 crystalline same magnesium adj2 oxide and (MTJ magnetic adj2 tunnel adj2 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 17:33
L13	30	poly near4 crystalline same (MgO magnesium adj2 oxide) and (MTJ magnetic adj2 tunnel adj2 junction)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 17:33
L14	133	poly near4 crystalline same (MgO magnesium adj2 oxide)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 17:36
L15	133	poly near4 crystalline same (MgO magnesium adj2 oxide)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 18:25
L16	3	(("20030128483") or ("20040139914") or ("5817366")).PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2018/11/27 18:31
L17	0	(001) with (MgO magnesium adj2 oxide)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 18:55
L18	7620	(MTJ magnetic adj2 tunnel adj2 junction) and (MgO magnesium adj2 oxide)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 18:58
L19	37	(MTJ magnetic adj2 tunnel adj2 junction) and (MgO magnesium adj2 oxide) same poly	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 19:00
L20	1	("5817366").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2018/11/27 19:16
L21	366	(MgO magnesium adj2 oxide) near4	US-PGPUB;	OR	ON	2018/11/27

		poly	USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			19:18
L22	15	(MgO magnesium adj2 oxide) near4 poly and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 19:58
L23	4052	(MgO magnesium adj2 oxide) and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 19:58
L24	1360	(MgO magnesium adj2 oxide) same crystal$5 and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 20:00
L25	1136	(MgO magnesium adj2 oxide) with crystal$5 and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 20:00
L26	462	257/$.ccls. and (MgO magnesium adj2 oxide) with crystal$5 and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 20:01
L27	229	438/$.ccls. and (MgO magnesium adj2 oxide) with crystal$5 and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 20:02
L28	461	26 AND ((H01L43/08 OR H01L43/10 OR H01L43/02 OR H01L43/12 OR H01L27/222 OR G11C11/161 OR G11C11/16 OR G11C11/15 OR H01F10/3254 OR B82y25/00 OR H01F10/132 OR H01L27/228 OR H01L27/11507).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2018/11/27 20:06

11/ 27/ 2018 8:06:50 PM
C:\ Users\ achambliss\ Documents\ EAST\ Workspaces\ 15799355.wsp

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

Substitute for Form 1449/PTO		
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	Application #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2837
	Examiner	Chambliss, Alonzo
Sheet 1 of 1	Docket #	P11338US02/NBT

U.S. PATENT DOCUMENTS

Initial (*)	Document No. Number – Kind Code	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Corresponds to

FOREIGN PATENT DOCUMENTS

Initial (*)	Country-Number-Kind Code if known	Publ. Date MM-DD-YYYY	Name Patentee or Applicant	Trans-lation
	JPA-2004-31605	01-29-2004	SONY CORPORATION	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

Examiner Signature	/ALONZO CHAMBLISS/	Date Considered	11/27/2018

* *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:10004:449926:1:ALEXANDRIA

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /A.C/

Electronic Patent Application Fee Transmittal

Application Number:	15428842
Filing Date:	09-Feb-2017
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Billy Aaron Schulman/Stacy Johnson
Attorney Docket Number:	P11338US02/NBT

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 - 1 month with $0 paid	1251	1	200	200
Miscellaneous:				
			Total in USD ($)	**200**

Electronic Acknowledgement Receipt	
EFS ID:	35326288
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
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:	P11338US02/NBT
Receipt Date:	05-MAR-2019
Filing Date:	09-FEB-2017
Time Stamp:	13:00:58
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$200
RAM confirmation Number	030519INTEFSW13014000
Deposit Account	120555
Authorized User	Stacy Johnson
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: 37 CFR 1.16 (National application filing, search, and examination fees) 37 CFR 1.17 (Patent application and reexamination processing fees)	

37 CFR 1.19 (Document supply fees)

37 CFR 1.20 (Post Issuance fees)

37 CFR 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		P11338US02Transmittal_ResponseAfterFinal.pdf	366436 cc8e5f20919dc645e0f427ad38bdc53d61c61f5b	yes	9
	Multipart Description/PDF files in .zip description				
	Document Description		Start	End	
	Transmittal Letter		1	1	
	Response After Final Action		2	9	
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	30919 ae5ccf24fd2002475b832981242d37534b1c4783	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	397355		

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 #	15/428,842
	Confirmation #	9576
	Filing Date	February 9, 2017
	First Inventor	YUASA
	Art Unit	2897
	Examiner	Chambliss, Alonzo
Total number of pages in this submission =	Docket #	P11338US02/NBT

ENCLOSURES *(check all that apply)*

☒ **Fees** calculated below	☐ Reply to **Missing Parts**/Incomplete Application
☒ including **Extension of Time Fee**	☐ **I**nformation **D**isclosure **S**tatement
☐ **Amendment/Reply**	☐
☐ including **Attachment**(s)	☐
☒ **After Final** Amendment/Reply	☐
☒ including **Attachment**(s)	

FEES CALCULATION: For claims if required and/or other fees as shown below:

STATUS of Applicant is:		☐ MICRO	☐ SMALL	☒ LARGE	FEE DUE
FEE FOR	**CALCULATION**	**$**	**$**	**$**	**$**
☒ TOTAL CLAIMS	14 - 29 = 0 (extra)	× 25 =	× 50 =	× 100 =	0
☒ INDEP. CLAIMS	3 - 3 = 0 (extra)	× 115 =	× 230 =	× 460 =	0
☒ Extension of Time for ONE month(s) *(serving as constructive EOT Petition)* =					200
☐ Other fee for					
				TOTAL	200

☒ **Payment** of **$** 200 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: March 5, 2019 /B. Aaron Schulman/

Signed By Name: B. Aaron Schulman
Attorney of Record Registration No.: 31,877

STITES & HARBISON PLLC ◆ 1800 Diagonal Road. ◆ Suite 325 ◆ Alexandria, VA 22314
TEL: 703-739-4900 ◆ FAX: 703-739-9577 ◆ Customer No. 881

2355LT:10004:464415:1:ALEXANDRIA

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	**Confirmation No. 9576**
YUASA	)	
	)	**Art Unit 2897**
Application Number: 15/428,842	)	
	)	**Examiner**
Filed: February 9, 2017	)	**Alonzo Chambliss**
	)	
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
ATTORNEY DOCKET NO. P11338US02/NBT	)	

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

RESPONSE AND AMENDMENT UNDER 37 C.F.R. § 1.116

Sir:

This is in response to the Final Office Action mailed on December 3, 2018, the period of response to which is set to expire on April 3, 2019. An extension of time is being requested herein. Please amend the above-referenced application as follows below on page 2. Remarks begin on page 6.

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IN THE CLAIMS

Claims 1-3, 11, 12, 14-17, 19, 20, 23, 25, and 26 are pending in this application, wherein claims 1, 15, and 23 are being amended to improve form, and wherein claims 7-9, 13, 18, 21, 22, 24, and 27-33 are being canceled without prejudice or disclaimer, as follows:

1. (Currently Amended) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode comprising a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed over the first electrode, the barrier layer comprising a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented; and

a second electrode disposed over the barrier layer and comprising a second ferromagnetic material layer that includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is entirely crystallized, and

wherein a value of x in MgOx for the MgO layer is greater than 0 and less than 1.

2. (Previously Presented) The MTJ device of claim 1, wherein the first ferromagnetic material layer is in direct contact with the barrier layer, and wherein the second ferromagnetic material layer is in direct contact with the barrier layer.

3. (Previously Presented) The MTJ device of claim 1, wherein the first ferromagnetic material layer is in direct contact with the MgO layer, and wherein the second ferromagnetic material layer is in direct contact with the MgO layer.

4-10. (Canceled).

11. (Original) The MTJ device of claim 1, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

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12. (Previously Presented) The MTJ device of claim 11, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device to an equation (1):

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

where J is a tunnel current density flowing through the 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 Planck's constant, Δs is an effective thickness of the barrier layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer.

13. (Canceled).

14. (Previously Presented) The MTJ device of claim 1, wherein a value of x in MgO_x for the MgO layer is greater than 0.9 and less than 1.

15. (Currently Amended) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode made of a first CoFeB layer;

a barrier layer made of a magnesium oxide (MgO) layer that is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented; and

a second electrode made of a second CoFeB layer, and

wherein the barrier layer is located between the first electrode and the second electrode, and

wherein both the first and second CoFeB layers are entirely crystallized, and

wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1.

16. (Previously Presented) The MTJ device of claim 15, wherein the first CoFeB layer is in direct contact with the MgO layer, and wherein the second CoFeB layer is in direct contact with the MgO layer.

17. (Previously Presented) The MTJ device of claim 15, wherein the MgO layer and the first CoFeB layer form a first interface of the MTJ, and wherein the MgO layer and the second CoFeB layer form a second interface of the MTJ.

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18. (Canceled).

19. (Original) The MTJ device of claim 15, wherein a barrier height φ of the MgO layer is in a range of 0.2 to 0.5 eV.

20. (Previously Presented) The MTJ device of claim 19, wherein the barrier height φ of the MgO layer is obtained by fitting J-V characteristics of the MTJ device 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 MgO 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 Planck's constant, Δs is an effective thickness of the MgO layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the MgO layer.

21-22. (Canceled).

23. (Previously Presented) A magnetic tunnel junction (MTJ) device, comprising:

a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed on the first ferromagnetic material layer, the barrier layer comprising a magnesium oxide (MgO) layer that is a poly-crystalline MgO in which (001) crystal plane is preferentially oriented; and

a second ferromagnetic material layer that is disposed on the barrier layer and includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is entirely crystallized.

24. (Canceled).

25. (Previously Presented) The MTJ device of claim 23, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

26. (Previously Presented) The MTJ device of claim 25, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device to an equation (1):

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

where J is a tunnel current density flowing through the 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 Planck's constant, Δs is an effective thickness of the barrier layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer.

27-33. (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 December 3, 2018 (U.S. Patent Office Paper No. 20181127). 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, 11, 12, 14-17, 19, 20, 23, 25, and 26 stand for consideration in this application, wherein claims 1, 15, and 23 are being amended to improve form, and wherein claims 7-9, 13, 18, 21, 22, 24, and 27-33 are being canceled without prejudice or disclaimer

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 claims 11-14, 19-22, and 24-26 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, 7-9, and 11-33 as being unpatentable over claim 4 of U.S. Patent No. 8,405,134 ("the '134 application") on grounds of nonstatutory obviousness-type double patenting. In response, Applicants respectfully submit that the present application and the '134 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. Moreover, Applicants note that a terminal disclaimer has already been filed in the present application with respect to the '134 application on October 2, 2017 and approved by the USPTO. Accordingly, Applicants respectfully submit that the non-statutory obviousness-type double patenting rejections are improper and, therefore, should be withdrawn.

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Prior Art Rejections

The Examiner rejected claims 1-3, 7-9, 15-18, 23, and 27-33 under 35 U.S.C. §103(a) as being unpatentable over Hosomi (Japanese Patent Application Pub. No. JP 2004-31605) in view of Nashimoto (U.S. Patent No. 5,514,484). Applicants have reviewed the above-noted rejections, and hereby respectfully traverse.

As outlined above, claims 7-9, 13, 18, 21, 22, 24, and 27-33 are being canceled without prejudice or disclaimer, and, therefore, claims 1-3, 11, 12, 14-17, 19, 20, 23, 25, and 26 are currently remain of record in the present application. Independent claim 1 is being amended to further include all of the limitations of claim 13 of the present application as previously presented in the Response submitted on September 21, 2018. Accordingly, claim 1 is now presented in a form that the Examiner stated would be allowable. Moreover, independent claim 15 is being amended to further include all of the limitations of claim 21 of the present application as previously presented in the Response submitted on September 21, 2018. Accordingly, claim 15 is now presented in a form that the Examiner stated would be allowable. Likewise, independent claim 23 is being amended to further include all of the limitations of claim 24 of the present application as previously presented in the Response submitted on September 21, 2018. Accordingly, claim 23 is now presented in a form that the Examiner stated would be allowable.

Moreover, because claims 2, 3, 11, 12, and 14, claims 16, 17, 19, and 20, and claims 25 and 26 each depends either directly or indirectly from claims 1, 15, and 23 respectively, Applicants respectfully submit that claims 2, 3, 11, 12, 14, 16, 17, 19, 20, 25, and 26 are also now in condition for allowance. Applicants therefore 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 telephone number indicated below.

Respectfully submitted,

/B. Aaron Schulman/
B. Aaron Schulman
Registration Number 31,870

Nicholas B. Trenkle
Registration Number 54,500

STITES & HARBISON PLLC
1800 Diagonal Road
Suite 325
Alexandria, VA 22314-2861
(703) 739-4900 Voice
(703) 739-9577 Fax
Customer No. 00881

March 5, 2019

2355LT:10004:464274:1

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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 15/428,842	Filing Date 02/09/2017	☐ 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 $80 =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*		x $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).				
☐ 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	03/05/2019	(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))	* 14	Minus	** 29	= 0		x $100 =	0
	Independent (37 CFR 1.16(h))	* 3	Minus	*** 3	= 0		x $460 =	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 $0 =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=		x $0 =	
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.	LIE
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".	/CHARRISSA S BROWN/
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".	
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.	

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

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NOTICE OF ALLOWANCE AND FEE(S) DUE

881 7590 03/20/2019

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER
CHAMBLISS, ALONZO

ART UNIT	PAPER NUMBER
2897	

DATE MAILED: 03/20/2019

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

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	$1000	$0.00	$0.00	$1000	06/20/2019

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

PTOL-85 (Rev. 02/11)

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PART B - FEE(S) TRANSMITTAL

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

By mail, send to: Mail Stop ISSUE FEE
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

By fax, send to: (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 03/20/2019
STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
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 transmitted to the USPTO via EFS-Web or by facsimile to (571) 273-2885, on the date below.

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

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

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	$1000	$0.00	$0.00	$1000	06/20/2019

EXAMINER	ART UNIT	CLASS-SUBCLASS
CHAMBLISS, ALONZO	2897	257-421000

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 03-09 or more recent) attached. **Use of a Customer Number is required.**

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

1 _____
2 _____
3 _____

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

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

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

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

4a. Fees submitted: ❑Issue Fee ❑Publication Fee (if required) ❑Advance Order - # of Copies _____

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

❑ Electronic Payment via EFS-Web ❑ Enclosed check ❑ Non-electronic payment by credit card (Attach form PTO-2038)

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

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

❑ Applicant certifying micro entity status. See 37 CFR 1.29

❑ Applicant asserting small entity status. See 37 CFR 1.27

❑ Applicant changing to regular undiscounted fee status.

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.
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.
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. _____

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UNITED STATES PATENT AND TRADEMARK OFFICE

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

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 03/20/2019

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	
ART UNIT	PAPER NUMBER
2897	

DATE MAILED: 03/20/2019

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)

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

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

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

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. 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.** 15/428,842	**Applicant(s)** YUASA, Shinji	
	Examiner ALONZO CHAMBLISS	**Art Unit** 2897	**AIA (FITF) 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 amendment after final filed on 3/5/19.
   ☐ 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 1-3,11-12,14-20,23 and 25-26 . 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 areply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

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

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

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

Attachment(s)

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

/ALONZO CHAMBLISS/
Primary Examiner, Art Unit 2897

Notice of Pre-AIA or AIA Status

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

2. The amendment filed on 3/5/19 has been fully considered and made of record in this application.

EXAMINER'S AMENDMENT

3. An examiner's amendment to the record appears below. Should the changes and/or additions be unacceptable to applicant, an amendment may be filed as provided by 37 CFR 1.312. To ensure consideration of such an amendment, it MUST be submitted no later than the payment of the issue fee.

Authorization for this examiner's amendment was given in a telephone interview with B. Aaron Schulman on March 14, 2019.

CLAIMS:

In claim 23, after " crystallized " insert -- , and wherein a value of x in MGOx for the MGO layer is greater than 0 and less than 1 --.

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

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."

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/March 14, 2019

/Alonzo Chambliss/

Primary Examiner, Art Unit 2897

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15/428,842	YUASA, Shinji
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

CPC - Searched*		
Symbol	**Date**	**Examiner**
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	6/25/17	AC
H01L43/10, 27/222, 43/02, 43/08, 43/12,: G11C11/161	11/7/17	AC
H01F10/3254, 10/132: B82Y25/00: G11C11/15, 11/15, 11/161: H01L43/08, 43/02, 43/10, 43/12, 27/222, 27/228, 27/11507	5/25/18	AC
H01F10/3254, 10/132: B82Y25/00: G11C11/15, 11/15, 11/161: H01L43/08, 43/02, 43/10, 43/12, 27/222, 27/228, 27/11507	11/27/2018	AC
H01F10/3254, 10/132: B82Y25/00: G11C11/15, 11/15, 11/161: H01L43/08, 43/02, 43/10, 43/12, 27/222, 27/228, 27/11507	03/14/2019	AC

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

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

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

Search Notes		
Search Notes	**Date**	**Examiner**
East text search only - see attached printout	6/25/17	AC
Updated prevous East text search only - see attached printout	11/7/17	AC
Updated previous East text search only - see attached printout	5/28/18	AC
Updated previous East text search only - see attached printout	11/27/2018	AC
Updated previous East text search only - see attached printout	03/14/2019	AC

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Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15/428,842	YUASA, Shinji
	Examiner	Art Unit
	ALONZO CHAMBLISS	2897

Interference Search			
US Class/CPC Symbol	**US Subclass/CPC Group**	**Date**	**Examiner**
H01L	43/10, 43/08, 43/12, 43/02, 27/222	11/7/17	AC
G11C	11/161	11/7/17	AC
US PGPUB text search only		03/14/2019	AC

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Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15/428,842	YUASA, Shinji
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

CPC						
Symbol					**Type**	**Version**
H01L	/	43	/	10	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	/	11507	I	2013-01-01
B82Y	/	25	/	00	I	2013-01-01
G11C	/	11	/	16	I	2013-01-01
H01F	/	10	/	3254	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	/	02	I	2013-01-01
G11C	/	11	/	161	I	2013-01-01
H01L	/	27	/	222	I	2013-01-01
H01L	/	27	/	22	A	2013-01-01
B82Y	/	10	/	00	A	2013-01-01

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

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	14	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897	14 March 2019	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1B

U.S. Patent and Trademark Office — Part of Paper No.: 20190314

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Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15/428,842	YUASA, Shinji
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

INTERNATIONAL CLASSIFICATION					
CLAIMED					
H01L	/	21	/	02	
H01L	/	21	/	00	

NON-CLAIMED					
	/		/		

US ORIGINAL CLASSIFICATION	
CLASS	**SUBCLASS**
257	295

CROSS REFERENCES(S)						
CLASS	**SUBCLASS (ONE SUBCLASS PER BLOCK)**					
257	427					
438	3					
365	171					

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	14	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897	14 March 2019	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1B

U.S. Patent and Trademark Office — Part of Paper No.: 20190314

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Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15/428,842	YUASA, Shinji
	Examiner	**Art Unit**
	ALONZO CHAMBLISS	2897

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

CLAIMS

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1		10	10	19										
2	2	4	11	11	20										
3	3	5	12		21										
	4		13		22										
	5	6	14	12	23										
	6	7	15		24										
	7	8	16	13	25										
	8	9	17	14	26										
	9		18												

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	14	
/ALONZO CHAMBLISS/ Primary Examiner.Art Unit 2897	14 March 2019	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1B

U.S. Patent and Trademark Office — Part of Paper No.: 20190314

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EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	1	("8405134").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2019/03/14 13:11
L2	463	257/$.ccls. and (MgO magnesium adj2 oxide) with crystal$5 and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/03/14 14:52
L3	229	438/$.ccls. and (MgO magnesium adj2 oxide) with crystal$5 and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/03/14 14:55
L4	0	361/$.ccls. and (MgO magnesium adj2 oxide) with crystal$5 and (MTJ magnetic adj2 tunnel adj2 junction) and CoFeB	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/03/14 14:58
L7	462	2 AND ((H01L43/08 OR H01L43/10 OR H01L43/02 OR H01L43/12 OR H01L27/222 OR G11C11/161 OR G11C11/16 OR G11C11/15 OR H01F10/3254 OR B82Y25/00 OR H01F10/132 OR H01L27/228 OR H01L27/11507).CPC.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/03/14 15:08

3/ 14/ 2019 3:09:55 PM
C:\ Users\ achambliss\ Documents\ EAST\ Workspaces\ 15799355.wsp

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Electronic Acknowledgement Receipt

EFS ID:	36062921
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
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:	P11338US02/NBT
Receipt Date:	20-MAY-2019
Filing Date:	09-FEB-2017
Time Stamp:	17:32:15
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	Amendment after Notice of Allowance (Rule 312)	P11338US02Amdt_Under_312.pdf	172479 43a4303a24b684218084ac8393944472ecfeb033	no	6
Warnings:					

Information:	
Total Files Size (in bytes):	172479

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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	)	
	)	**Confirmation No. 9576**
YUASA	)	
	)	**Art Unit 2897**
Application Number: 15/428,842	)	
	)	**Examiner**
Filed: February 9, 2017	)	**Alonzo Chambliss**
	)	
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
ATTORNEY DOCKET NO. P11338US02/NBT	)	

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AMENDMENT UNDER RULE 312

Honorable Commissioner:

This is in response to the Notice of Allowance mailed on March 20, 2019, please amend the claims of the above-referenced application as follows below on page 2. Remarks begin on page 6.

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IN THE CLAIMS

Claims 1-3, 11, 12, 14-20, 23 and 25, and 26 are allowed in this application, wherein claim 23 is being amended to improve form, as follows:

1. (Previously Presented) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode comprising a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed over the first electrode, the barrier layer comprising a magnesium oxide (MgO) layer that is formed of a poly-crystalline MgO in which a (001) crystal plane is preferentially oriented; and

a second electrode disposed over the barrier layer and comprising a second ferromagnetic material layer that includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is entirely crystallized, and

wherein a value of x in MgOx for the MgO layer is greater than 0 and less than 1.

2. (Previously Presented) The MTJ device of claim 1, wherein the first ferromagnetic material layer is in direct contact with the barrier layer, and wherein the second ferromagnetic material layer is in direct contact with the barrier layer.

3. (Previously Presented) The MTJ device of claim 1, wherein the first ferromagnetic material layer is in direct contact with the MgO layer, and wherein the second ferromagnetic material layer is in direct contact with the MgO layer.

4-10. (Canceled).

11. (Original) The MTJ device of claim 1, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

12. (Previously Presented) The MTJ device of claim 11, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device to an equation (1):

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

where J is a tunnel current density flowing through the 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 Planck's constant, Δs is an effective thickness of the barrier layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer.

13. (Canceled).

14. (Previously Presented) The MTJ device of claim 1, wherein a value of x in MgO_x for the MgO layer is greater than 0.9 and less than 1.

15. (Previously Presented) A magnetic tunnel junction (MTJ) device, comprising:

a first electrode made of a first CoFeB layer;

a barrier layer made of a magnesium oxide (MgO) layer that is a poly-crystalline layer in which a (001) crystal plane is preferentially oriented; and

a second electrode made of a second CoFeB layer, and

wherein the barrier layer is located between the first electrode and the second electrode, and

wherein both the first and second CoFeB layers are entirely crystallized, and

wherein a value of x in MgO_x for the MgO layer is greater than 0 and less than 1.

16. (Previously Presented) The MTJ device of claim 15, wherein the first CoFeB layer is in direct contact with the MgO layer, and wherein the second CoFeB layer is in direct contact with the MgO layer.

17. (Previously Presented) The MTJ device of claim 15, wherein the MgO layer and the first CoFeB layer form a first interface of the MTJ, and wherein the MgO layer and the second CoFeB layer form a second interface of the MTJ.

18. (Canceled).

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19. (Original) The MTJ device of claim 15, wherein a barrier height φ of the MgO layer is in a range of 0.2 to 0.5 eV.

20. (Previously Presented) The MTJ device of claim 19, wherein the barrier height φ of the MgO layer is obtained by fitting J-V characteristics of the MTJ device to an equation (1):

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

where J is a tunnel current density flowing through the MgO 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 Planck's constant, Δs is an effective thickness of the MgO layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the MgO layer.

21-22. (Canceled).

23. (Currently amended) A magnetic tunnel junction (MTJ) device, comprising:

a first ferromagnetic material layer that includes Co, Fe, and B;

a barrier layer disposed on the first ferromagnetic material layer, the barrier layer comprising a magnesium oxide (MgO) layer that is a poly-crystalline MgO in which (001) crystal plane is preferentially oriented; and

a second ferromagnetic material layer that is disposed on the barrier layer and includes Co, Fe, and B, and

wherein each of the first and second ferromagnetic material layers is entirely crystallized, and wherein a value of x in ~~MGOx~~MgOx for the ~~MGO~~MgO layer is greater than 0 and less than 1.

24. (Canceled).

25. (Previously Presented) The MTJ device of claim 23, wherein a barrier height φ of the barrier layer is in a range of 0.2 to 0.5 eV.

26. (Previously Presented) The MTJ device of claim 25, wherein the barrier height φ of the barrier layer is obtained by fitting J-V characteristics of the MTJ device to an equation (1):

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

where J is a tunnel current density flowing through the 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 Planck's constant, Δs is an effective thickness of the barrier layer that is equivalent to (t_{MgO}−0.5 nm), and t_{MgO} is an actual thickness of the barrier layer.

27-33. (Canceled).

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REMARKS

By this amendment, a minor correction is made to Claim 23 in response to the Examiner's Amendment on page 2 of the Notice of Allowance dated March 20, 2019. As can be observed in the Examiner's amendment, the formula "MgOx" was incorrectly indicated as "MGOx", and the formula MgO was indicated as "MGO". Applicant has now made the necessary corrections to this claim.

Conclusion

In light of the foregoing, the present amendments should be entered under Rule 312. Such action is respectfully requested.

Respectfully submitted,

/B. Aaron Schulman/
B. Aaron Schulman
Registration Number 31,870

Nicholas B. Trenkle
Registration Number 54,500

STITES & HARBISON PLLC
1800 Diagonal Road
Suite 325
Alexandria, VA 22314-2861
(703) 739-4900 Voice
(703) 739-9577 Fax
Customer No. 00881

May 20, 2019

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

881 7590 06/14/2019

STITES & HARBISON PLLC
1800 Diagonal Road
SUITE 325
ALEXANDRIA, VA 22314

EXAMINER	
CHAMBLISS, ALONZO	

ART UNIT	PAPER NUMBER
2897	

NOTIFICATION DATE	DELIVERY MODE
06/14/2019	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

Response to Rule 312 Communication	Application No.	Applicant(s)	
	15/428,842	YUASA, Shinji	
	Examiner	Art Unit	AIA Status
	ALONZO CHAMBLISS	2897	No

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

1. ☑ The amendment filed on 20 May 2019 under 37 CFR 1.312 has been considered, and has been:

a) ☐ entered.

b) ☑ entered as directed to matters of form not affecting the scope of the invention.

c) ☐ disapproved because the amendment was filed after the payment of the issue fee.

Any amendment filed after the date the issue fee is paid must be accompanied by a petition under 37 CFR 1.313(c)(1) and the required fee to withdraw the application from issue.

d) ☐ disapproved. See explanation below.

e) ☐ entered in part. See explanation below.

/ALONZO CHAMBLISS/
Primary Examiner, Art Unit 2897

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Page 360

OK TO ENTER: /A.C/

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. Patent Application of	)	
	)	**Confirmation No. 9576**
YUASA	)	
	)	**Art Unit 2897**
Application Number: 15/428,842	)	
	)	**Examiner**
Filed: February 9, 2017	)	**Alonzo Chambliss**
	)	
For: MAGNETIC TUNNEL JUNCTION DEVICE	)	
	)	
ATTORNEY DOCKET NO. P11338US02/NBT	)	

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Alexandria, VA 22313-1450

AMENDMENT UNDER RULE 312

Honorable Commissioner:

This is in response to the Notice of Allowance mailed on March 20, 2019, please amend the claims of the above-referenced application as follows below on page 2. Remarks begin on page 6.

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Page 361

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

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

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881 7590 03/20/2019
STITES & HARBISON PLLC
1800 Diagonal Road
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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.

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

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

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	02/09/2017	Shinji YUASA	P11338US02/NBT	9576

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	$1000	$0.00	$0.00	$1000	06/20/2019

EXAMINER	ART UNIT	CLASS-SUBCLASS
CHAMBLISS, ALONZO	2897	257-421000

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 03-09 or more recent) attached. **Use of a Customer Number is required.**

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

1 B. Aaron Schulman, Esq.
2 Nicholas Trenkle, Esq.
3 Stites & Harbison, PLLC

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

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

(A) NAME OF ASSIGNEE	(B) RESIDENCE: (CITY and STATE OR COUNTRY)
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. Fees submitted: ☒ Issue Fee ❑ Publication Fee (if required) ❑ Advance Order - # of Copies _____

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

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

❑ Applicant certifying micro entity status. See 37 CFR 1.29

❑ Applicant asserting small entity status. See 37 CFR 1.27

❑ Applicant changing to regular undiscounted fee status.

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.
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.
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 /B. Aaron Schulman/ Date June 20, 2019

Typed or printed name B. Aaron Schulman Registration No. 31,877

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Page 362

Electronic Patent Application Fee Transmittal

Application Number:	15428842
Filing Date:	09-Feb-2017
Title of Invention:	MAGNETIC TUNNEL JUNCTION DEVICE
First Named Inventor/Applicant Name:	Shinji YUASA
Filer:	Billy Aaron Schulman/Stacy Johnson
Attorney Docket Number:	P11338US02/NBT

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	1000	1000

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**1000**

Electronic Acknowledgement Receipt	
EFS ID:	36363322
Application Number:	15428842
International Application Number:	
Confirmation Number:	9576
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:	P11338US02/NBT
Receipt Date:	20-JUN-2019
Filing Date:	09-FEB-2017
Time Stamp:	16:14:52
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$1000
RAM confirmation Number	062119INTEFSW16152700
Deposit Account	120555
Authorized User	Stacy Johnson
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37 CFR 1.19 (Document supply fees)

37 CFR 1.20 (Post Issuance fees)

37 CFR 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)	P11338US02IssueFeeTransmittal.pdf	185551 01e8e0c2f6a3b91b9942e767796d8fd38ba0044e	no	1
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	30393 aabc78eae448953949e310257e0d44bd8b34fbfc	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	215944		

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New Applications Under 35 U.S.C. 111
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New International Application Filed with the USPTO as a Receiving Office
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APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/428,842	07/30/2019	10367138	P11338US02/NBT	9576

881 7590 07/10/2019

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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.

APPLICANT(s) (Please see PAIR WEB site http://pair.uspto.gov for additional applicants):

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

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