(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 589 594 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
19.06.2013 Bulletin 2013/25

(21) Application number: **04704713.9**

(22) Date of filing: **23.01.2004**

(51) Int Cl.:
G01R 33/09 $^{(2006.01)}$
G11C 11/15 $^{(2006.01)}$
H01F 10/32 $^{(2006.01)}$
H01L 43/08 $^{(2006.01)}$
B82Y 10/00 $^{(2011.01)}$
B82Y 25/00 $^{(2011.01)}$
H01L 27/22 $^{(2006.01)}$

(86) International application number:
PCT/JP2004/000594

(87) International publication number:
WO 2004/068607 (12.08.2004 Gazette 2004/33)

(54) CPP-TYPE GIANT MAGNETORESISTANCE EFFECT ELEMENT AND MAGNETIC COMPONENT AND MAGNETIC DEVICE USING IT

RIESEN-MAGNETOWIDERSTANDSEFFEKTELEMENT DES CCP-TYPS UND MAGNETISCHE KOMPONENTE UND MAGNETISCHE EINRICHTUNG DAMIT

ELEMENT A EFFET DE MAGNETORESISTANCE GEANTE DE TYPE CPP ET COMPOSANT MAGNETIQUE ET DISPOSITIF MAGNETIQUE DANS LESQUELS LEDIT ELEMENT EST UTILISE

(84) Designated Contracting States:
DE FR NL

(30) Priority: **31.01.2003 JP 2003024981**
15.05.2003 JP 2003137945

(43) Date of publication of application:
26.10.2005 Bulletin 2005/43

(60) Divisional application:
10011433.9 / 2 267 811

(73) Proprietor: **Japan Science and Technology Agency**
Kawaguchi-shi,
Saitama 332-0012 (JP)

(72) Inventors:
- **Inomata, Kouichiro**
  Sendai-shi,
  Miyagi 989-3123 (JP)
- **Tezuka, Nobuki**
  Sendai-shi,
  Miyagi 9800011 (JP)

(74) Representative: **Henseler, Daniela et al**
Sparing Röhl Henseler
Patentanwälte
Postfach 14 04 43
40074 Düsseldorf (DE)

(56) References cited:
EP-A2- 1 085 586
WO-A-02/052650
JP-A- 2003 298 142
US-A1- 2001 028 537
US-A1- 2002 034 055
US-A1- 2002 081 458
US-A1- 2003 011 364
US-A1- 2003 011 945
US-A1- 2003 197 505

- **TEZUKA N ET AL: "Single domain observation for synthetic antiferromagnetically coupled bits with low aspect ratios" APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, US, vol. 82, no. 4, 27 January 2003 (2003-01-27), pages 604-606, XP012034651 ISSN: 0003-6951**
- **INOMATA K. ET AL: 'Magnetic switching field and giant magnetoresistance effect of multilayers with synthetic antiferromagnet free layers' APPLIED PHYSICS LETTERS vol. 81, no. 2, 08 July 2002, pages 310 - 312, XP012032461**
- **TEZUKA N. ET AL: 'Single domain observation for synthetic antiferromagnetically coupled bits with low aspect ratios' APPLIED PHYSICS LETTERS vol. 82, no. 4, 27 January 2003, pages 604 - 606, XP012034651**

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

Printed by Jouve, 75001 PARIS (FR)

Description

Technical Field

[0001] The present invention relates to a giant magnetoresistance device that exhibits a giant magnetoresistance effect by spin dependent current in a direction perpendicular to a film plane (hereinafter referred to as "CPP type giant magnetoresistance device") and also to magnetic components and units using the same.

Background Art

[0002] In recent years there has been developed a giant magnetoresistance (GMR) effect device that is made of a ferromagnetic layer, a nonmagnetic metal layer and a ferromagnetic layer laid adjacent one to another. The GMR is due to spin dependent scattering at an interface and is based on the fact that two ferromagnetic layers, when their magnetizations are switched to orient parallel or antiparallel to each other on controlled application of external magnetic filed, have a change in electrical resistance.

[0003] GMR devices have already been put to practical use as in magnetic sensors and reproducing heads in hard disk drives. Then, current is passed in a film plane, when the GMR device is called "CIP-GMR" device where CIP stands for Current In Plane. The CIP-GMR device generally makes use of an element called what is of spin valve in which an antiferromagnet is brought adjacent to one of the ferromagnets to fix spins in the one ferromagnet. On the other hand, there has also been known a GMR device called what is of "CPP" (which stands for Current Perpendicular to the Plane) type in which current is passed in a direction perpendicular to a film plane.

[0004] It is further known that generally CPP-GMR is greater in magnitude than CIP-GMR. Using such CPP-GMR, there is the proposed development to a CPP-type giant magnetoresistive effect device in which spiral magnetic domains generated by a sense current in a free magnetic layer are controlled to develop and then to a reproducing head using the device. See, the Japanese laid open patent application, for example, JP 2002-359415 A.

[0005] There are also proposals to apply a spin valve structure to a densified recording head to improve its head characteristics. See the Japanese laid open patent application, for example, JP 2002-124721 A.

[0006] There is also a proposal by the present inventors for a three-layer structure having antiparallel magnetizations identical in magnitude. See the Japanese laid open patent application, JP H09-251621 A.

[0007] A CPP-GMR device so far proposed is small in resistance, however, since its current path is small. Being poor in utility unless it is made enough smaller, the device has not yet been put to practical use.

[0008] Although in the CPP-GMR device, too, the spin valve type has been considered having an antiferromagnetic layer 81 brought adjacent to a ferromagnetic fixed layer 82 as shown in Fig. 10, the antiferromagnetic layer 81 is larger in resistance than a GMR film made of a ferromagnetic free layer 84, a nonmagnetic conductive layer 83 and the ferromagnetic fixed layer 82 to an extent that the spin valve element then will generally have to have its rate of resistance change as small as less than 1 % and its resistance change Δ R that is small, too. This becomes a primary and large factor that prevents a CPP-GMR device from its practical use.

[0009] Therefore, a problem that prevents a conventional spin valve type CPP-GMR device from its practical use is that it is small in resistance change Δ R and rate of change of magnetic resistance.

[0010] The present inventors have discovered that coupling a pair of ferromagnetic layers antiparallel to each other via a nonmagnetic metal layer while using this three-layer structure (SyAF) with different magnitudes of magnetization for a free and/or a fixed layer gives rise to a CPP-GMR device of spin valve type of which Δ R is large and the rate of change of magnetic resistance is increased to 8 % or more and then have reached the present invention.

The features of the preamble of claim 1 are known from D1 (US 2002/0034055 A1. Another device is known from US 2003/0011945 A1.

Disclosure of the Invention

[0011] It is accordingly an object of the present invention to provide a CPP type giant magnetoresistance device that exhibits a giant magnetoresistance effect by spin dependent current in a direction perpendicular to a film plane, and magnetic components and units.

[0012] In order to achieve the object mentioned above there is provided in accordance with the present invention in a first aspect, a CPP type giant magnetoresistance device having a ferromagnetic fixed layer, a nonmagnetic conductive layer and a ferromagnetic free layer according to claim 1.

[0013] In order to achieve the object mentioned above, there is also provided in accordance with the present invention in a second aspect thereof as set forth in claim 3 a magnetic part having a CPP type giant magnetoresistance device, characterized by having a CPP type giant magnetoresistance device as set forth in claim 1 or 2.

[0014] The present invention also provides as set forth in claim 4, a magnetic head for reading recorded information by detecting a leakage magnetic field from a recording medium, characterized in that it comprises a CPP type giant magnetoresistance device as set forth in claim 1 or 2, wherein a said ferromagnetic free layer is adapted to reverse its magnetization in response to a leakage magnetic field from the said recording medium to cause the device to exhibit CPP-GMR based on spin dependent scattering of sensor electrons, thereby detecting a direction of the said leakage magnetic field as a change in resistance.

[0015] The magnetic head of the present invention as set forth in claim 5 is further characterized in that, in addition to the makeup mentioned above, the second magnetic layer in said ferromagnetic free layer has an end face set face to face with the said recording medium for detecting the leakage magnetic field therefrom.

[0016] The magnetic head of the present invention as set forth in claim 6 is further characterized in that a stratal end face of the said ferromagnetic free layer on which its multi-layered structure appears is set face to face with the said recording medium for detecting the leakage magnetic field therefrom.

[0017] The magnetic head of the present invention as set forth in claim 7 is further characterized by comprising an electrode for supplying sensor electrons to the CPP type giant magnetoresistance device, the said electrode also serving as a magnetic shield against the leakage magnetic field from the said recording medium.

[0018] Constructed as mentioned above and having a CPP type giant magnetoresistance device incorporated therein, a magnetic component can have an electrical resistance therein varied by the CPP-GMR that the device exhibits and which is increased by spin dependent scattering in the device. The magnetic component of the present invention can thus detect a direction of a magnetic field as a change in electrical resistance.

[0019] In order to achieve the object mentioned above there is also provided in accordance with the present invention in a third aspect a magnetic unit as set forth in claim 8 using a CPP type giant magnetoresistance device, according to claim 1 or 2 .

[0020] The present invention also provides a magnetic memory unit characterized in that a CPP type giant magnetoresistance device according to claim 1 or 2 is arranged to lie at each of intersections of word lines and bit lines to form a nonvolatile storage, as set forth in claim 9.

[0021] In the magnetic memory unit of the present invention, the ferromagnetic free layer can be adapted to reverse its magnetic field in response to spin injection from each such word line, as set forth in claim 10.

[0022] A magnetic memory unit constructed as mentioned above allows writing or reading by passing a spin dependent current. The magnetic memory unit of the present invention provides nonvolatile magnetic storage capability and its operation only requires a spin dependent current to be passed.

Brief Description of the Drawings

[0023] The present invention will better be understood from the following detailed description and the drawings attached hereto showing certain illustrative forms of implementation of the present invention. In this connection, it should be noted that such forms of implementation illustrated in the accompanying drawings hereof are intended in no way to limit the present invention but to facilitate an explanation and understanding thereof. In the drawings,

Fig. 1 represents in conceptual views a CPP type giant magnetoresistance device of spin valve type according to a first form wherein a first magnetic layer of SyAF and a fixed layer are magnetized antiparallel and parallel to each other as shown at (a) and (b), respectively;
Fig. 2 is a cross sectional view illustrating the makeup of a CPP type giant magnetoresistance device of spin valve type according to a second form;
Fig. 3 is a cross sectional view illustrating the makeup of a CPP type giant magnetoresistance device of spin valve type as a modification of the second form ;
Fig. 4 is a cross sectional view illustrating the makeup of a CPP type giant magnetoresistance device of spin valve type according to a form of implementation of the present invention;
Fig. 5 is a conceptual diagram illustrating a magnetic head
;
Fig. 6 is a conceptual diagram illustrating another form of the magnetic head ;
Fig. 7 is a conceptual diagram illustrating a magnetic memory unit;
Fig. 8 is a diagrammatic view illustrating the first form and a four terminal technique used in connection therewith;
Fig. 9 is a graph depicting CPP-GMR curves obtained in the first form; and
Fig. 10 is a diagrammatic view illustrating a conventional CPP-GMR device.

Best Modes for Carrying Out the Invention

[0024] Hereinafter, the present invention will be described in detail with respect to certain suitable forms of implementation thereof illustrated in Figs. 4(a) and 4(b) and to examples illustrated in Figs. 1 to 3 and 5 to 9 wherein identical reference characters are used to designate identical or corresponding components shown and described.

[0025] Fig. 1 depicts in conceptual views a CPP type giant magnetoresistance device of spin valve type according to a first form wherein a first magnetic layer in a ferromagnetic free layer and a fixed layer are magnetized antiparallel and parallel to each other as shown at (a) and (b), respectively. As shown in Fig. 1, the CPP type giant magnetoresistance device of the first form, here designated by reference character 10, has a multi-layered structure of an antiferromagnetic layer 9, a ferromagnetic fixed layer 11, a nonmagnetic conductive layer 12 and a ferromagnetic free layer 13 wherein the ferromagnetic free layer 13 has a first magnetic layer 14 and a second magnetic layer 16 magnetically coupled together antiparallel to each other via a magnetic coupler 15 and formed to have different magnitudes of magnetization M_1 and M_2, respectively. These layers of the multi-layered structure are formed each having a film thickness of a nanometer size. This nanometer size means a size such that an electron while conserving its momentum and spin is capable of conducting. Thus, inasmuch as electrons in a metal have their mean free path less than 1 μm, it will be seen that spins in a device of this size can, without relaxing, flow from one side into another.

[0026] While in this form of implementation the CPP type giant magnetoresistance device of spin valve type includes the antiferromagnetic layer 9 adjacent to the ferromagnetic fixed layer 11 as a fixed layer, the antiferromagnetic layer 9 may be omitted when the ferromagnetic fixed layer 11 is formed of a film having a coercive force large enough for it alone to serve as a fixed layer. The nonmagnetic conductive layer 12 should effectively be a metal layer made of copper (Cu). Cu allows giving rise to much larger spin dependent scattering than the other metals capable of spin dependent scattering.

[0027] The ferromagnetic free layer 13 is shown here as having applied thereto or to a free layer, a three-layer structure in which two ferromagnetic layers, namely the first and second magnetic layers 14 and 16, are magnetically coupled together antiparallel to each other via the magnetic coupler 15 and formed to have different magnitudes of magnetization from each other. This three-layer structure according to the present invention will also be referred to hereinafter as "SyAF" that stands for "Synthetic Anti-Ferromagnet". The ferromagnetic free layer 13 may not only be made up of this three-layer structure singly, but also it may comprise a multi-layer of more than one such three-layer structural units to increase the device's CPP-GMR.

[0028] The SyAF in this form is a single domain structure if the aspect ratio: $k \leqq 2$ and especially $k = 1$, which is extremely small with its flex reversing field not dependent on the device size; hence its magnetization can be reversed by spin injection.

[0029] The magnetization of the ferromagnetic free layer 13 is given by difference Δ M between magnetization M_1 of the first magnetic layer 14 and magnetization M_2 of the second magnetic layer 16; thus $\Delta M = M_1 - M_2$ where $M_1 > M_2$. If the first and second magnetic layers 14 and 16 are composed of an identical material, then they may be formed to have a difference in film thickness and thereby to make a difference in magnitude of magnetization between them. Magnetizations 17 and 18 of the first and second magnetic layers 14 and 16 are here capable of being jointly reversed e. g., under flux reversing magnetic field applied externally, while maintaining their mutual antiparallel relationship of magnetization.

[0030] The magnetic coupler 15 has a function of antiferromagnetic coupling. For example, as a nonmagnetic material a nonmagnetic metal or semiconductor may be used to form the magnetic coupler 15. Specifically, use may be made of one or more of ruthenium (Ru), iridium (Ir), rhodium (Rh), rhenium (Re) and chromium (Cr). More than one of them may be used in the form of a multi-layer or an alloy body to constitute the coupler. In addition, a FeSi alloy and Si as a semiconductor element may be utilized. Also, the magnetic coupler 15 in the form of a layer should preferably have a film thickness as thin as 1.5 nm or less. Forming it in a thin film of 1.5 nm or less brings about strong antiparallel exchange coupling and is thus advantageous.

[0031] Mention is next made of the effectiveness of using a SyAF film for the ferromagnetic free layer 13, with reference to an example in which ruthenium is used to form the magnetic coupler 15.

[0032] When an electric current is passed in a direction perpendicular to a film plane, with the assumption that an electrode resistance is negligible as small, then the resistance R of SyAF film is given by:

$$\mathbf{R = A + B + C}$$

where A is the sum of resistances of magnetic layers each of which is given by [(specific resistance) X (film thickness)], B is the sum of resistances of interfaces, and C is the sum of resistances of antiferromagnetic layers each of which is given by [(specific resistance) X (film thickness)]. Then, the CPP-GMR can be expressed by:

$$\mathrm{CPP\text{-}GMR} = \{(A + B)_{AF} - (A + B)_{F}\} / \{(A + B)_{F} + C\}$$

Here, subscripts "F" and "AF" mean the magnetizations of the free layer and fixed layers being parallel and antiparallel to each other, respectively. From the above it can be seen that the larger the resistance C excessively than the resistance (A + B), the smaller the CPP-GMR.

[0033] When used for the ferromagnetic free layer 13, the SyAF being the three-layer structure will make its resistance larger than a monolayer film but not much as an antiferromagnet. For this reason, with this effect alone it is not expected that the use of a SyAF for a free layer would give rise to an extreme increase in CPP-GMR. The present inventors have found, however, that the CPP-GMR device made with the SyAF used for the ferromagnetic free layer 13 has a CPP-GMR that is increased by 8 % or more, or one figure larger, than that which has hitherto be obtained.

[0034] While precise operations and effects for this have not yet been clarified, they are considered at least qualitatively as stated below.

[0035] As shown in Fig. 1(a), let it be assumed that spin conserved electrons are conducting from the left to the right in the Figure in a direction perpendicular to the film plane. Then, an electron 5 as shown with its spin (↑) oriented upwards the same as the magnetization of the fixed layer will, according to the GMR principle, be scattered intensely at the interface between the nonmagnetic conductive layer 12 and the first magnetic layer 14 whose magnetization 17 is opposite in orientation to the spin. On the other hand, an electron 6 as shown with its spin (↓) oriented downwards the same as the magnetization 17 of the first magnetic layer 14 will not be scattered at the interface between the nonmagnetic conductive layer 12 and the first magnetic layer 14 and will be scattered intensely at the interface between the first magnetic layer 14 and the Ruthenium layer 15. Electrons so scattered will then be scattered at the interface between the nonmagnetic conductive layer 12 and the ferromagnetic fixed layer 11. As a result, electrons of these two classes different in pin orientation will have paths of conduction as indicated by refracted lines 1 and 2, respectively, in Fig. 1(a).

[0036] Now, assume that the magnetizations of the SyAF 13 in the state shown in Fig. 1(a) are reversed, e. g., by applying external magnetic field thereto, while maintaining their mutual antiparallel relationship itself. Then, as shown in Fig. 1(b) electrons 5 each with its spin oriented upwards (↑) in the fixed layer as is the magnetization 19 of the first magnetic layer 14 will not be scattered at the interface between the nonmagnetic conductive layer 12 and the first magnetic layer 14 and will intensely be scattered at the interface between the first magnetic layer 14 and the Ruthenium layer 15. This is due to the known fact that in the case of a Co/Ru multi-layered film, many spins, here, electrons with upward spins (↑) are intensely scattered more at a Ruthenium interface. See K. Eid, R. Fronk, M. Alhaj, W. P. Pratt, Jr. and J. Bass, "Current-perpendicular-to-plane magneto-resistance properties of Ru and Co/Ru interfaces" J. Appl. Phys. 91, 8102 (2002).

[0037] The electrons 5 with upwards spins (↑) which are scattered at the Ruthenium 15 interface will not be scattered at the interface between the ferromagnetic fixed layer 11 and the nonmagnetic conductive layer 12 and will be scattered at the interface between the antiferromagnetic layer 9 and the ferromagnetic fixed layer 11. In the meantime, the electrons 5 whose mean free path is thus long will each be able to make a number of round rips while having its spin conserved. On the other hand, the electrons 6 with downward spins (↓) will, as in Fig. 1(a), be scattered at the interface between the nonmagnetic conductive layer 12 and the first magnetic layer 14. The conduction paths of these electrons are indicated by refracted lines 3 and 4 as shown in Fig. 1(b).

[0038] From comparing the paths of conduction in the states of Figs. 1(a) and 1(b), it is seen that the state of Fig. 1(b) is lower in resistance. In this way, the CPP-GMR manifests itself. To wit, the CPP-GMR increases due to the presence of Ru. It will therefore be apparent that in this form of implementation, the CPP-GMR is increased by the magnetization reversal of the free layer by 8 % or more, one figure larger, than that which has hitherto be obtained.

[0039] Mention is next made of a second form.

[0040] Fig. 2 is a cross sectional view illustrating the makeup of a CPP type giant magnetoresistance device of spin valve type according to the second form. In Fig. 2, there is shown such a CPP type giant magnetoresistance device 20 according to the second form of implementation, which has a multi-layered structure comprising an antiferromagnetic layer 9, a ferromagnetic fixed layer 11A, a nonmagnetic conductive layer 12 and a ferromagnetic free layer 13A.

[0041] In the CPP type giant magnetoresistance device 20 according to the second form, the ferromagnetic fixed layer 11A has a SyAF structure wherein the ferromagnetic fixed layer 11A has a first magnetic layer 14A and a second magnetic layer 16A which are coupled together magnetically antiparallel to each other via a magnetic coupler 15A and formed to have different magnitudes of magnetization 17' and 18', respectively. These layers of the multi-layered structure are formed each having a film thickness of a nanometer size.

[0042] To form the magnetic coupler 15A in the SyAF structure, one or more of ruthenium, iridium, rhodium, rhenium and chromium may be used. More than one of them may be used in the form of a multi-layer or an alloy body to constitute the coupler. In addition, a FeSi alloy and Si as a semiconductor element may be utilized. Also, the magnetic coupler 15A in the form of a layer should preferably have a film thickness as thin as 1.5 nm or less. Forming it in a thin film of 1.5 nm or less brings about strong antiparallel exchange coupling and is thus advantageous.

[0043] An increase in CPP-GMR is obtained in the CPP type giant magnetoresistance device 20 of the second form as in the CPP type giant magnetoresistance device 10 of the first form.

[0044] Formed of the three-layer structure, the ferromagnetic fixed layer 11A may not only be made up of this three-layer structure singly but also may comprise a multi-layer of more than one such three-layer structural units to increase the device's CPP-GMR.

[0045] As to the rise in CPP-GMR thus achieved here when the ferromagnetic fixed layer 11A is made in the form of the SyAF structure, precise operations and effects for this have not yet been clarified as for the CPP type giant magnetoresistance device 10 of the first form of implementation. However, they are considered at least qualitatively to be due to the spin dependent scattering at an interface of the magnetic coupler 15A such as of Ru with the nonmagnetic metal layer in the SyAF structure as mentioned in connection with the CPP type giant magnetoresistance device 10 of the first form.

[0046] Mention is next made of a modification of the second form.

[0047] Fig. 3 is a cross sectional view illustrating the makeup of a CPP type giant magnetoresistance device of spin valve type as a modification of the second form . In Fig. 3, there is shown such a CPP type giant magnetoresistance device 25 that has a multi-layered structure comprising an antiferromagnetic layer 9, a ferromagnetic fixed layer 11A of SyAF structure, a nonmagnetic conductive layer 12 and a ferromagnetic free layer 13 of SyAF structure.

[0048] The ferromagnetic free layer of SyAF structure 13 has a first magnetic layer 14 and a second magnetic layer 16 which are coupled together magnetically antiparallel to each other via a magnetic coupler 15 and formed to have different magnitudes of magnetization 17 and 18, respectively. And, the ferromagnetic fixed layer 11A of SyAF structure has a first magnetic layer 14A and a second magnetic layer 16A which are coupled together magnetically antiparallel to each other via a magnetic coupler 15A and formed to have different magnitudes of magnetization 17' and 18', respectively.

[0049] These layers of the multi-layered structure are formed each having a film thickness of a nanometer size. Here, to form the magnetic coupler 15, 15A in each SyAF structure, one or more of ruthenium, iridium, rhodium, rhenium and chromium may be used. More than one of them may be used in the form of a multi-layer or an alloy body to constitute the coupler. In addition, a FeSi alloy and Si as a semiconductor element may be utilized. Also, the magnetic coupler 15, 15A in the form of a layer should preferably have a film thickness as thin as 1.5 nm or less. Forming it in a thin film of 1.5 nm or less brings about strong antiparallel exchange coupling and is thus advantageous.

[0050] In this CPP type giant magnetoresistance device 25, too, an increase in CPP-GMR is obtained as in the CPP type giant magnetoresistance device 10 of the first form and the CPP type giant magnetoresistance device 20 of the second form.

[0051] Formed of the three-layer structure, each of the ferromagnetic fixed and free layers 11A and 13 may not only be made up of this three-layer structure singly but also may comprise a multi-layer of more than one such three-layer structural units to increase the device's CPP-GMR.

[0052] As to the rise in CPP-GMR thus achieved here when the ferromagnetic free and fixed layers 13 and 11A are each made in the form of the SyAF structure, precise operations and effects for this have not yet been clarified as for the CPP type giant magnetoresistance device 10 of the first form. However, as mentioned in connection with the CPP type giant magnetoresistance device 10 of the first form, they are considered at least qualitatively to be due to the spin dependent scattering at an interface of the magnetic coupler 15, 15A such as of Ru with the nonmagnetic metal layer in the SyAF structure forming the ferromagnetic free layer 13 or the ferromagnetic fixed layer 11A.

[0053] Mention is next made of a form of implementation of the present invention.

[0054] Fig. 4 is a cross sectional view illustrating the makeup of a CPP type giant magnetoresistance device of spin valve type according to a form of implementation of the present invention. As shown in Fig. 4, such a CPP type giant magnetoresistance device 30 of the form of implementation has a multi-layered structure comprising a ferromagnetic fixed layer 11, a nonmagnetic conductive layer 12 and a ferromagnetic free layer 13A and may take a structure as shown in Fig. 4(a) in which a nonmagnetic metal layer 21 is formed between the ferromagnetic fixed layer 11 and the nonmagnetic conductive layer 12, or a structure as shown in Fig. 4(b) in which a nonmagnetic metal layer 21 is formed between the ferromagnetic fixed layer 11 and the nonmagnetic conductive layer 12 and another nonmagnetic metal layer 21 on a surface of the ferromagnetic free layer 13A.

[0055] Here, such a nonmagnetic metal layer 21 is a layer made of one or more of ruthenium, iridium, rhodium, rhenium and chromium. These layers of the multi-layered structure are formed each having a film thickness of a nanometer size. And, the nonmagnetic metal layer 21 in each case should preferably have a film thickness as thin as 1.5 nm or less. Also, the structure may further have an antiferromagnetic layer formed on the ferromagnetic fixed layer 11 to make a CPP type giant magnetoresistance device of spin valve type.

[0056] In the CPP type giant magnetoresistance device 30 according to the form of implementation, an increase in CPP-GMR is likewise obtained as in the CPP type giant magnetoresistance device 10 according to the first form and the CPP type giant magnetoresistance device 20, 25 according to the second form of .

[0057] As to the rise in CPP-GMR thus achieved here when a nonmagnetic metal layer 21 is formed between the ferromagnetic fixed layer 11 and the nonmagnetic conductive layer 12 and/or on the ferromagnetic free layer 13A, precise operations and effects for this have not yet been clarified as for the CPP type giant magnetoresistance device 10 of the first form. However, as mentioned in connection with the CPP type giant magnetoresistance device 10 of the first form, they are considered at least qualitatively to be due to the spin dependent scattering at interfaces of the nonmagnetic metal layer 21 with the ferromagnetic fixed layer 11 and the nonmagnetic conductive layer 12 and/or at an interface between the nonmagnetic metal layer 21 and the ferromagnetic free layer 13A.

[0058] Mention is next made of a magnetic head with a CPP type giant magnetoresistance device applied thereto.

[0059] Fig. 5 is a conceptual diagram illustrating a magnetic head Referring to Fig. 5, such a magnetic head 40 comprises a CPP type giant magnetoresistance device 10, which may be a device of the present invention, and a first and a second electrode 44 and 46. The CPP-GMR device 10 is shown having an antiferromagnetic layer 9 and a SyAF with a second magnetic layer 16 and has two opposite ends covered with insulating layers 41 and 41. The first electrode 44 is designed to supply spin dependent sensor electrons 42 from the antiferromagnetic layer 9 and also serves as a magnetic shield. The second electrode 46 is disposed in contact with an end face 45 of the second magnetic layer 16 in the SyAF to serve as a magnetic shield, too. A recording medium 43 such as a magnetic disk lies opposed to the end face 45 of the second magnetic layer 16 in the SyAF side of the CCP type giant magnetoresistance device.

[0060] Then, although it is desirable to dispose the magnetic head so that a magnetic field to be detected acts parallel to the direction of magnetization of the SyAF, it may be disposed at an angle at which the SyAF is allowed to reverse its magnetization. The insulating layers 41 and 41 may be such as to control the conduction path of sensor electrons to permit their conduction in a direction perpendicular to film planes. The first and second electrodes 44 and 46 of the magnetic head 40 should satisfactorily be not less than the width of the CPP type giant magnetoresistance device and it is satisfactory at least if the magnetic head has a width L that is not more than the track width W of the recording medium. The arrow 47 in Fig. 5 indicates the direction in which the recording medium is moved.

[0061] The magnetic head 40 so constructed as mentioned above will have the SyAF caused to reverse its magnetizations in response to a leakage magnetic field from the recording medium to bring about CPP-GMR based on the spin dependent scatterings of sensor electrons and will have its electrical resistance varied thereby. Thus, the magnetic head according to this form allows detecting the direction of a magnetic field from the recording medium as a change in electrical resistance. Further, since a magnetic field to be shielded is confined to its width or so, the magnetic head can achieve magnetic shielding even if the recording medium is highly densified.

[0062] Mention is next made of an alternative form of implementation of the magnetic head. Fig. 6 is a conceptual diagram illustrating another form of implementation of the magnetic head. Such a magnetic head 50 shown in Fig. 6 is of the form in which a stratal face 48 of the CPP type giant magnetoresistance device 10, 20, 25 on which its multi-layered structure appears is set face to face with a recording medium 43. It has a first electrode 44 formed in contact with a whole or part surface of the end face of the antiferromagnetic layer 9 and a second electrode 46 formed in contact with a whole or part surface of the end face of the second magnetic layer 16 in the SyAF. In this magnetic head 50, too, magnetic shield layers via insulating layers as shown in connection with the second form of implementation may be provided. While these magnetic shields may serve also as the electrodes, the first and second electrodes 44 and 46 should be insulated from each other. These magnetic shields may each be of any form if it can magnetically shield the SyAF. The magnetic head so constructed makes it possible to detect a magnetic field from the recording medium having a track width W of a size of the width L of the SyAF and can make reproductions even from a highly densified recording medium.

[0063] While a magnetic head has been described a CPP type giant magnetoresistance device according to the present invention can widely be utilized in what can be called magnetic components such as a field sensor, an angle sensor and an angular displacement sensor.

[0064] Mention is next made of a another use of the present invention.

[0065] Fig. 7 is a conceptual diagram illustrating a magnetic memory unit capable of storing information to which a CPP type giant magnetoresistance device of the invention is applied. In Fig. 7 there is shown a structure in which a CPP type giant magnetoresistance device 10, 20, 25 is disposed at each of intersections of word lines 64 and bit lines 66. Since the magnetic field which the SyAF 13 of the invention requires to reverse its magnetizations is extremely small, passing an electric current of several milliamperes or so, e. g., 5 mA, for spin injection is sufficient to cause the SyAF 13 to reverse its magnetizations.

[0066] In the magnetic memory unit so constructed as mentioned above, writing is performed by selecting a CPP type giant magnetoresistance device from a combination of a word and a bit lines and passing an electric current, e. g., of 5 mA, from the word line for spin injection to reverse magnetizations of the SyAF therein. For reading, a CPP type giant magnetoresistance device is selected and from its word line an electric current of, e. g., 1 mA, that is smaller than that required for writing is passed to develop CPP-GMR by spin dependent electron scattering and then to determine a change in resistance of the CPP type magnetoresistance device or whether the resistance is large or small.

[0067] Thus, in the magnetic memory unit according to the present invention, information units "1" and "0" can be determined depending on whether the fixed and free layers are magnetized parallel and antiparallel to each other, and causing the free layer to remain magnetized after the current supply is cut off allows forming a MRAM as a nonvolatile memory.

[0068] While reference has been made to a particular magnetic memory unit, it should be understood that the present invention in this aspect is applicable to various magnetic devices such as a digital CTR in which CPP type giant magnetoresistance devices or elements of the invention are applied to a magnetic head as well as a variety of magnetic recording devices such as a hard disk drive (HDD).

[0069] Specific Examples in which the present invention can be used are given below.

[0070] Fig. 8 is a diagrammatic view illustrating a CPP type giant magnetoresistance device according to the first form and a four terminal technique used to determine its properties. For this first Example, use is made of a CPP-GMR structure corresponding to that shown in Fig. 1. As shown in Fig. 8, a thermally oxidized silicon substrate 51 has a lower electrode 52 and a lower, highly conductive layer 53 laid thereon, and mounted on the latter the first Example has a CPP-GMR structure 58 in which are successively multi-layered a CPP type magnetoresistance device 10 as a multi-layered structure of an antiferromagnetic layer, a ferromagnetic fixed layer, a nonmagnetic conductive layer and SyAF, an upper electrode 54 and an upper highly conductive layer 55. The first Example is further provided with insulating layers 56 and 56 for insulating the CPP-GMR structure 58, a voltmeter 57 for sensing a signal voltage, a first electrode 59, a power supply 61 for supplying sense electrons and a second electrode 62.

[0071] The CPP-GMR structure 58 was prepared as stated below.

[0072] First, using an utrahigh vacuum sputtering apparatus, the thermally oxidized Si substrate had successively multi-layered thereon, Ta (10 nm), Cu (2.5 nm), IrMn (10 nm), $Co_{90}Fe_{10}$ (3 nm), Cu (2.5 nm), $Co_{90}Fe_{10}$ (5 nm), Ru (0.45 nm), $Co_{90}Fe_{10}$ (3 nm) and Ta (5 nm).

[0073] Here, film thicknesses are indicated in parentheses. Lower Ta (10 nm), IrMn and upper Ta (5 nm) form the lower electrode, the antiferromagnetic layer and the upper electrode, respectively. $Co_{90}Fe_{10}$ (5 nm), Ru (0.45 nm) and $Co_{90}Fe_{10}$ (3nm) form the SyAF in which Ru magnetically couples two $Co_{90}Fe_{10}$ magnetic layers together antiparallel to each other. The $Co_{90}Fe_{10}$ (3 nm) in contact with IrMn has spins fixed therein, thus constituting the fixed layer.

[0074] Then, using electron beam lithography and Ar ion milling, these films were micromachined to prepare a CPP-GMR device having a sectional structure as shown in Fig. 8. The device had a size of 1 x 0.5 μ m^2.

[0075] For this CPP-GMR device was used the four terminal technique shown in Fig. 8 whereby an electric current of 1 mA was passed between the upper highly conductive layer and the second electrode, and resistance was measured at room temperature under magnetic field of varying strength. Measurement results are shown as a function of magnetic field in Fig. 9, from which it is seen that resistance change Δ R = 0.023 Ω and CPP-GMR is 8.24 %. This value of GMR is found to be about 10 (ten) times as large as that of the conventional CPP-GMR device without a SyAF free layer.

[0076] Next, a second Example was performed in which as in the first Example, films of Ta (10 nm), Cu (20 nm), IrMn (10 nm), $Co_{90}Fe_{10}$ (3 nm), Cu (6 nm), $Co_{90}Fe_{10}$ (3 nm), Ru (0.45 nm), $Co_{90}Fe_{10}$ (5 nm), Ta (3 nm) and Cu (50 nm) were formed on a thermally oxidized Si substrate.

[0077] These films were micromachined using electron beam lithography and Ar ion milling, to prepare a CPP-GMR device having a sectional structure as shown in Fig. 8. The device had a size of 0.5 x 0.5 μ m^2.

[0078] For this device was used the four terminal technique shown in Fig. 8 whereby an electric current of 1 mA was passed between the upper highly conductive layer and the second electrode, and resistance was measured under magnetic field of varying strength. From results of the measurement, it was found that resistance change Δ R = 0.5 Ω and CPP-GMR is 6.6 %. This value of CPP-GMR is found to be about 10 (ten) times as large as that of the conventional CPP-GMR device without a SyAF free layer.

[0079] A comparative example is given below.

[0080] The comparative example was carried out in the same way as the first Example except that $Co_{90}Fe_{10}$ (3 nm), Ru (0.45 nm) and $Co_{90}Fe_{10}$ (5 nm) were replaced by $Co_{90}Fe_{10}$ (8 nm) to prepare a conventional CPP-GMR device.

[0081] As in the first Example the CPP-GMR was measured and determined to be 0.5 %, which amounts to 1/10 or less of the value in the first Example.

Industrial Applicability

[0082] As will be appreciated from the foregoing description, the present invention provides a CPP type giant magnetoresistance device which is extremely large in CPP-GMR and hence can be used to detect the direction of a magnetic field such as from a recording medium as a large change in electrical resistance and can be applied to what are called magnetic components such as a magnetic field sensor, an angle sensor and an angular displacement sensor.

[0083] The present invention further provides a magnetic device or unit which, having the capability of writing or reading upon passing spin dependent current while having nonvolatile magnetic storage capability, can be used in a variety of types of magnetic recorders such as a digital VTR and a hard disk drive (HDD), and also in a MRAM.

Claims

1. A Current Perpendicular to the Plane (CPP) type giant magnetoresistance device comprising:

   a ferromagnetic fixed layer (11);
   a nonmagnetic conductive layer (12); and
   a ferromagnetic free layer (13A), wherein
   the nonmagnetic conductive layer (12) is formed on said ferromagnetic fixed layer (11);
   and the ferromagnetic free layer (13A) is formed contacted with said nonmagnetic conductive layer (12),
   the device further comprising:

      a nonmagnetic metal layer (21) made of one or more of ruthenium, iridium, rhodium, rhenium and chromium between said ferromagnetic fixed (11) and said nonmagnetic conductive layers (12);
      characterized in that the nonmagnetic metal layer (21) is in direct contact with the non-magnetic conductive layer (12).

2. A Current Perpendicular to the Plane (CPP) type giant magnetoresistance device as set forth in Claim 1, **characterized in that** another nonmagnetic metal layer (21) is provided on an outermost surface of said ferromagnetic free layer (13A).

3. A magnetic part using a CPP type giant magnetoresistance device, characterized to have a CPP type giant magnetoresistance device as set forth in any one of Claims 1 or 2.

4. A magnetic head, **characterized in that** the ferromagnetic free layer (13A) of the CPP type giant magnetoresistance device as set forth in any one of Claims 1 or 2 is magnetization-reversed by leakage magnetic field of said recording medium, CPP-GMR is realized based on spin dependent scattering of sensor electrons, and the direction of magnetic field of said recording medium is detected as electric resistance.

5. The magnetic head as set forth in Claim 4, **characterized in that** the leakage magnetic field of said recording medium is detected by facing a ferromagnetic layer end face of said ferromagnetic free layer (13A) to said recording medium.

6. The magnetic head as set forth in Claim 5, **characterized in that** the leakage magnetic field is detected by facing the cross-sectional face where the multi-layer structure of said ferromagnetic free layer (13A) appears to said recording medium.

7. The magnetic head as set forth in Claim 4 or 5, **characterized in that** an electrode of sensor electrons to supply to said CPP type giant magnetoresistance device is used also as a magnetic shield for the leakage magnetic field of said recording medium.

8. A magnetic unit using a CPP type giant magnetoresistance device, characterized to have a CPP type giant magnetoresistance device as set forth in any one of Claims 1 or 2.

9. A magnetic memory unit, characterized to have a CPP type giant magnetoresistance device as set forth in any one of Claims 1 or 2 as a nonvolatile memory by providing it at the cross section of a word and a bit lines.

10. The magnetic memory unit as set forth in Claim 9, **characterized in that** the magnetization of the ferromagnetic free layer (13A) can be reversed by spin injection from said word line.

Patentansprüche

1. Riesenmagnetowiderstandsvorrichtung des Typs mit Strom senkrecht zur Ebene (CPP-Typs), die umfasst:

   eine ferromagnetische feste Schicht (11);
   eine nicht magnetische leitfähige Schicht (12); und
   eine ferromagnetische freie Schicht (13A), wobei
   die nicht magnetische leitfähige Schicht (12) auf der ferromagnetischen festen Schicht (11) ausgebildet ist;

und die ferromagnetische freie Schicht (13A) in Kontakt mit der nicht magnetischen leitfähigen Schicht (12) ausgebildet ist,
wobei die Vorrichtung ferner umfasst:

eine nicht magnetische Metallschicht (21), die zwischen der ferromagnetischen festen Schicht (11) und der nicht magnetischen leitfähigen Schicht (12) aus Ruthenium und/oder Iridium und/oder Rhodium und/oder Rhenium und/oder Chrom hergestellt ist;
dadurch gekennzeichnet, dass sich die nicht magnetische Metallschicht (21) mit der nicht magnetischen leitfähigen Schicht (12) in direktem Kontakt befindet.

2. Riesenmagnetowiderstandsvorrichtung des Typs mit Strom senkrecht zur Ebene (CPP-Typs) nach Anspruch 1, **dadurch gekennzeichnet, dass** eine weitere nicht magnetische Metallschicht (21) auf einer äußersten Oberfläche der ferromagnetischen freien Schicht (13A) vorgesehen ist.

3. Magnetbauteil unter Verwendung einer Riesenmagnetowiderstandsvorrichtung des CPP-Typs, **dadurch gekennzeichnet, dass** es eine Riesenmagnetowiderstandsvorrichtung des CPP-Typs nach einem der Ansprüche 1 oder 2 besitzt.

4. Magnetkopf, **dadurch gekennzeichnet, dass** die ferromagnetische freie Schicht (13A) der Riesenmagnetowiderstandsvorrichtung des CPP-Typs nach einem der Ansprüche 1 oder 2 durch ein magnetisches Streufeld des Aufzeichnungsmediums eine umgekehrte Magnetisierung besitzt, die CPP-GMR basierend auf der spinabhängigen Streuung der Sensorelektronen verwirklicht ist und die Richtung des Magnetfelds des Aufzeichnungsmediums als ein elektrischer Widerstand detektiert wird.

5. Magnetkopf nach Anspruch 4, **dadurch gekennzeichnet, dass** das magnetische Streufeld des Aufzeichnungsmediums detektiert wird, indem eine Stirnfläche der ferromagnetischen Schicht der ferromagnetischen freien Schicht (13A) dem Aufzeichnungsmedium zugewandt wird.

6. Magnetkopf nach Anspruch 5, **dadurch gekennzeichnet, dass** das magnetische Streufeld detektiert wird, indem die Querschnittsfläche, in der die Mehrschichtstruktur der ferromagnetischen freien Schicht (13A) erscheint, dem Aufzeichnungsmedium zugewandt wird.

7. Magnetkopf nach Anspruch 4 oder 5, **dadurch gekennzeichnet, dass** eine Elektrode, um die Sensorelektronen der Riesenmagnetowiderstandsvorrichtung des CPP-Typs zuzuführen, außerdem als eine magnetische Abschirmung für das magnetische Streufeld des Aufzeichnungsmediums verwendet wird.

8. Magneteinheit unter Verwendung einer Riesenmagnetowiderstandsvorrichtung des CPP-Typs, **dadurch gekennzeichnet, dass** sie eine Riesenmagnetowiderstandsvorrichtung des CPP-Typs nach einem der Ansprüche 1 oder 2 besitzt.

9. Magnetspeichereinheit, **dadurch gekennzeichnet, dass** sie eine Riesenmagnetowiderstandsvorrichtung des CPP-Typs nach einem der Ansprüche 1 oder 2 als einen nichtflüchtigen Speicher besitzt, in dem sie am Schnittpunkt einer Wort- und einer Bitleitung vorgesehen ist.

10. Magnetspeichereinheit nach Anspruch 9, **dadurch gekennzeichnet, dass** die Magnetisierung der ferromagnetischen freien Schicht (13A) durch die Spininjektion von der Wortleitung umgekehrt werden kann.

Revendications

1. Un dispositif à magnétorésistance géante du type à courant perpendiculaire au plan (CPP), qui comprend:

une couche fixée ferromagnétique (11);
une couche conductrice non-magnétique (12); et
une couche libre ferromagnétique (13A), pour lequel
la couche conductrice non-magnétique (12) est formée sur ladite couche fixée ferromagnétique (11);
et la couche libre ferromagnétique (13A) est formée en contact avec ladite couche conductrice non-magnétique (12),

le dispositif comprenant en outre:

une couche métallique non-magnétique (21) composée d'un ou plusieurs métaux, tels que le ruthénium, l'iridium, le rhodium, le rhénium et le chrome entre ladite couche fixée ferromagnétique (11) et ladite couche conductrice non-magnétique (12);
caractérisé en ce que la couche métallique non-magnétique (21) est en contact direct avec la couche conductrice non-magnétique (12).

2. Un dispositif à magnétorésistance géante du type à courant perpendiculaire au plan (CPP) selon la revendication 1, **caractérisé en ce qu'**une autre couche métallique non-magnétique (21) est prévue sur une surface la plus éloignée de ladite couche libre ferromagnétique (13A).

3. Une partie magnétique, qui utilise un dispositif à magnétorésistance géante du type CPP, caractérisée pour avoir un dispositif à magnétorésistance géante du type CPP selon l'une des revendications 1 et 2.

4. Une tête magnétique, **caractérisée en ce que** la couche libre ferromagnétique (13A) du dispositif à magnétorésistance géante du type CPP selon l'une des revendications 1 et 2, est à magnétisation inversée par le champ magnétique de fuite dudit moyen d'enregistrement, CPP-GMR est réalisé sur la base de la dispersion dépendante du spin des électrons capteur, et la direction du champ magnétique du moyen d'enregistrement est détecté comme une résistance électrique.

5. La tête magnétique selon la revendication 4, **caractérisée en ce que** le champ magnétique de fuite dudit moyen d'enregistrement est détecté en faisant face à une face d'extrémité d'une couche ferromagnétique de ladite couche libre ferromagnétique (13A) audit moyen d'enregistrement.

6. La tête magnétique selon la revendication 5, **caractérisée en ce que** le champ magnétique de fuite est détecté en faisant face à la face transversale, où la structure multicouche de ladite couche libre ferromagnétique (13A) apparaît audit moyen d'enregistrement.

7. La tête magnétique selon la revendication 4 ou 5, **caractérisée en ce qu'**une électrode des électrons capteur pour alimenter ledit dispositif à magnétorésistance géante du type CPP, est utilisée également comme un écran magnétique pour le champ magnétique de fuite dudit moyen d'enregistrement.

8. Une unité magnétique, qui utilise un dispositif à magnétorésistance géante du type CPP, caractérisée pour avoir un dispositif à magnétorésistance géante du type CPP selon l'une des revendications 1 et 2.

9. Une unité à mémoire magnétique, caractérisée pour avoir un dispositif à magnétorésistance géante du type CPP selon l'une des revendications 1 et 2 comme une mémoire non-volatile en lui fournissant à la section transversale des lignes de mots et de bits.

10. L'unité à mémoire magnétique selon la revendication 9, **caractérisée en ce que** la magnétisation de la couche libre ferromagnétique (13A) peut être inversée par l'injection du spin provenant de ladite ligne de mots.

FIG. 1

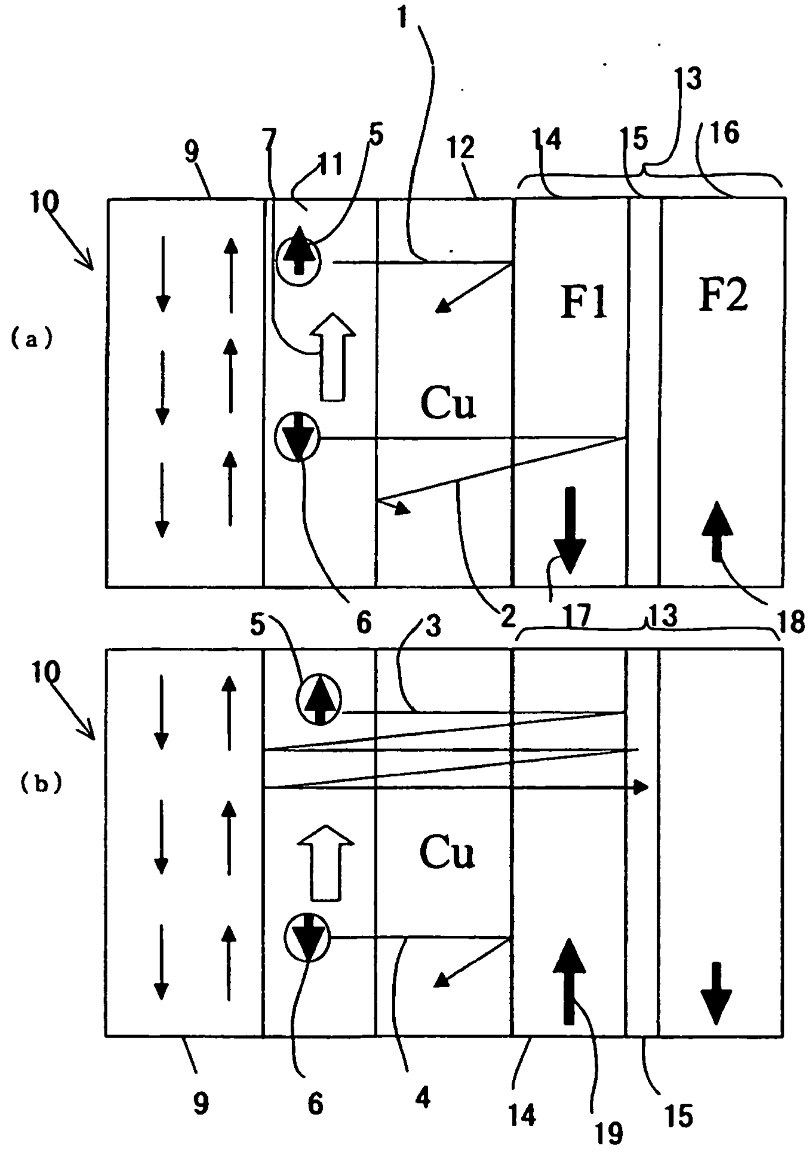

1
13
9
7
11
5
12
14
15
16
10
(a)
F1
F2
Cu
6
2
17
13
18
5
6
3
10
(b)
Cu
9
6
4
14
19
15

FIG. 2

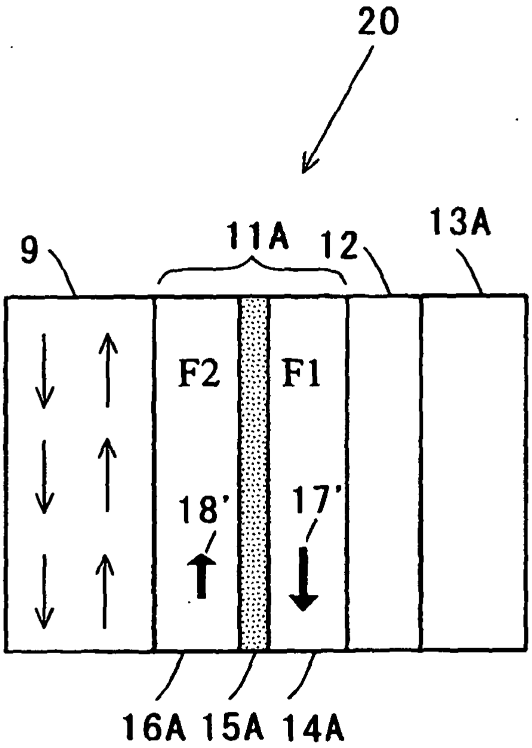


FIG. 3

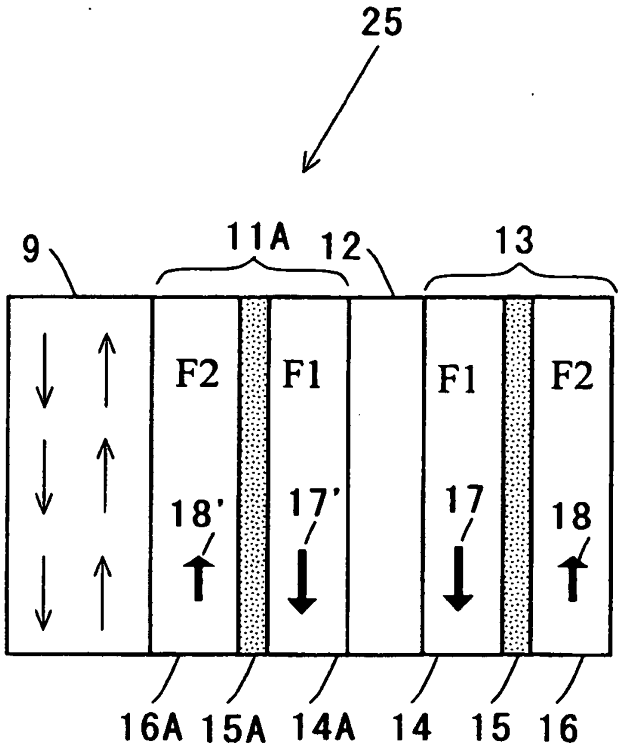


FIG. 4

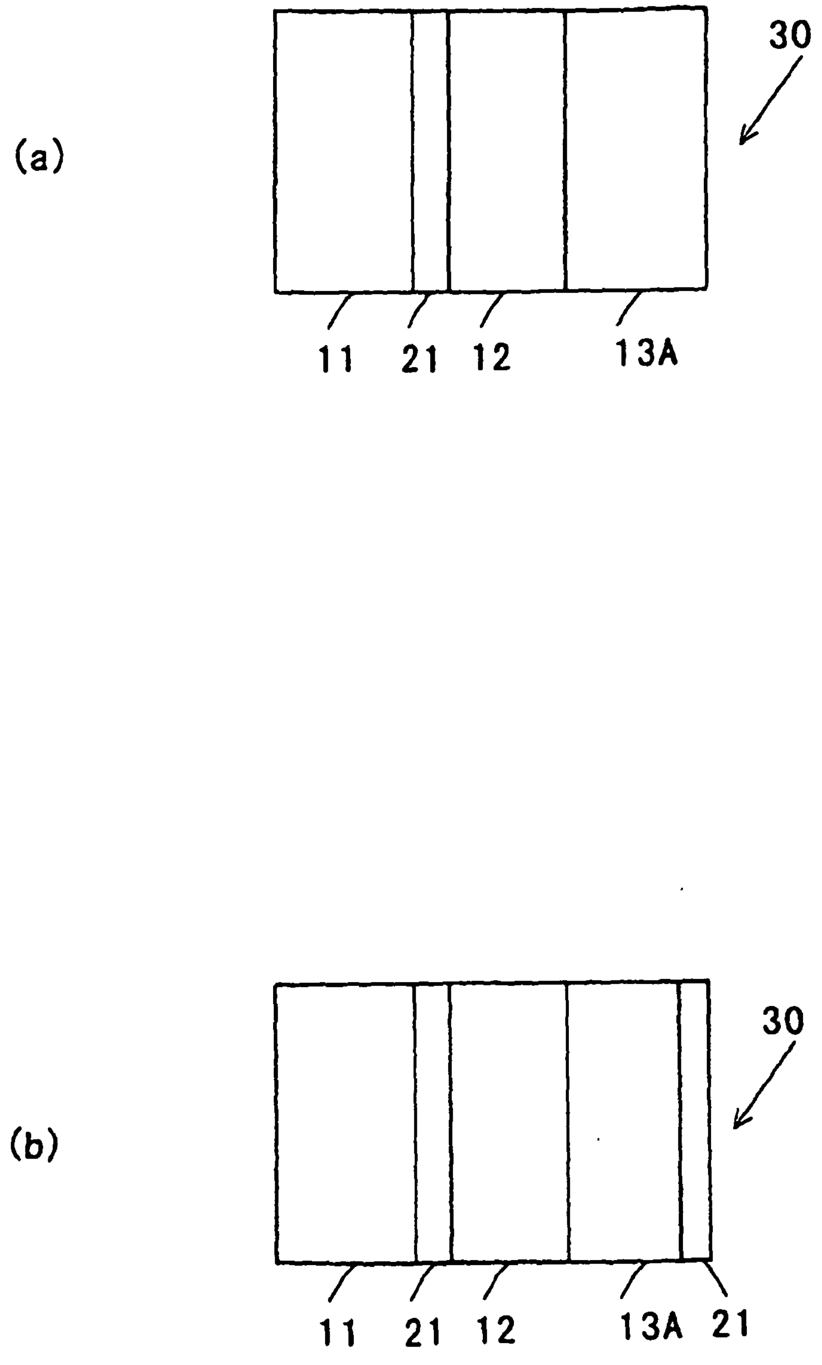


FIG. 5

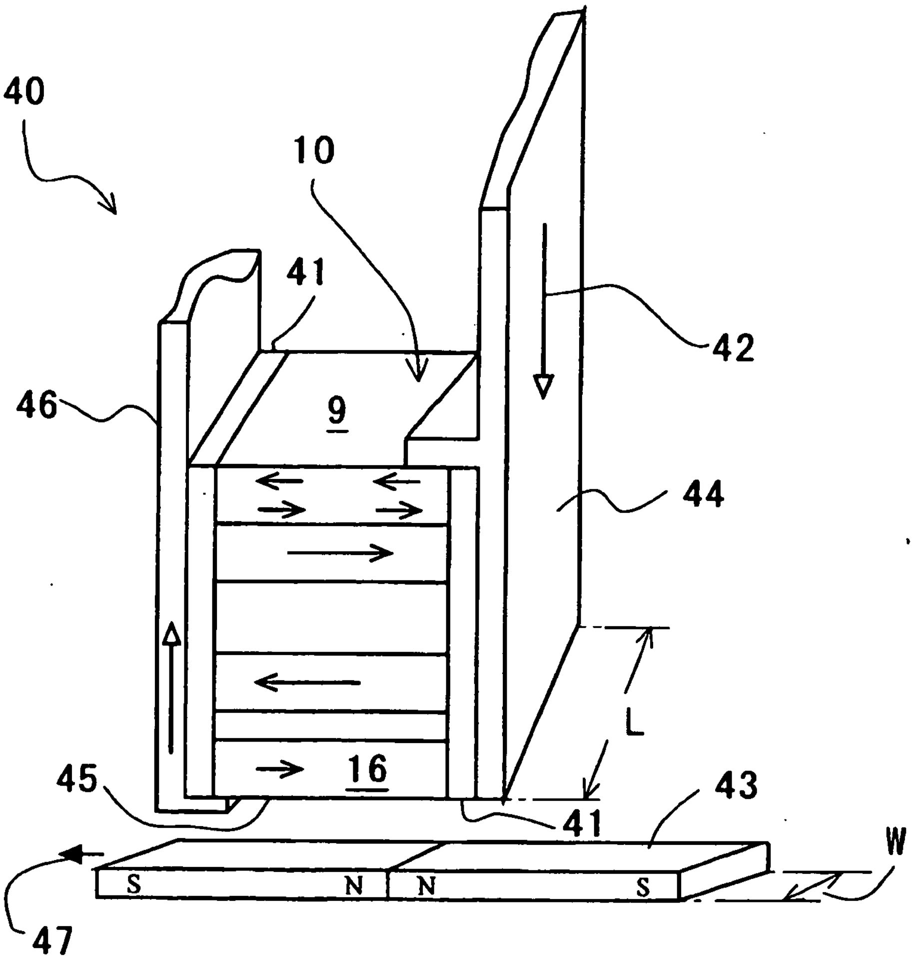


FIG. 6

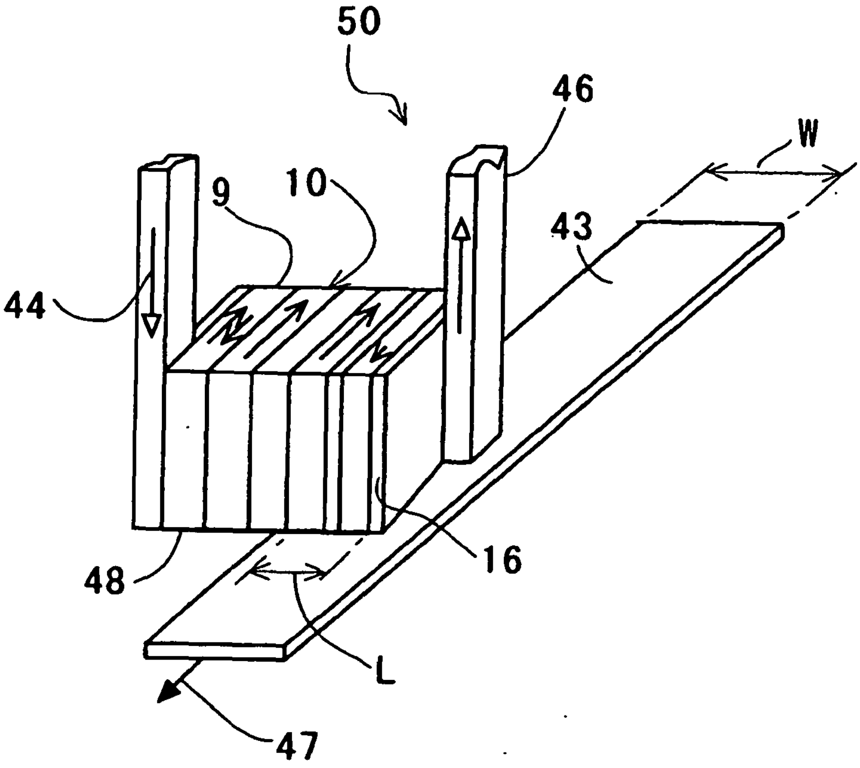


FIG. 7

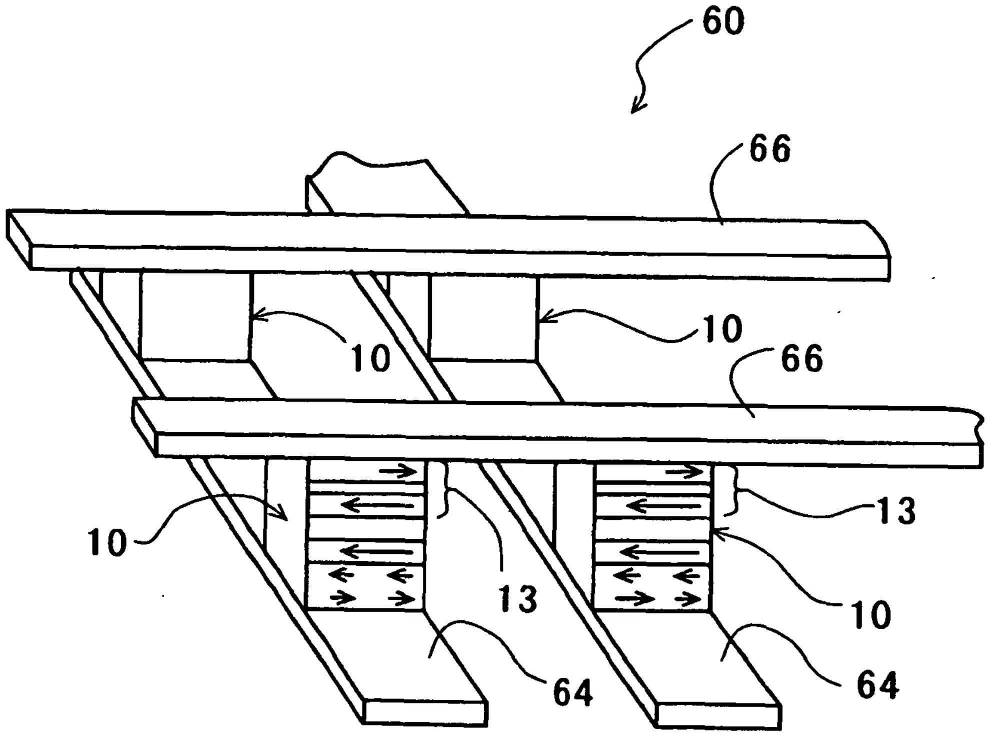


FIG. 8

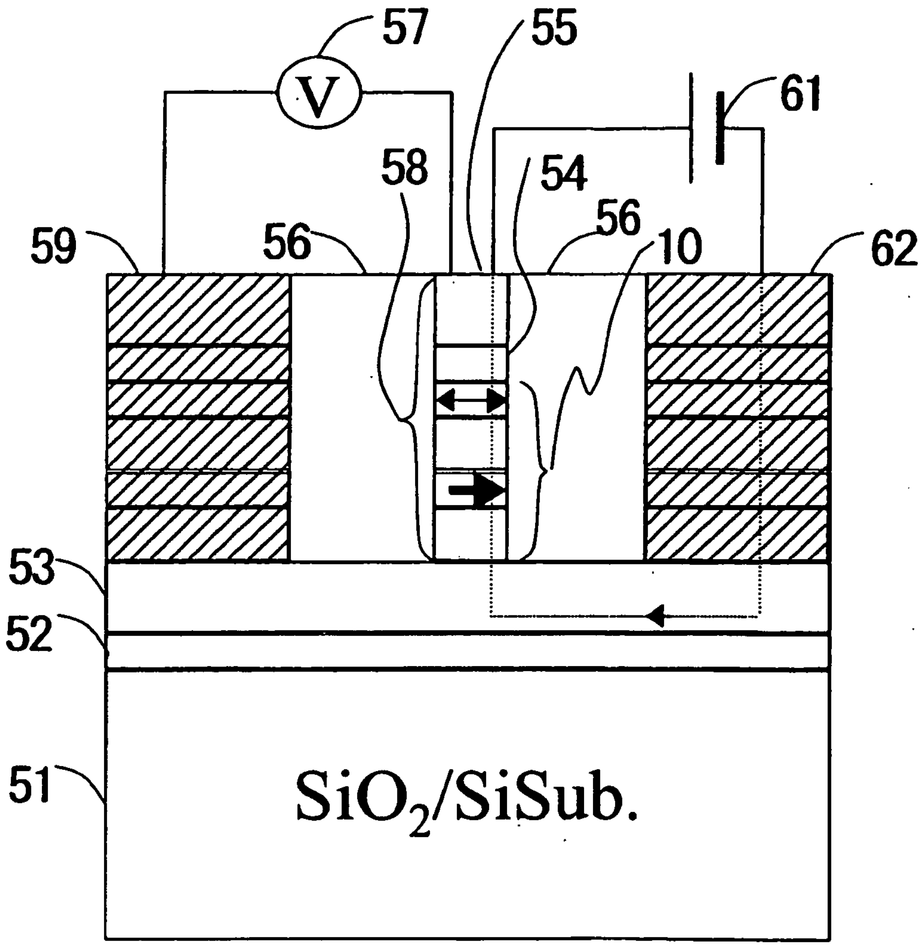


FIG. 9

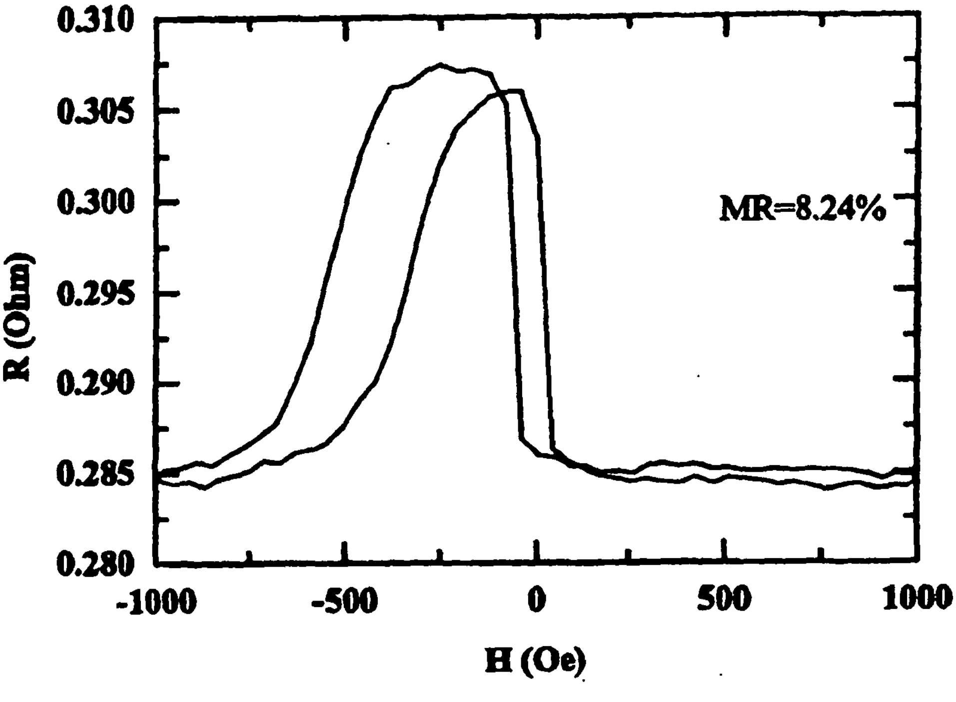
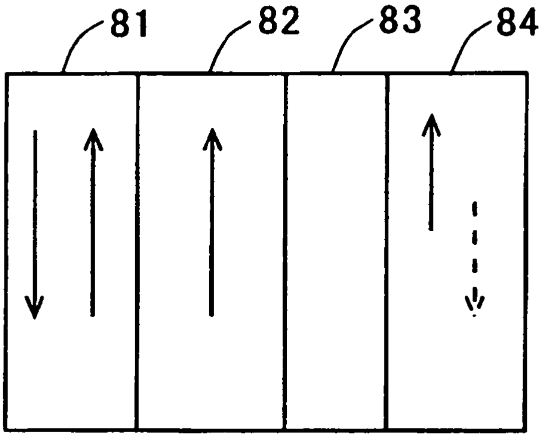

0.310
0.305
0.300
0.295
0.290
0.285
0.280
R (Ohm)
-1000
-500
0
500
1000
H (Oe)
MR=8.24%

FIG. 10



REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2002359415 A **[0004]**
- JP 2002124721 A **[0005]**
- JP H09251621 A **[0006]**
- US 20020034055 A1 **[0010]**
- US 20030011945 A1 **[0010]**

Non-patent literature cited in the description

- **K. EID ; R. FRONK ; M. ALHAJ ; W. P. PRATT, JR. ; J. BASS.** Current-perpendicular-to-plane magneto-resistance properties of Ru and Co/Ru interfaces. *J. Appl. Phys.,* 2002, vol. 91, 8102 **[0036]**