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(54) **Title**: MAGNETIC STACK HAVING REFERENCE LAYERS WITH ORTHOGONAL MAGNETIZATION ORIENTATION DIRECTIONS

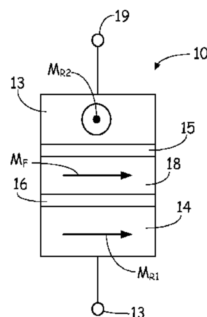

FIG. 1A

(57) **Abstract**: A magnetic cell (10) includes a ferromagnetic free layer (18) having a free magnetization orientation direction (M_F) and a first ferromagnetic pinned reference layer (14) having a first reference magnetization orientation direction (M_{R1})that is parallel or anti-parallel to the free magnetization orientation direction. A first oxide barrier layer (16) is between the ferromagnetic free layer and the first ferromagnetic pinned reference layer. The magnetic cell further includes a second ferromagnetic pinned reference layer (13) having a second reference magnetization orientation direction (M_{R2}) that is orthogonal to the first reference magnetization orientation direction. The ferromagnetic free layer is between the first ferromagnetic pinned reference layer and the second ferromagnetic pinned reference layer.

MAGNETIC STACK HAVING REFERENCE LAYERS WITH ORTHOGONAL MAGNETIZATION ORIENTATION DIRECTIONS

BACKGROUND

[01] Spin torque transfer technology, also referred to as spin electronics, combines semiconductor technology and magnetics, and is a more recent development. In spin electronics, the spin of an electron, rather than the charge, is used to indicate the presence of digital information. The digital information or data, represented as a “0” or “1”, is storable in the alignment of magnetic moments within a magnetic element. The resistance of the magnetic element depends on the moment's alignment or orientation. The stored state is read from the element by detecting the component's resistive state.

[02] The magnetic element, in general, includes a ferromagnetic pinned layer and a ferromagnetic free layer, each having a magnetization orientation that defines the resistance of the overall magnetic element. Such an element is generally referred to as a “spin tunneling junction,” “magnetic tunnel junction”, “magnetic tunnel junction cell”, and the like. When the magnetization orientations of the free layer and pinned layer are parallel, the resistance of the element is low. When the magnetization orientations of the free layer and the pinned layer are antiparallel, the resistance of the element is high.

[03] Application of spin torque transfer memory has a switching current density requirement generally at 10^6 to 10^7 A/cm^2, which leads to difficulty in integrating with a regular CMOS process. It is desirable to reduce the switching current density significantly in order to make a feasible product. Various attempts have been made.

However, there is a dilemma between switching current and data stability in spin torque transfer cells. A low switching current can reduce data retention due to thermal instability of the spin torque transfer cells. Spin torque transfer cell design that can achieve both low switching current with sufficient data retention is desired.

BRIEF SUMMARY

[04] The present disclosure relates to magnetic cells, such as a spin torque memory cell, that have magnetic two reference layers or elements that have orthogonal magnetization orientation directions. These spin torque memory cells quickly switch between a high resistance data state and a low resistance data state and include a free magnetic layer between two oxide barrier layers. The two reference layers are aligned perpendicularly.

[05] In an embodiment of this disclosure is a magnetic cell that includes a ferromagnetic free layer having a free magnetization orientation direction and a first ferromagnetic pinned reference layer having a first reference magnetization orientation direction that is parallel or anti-parallel to the free magnetization orientation direction. A first oxide barrier layer is between the ferromagnetic free layer and the first ferromagnetic pinned reference layer. The magnetic cell further includes a second ferromagnetic pinned reference layer having a second reference magnetization orientation direction that is orthogonal to the first reference magnetization orientation direction. The ferromagnetic free layer is between the first ferromagnetic pinned reference layer and the second ferromagnetic pinned reference layer.

[06] These and various other features and advantages will be apparent from a reading of the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[07] The disclosure may be more completely understood in consideration of the following detailed description of various embodiments of the disclosure in connection with the accompanying drawings, in which:

[08] **FIG. 1A** is a schematic side view diagram of a magnetic cell in a low resistance data state and with orthogonal reference layer magnetization orientations;

[09] **FIG. 1B** is a schematic side view diagram of a magnetic cell in a high resistance data state and with orthogonal reference layer magnetization orientations;

[10] **FIG. 2** is a schematic diagram of an illustrative memory unit including a memory cell and a semiconductor transistor;

[11] **FIG. 3** is a schematic diagram of an illustrative memory array;

[12] **FIG. 4** is a schematic side view diagram of another magnetic cell with orthogonal reference layer magnetization orientations; and

[13] **FIG. 5** is a schematic side view diagram of another magnetic cell with orthogonal reference layer magnetization orientations.

[14] The figures are not necessarily to scale. Like numbers used in the figures refer to like components. However, it will be understood that the use of a number to refer to a component in a given figure is not intended to limit the component in another figure labeled with the same number.

DETAILED DESCRIPTION

[15] This disclosure is directed to magnetic stacks or cells (e.g., spin torque memory (STRAM) cells) having magnetic two reference layers or elements that have orthogonal magnetization orientation directions. These spin torque memory cells quickly switch between a high resistance data state and a low resistance data state and include a free magnetic layer between two oxide barrier layers. The two reference layers are aligned perpendicularly. This data cell construction increases the write speed and improves the tunneling magneto-resistance ratio of the data cell over conventional data cells that do not have perpendicularly aligned reference layers.

[16] In the following description, reference is made to the accompanying set of drawings that form a part hereof and in which are shown by way of illustration several specific embodiments. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense. Any definitions provided herein are to facilitate understanding of certain terms used frequently herein and are not meant to limit the scope of the present disclosure.

[17] Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.

[18] As used in this specification and the appended claims, the singular forms "a", "an", and "the" encompass embodiments having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

[19] It is noted that terms such as "top", "bottom", "above, "below", etc. may be used in this disclosure. These terms should not be construed as limiting the position or orientation of a structure, but should be used as providing spatial relationship between the structures.

[20] While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples provided below.

[21] **FIG. 1A** is a schematic side view diagram of a magnetic cell **10** in a low resistance data state and with orthogonal reference layer magnetization orientations. **FIG. 1B** is a schematic side view diagram of a magnetic cell **10** in a high resistance data state and with orthogonal reference layer magnetization orientations. The magnetic tunnel junction cell **10** includes a first ferromagnetic pinned reference layer or element **14** having a first reference

$_{R1}$, a ferromagnetic free element or layer **18** having a free magnetization orientation direction $\mathbf{M_F}$ and a first tunneling barrier **16** separating the first ferromagnetic pinned reference magnetic element **14** from the ferromagnetic free element **18**. A second ferromagnetic pinned reference layer or element **13** has a second reference magnetization orientation direction $\mathbf{M_{R2}}$ that is orthogonal to the first reference magnetization orientation direction $\mathbf{M_{R1}}$. The ferromagnetic free layer is between the first ferromagnetic pinned reference layer **14** and the second ferromagnetic pinned reference layer **13**. In many embodiments, a second tunneling barrier **15** separates the second ferromagnetic pinned reference magnetic element **13** from the ferromagnetic free element **18**.

[22] These elements or layers are disposed electrically between a first electrode **13** and a second electrode **19**. While a single magnetic tunnel junction cell **10** is shown, it is understood that a plurality of magnetic tunnel junction cell **10** can be arranged in an array to form a memory array. Other layers, such as seed or capping layers, are not depicted for clarity.

[23] The ferromagnetic free element **18** has a free magnetization orientation direction $\mathbf{M_F}$ that is switchable between a high resistance data state (i.e., anti-parallel direction relative to the first ferromagnetic pinned reference magnetic element **14** magnetization orientation direction $\mathbf{M_{R1}}$ and illustrated in **FIG. 1B**) and a low resistance data state (i.e., parallel direction relative to the first ferromagnetic pinned reference magnetic element **14** magnetization orientation direction $\mathbf{M_{R1}}$ and illustrated in **FIG. 1A**). The ferromagnetic free element or layer **18,** first ferromagnetic pinned reference magnetic element **14**, and second ferromagnetic pinned reference magnetic element **13** have in-plane magnetic anisotropy.

[24] While the first ferromagnetic pinned reference element **14** is illustrated as a single layer, it is understood that this element **14** can include two or more layer such as, a ferromagnetic reference (pinned) layer and a antiferromagnetic reference (pinning) layer, where the antiferromagnetic reference layer serves to fix the magnetization of the ferromagnetic reference layer. In other embodiments, the first ferromagnetic pinned reference element **14** includes more than one ferromagnetic layer that are coupled anti-ferromagnetically to each other (e.g., synthetic antiferromagnet). The ferromagnetic reference layer can be formed of

[25] While the second ferromagnetic pinned reference element **13** is illustrated as a single layer, it is understood that this element **13** can include two or more layer such as, a ferromagnetic reference (pinned) layer and an antiferromagnetic reference (pinning) layer, where the antiferromagnetic reference layer serves to fix the magnetization of the ferromagnetic reference layer. In other embodiments, the second ferromagnetic pinned reference element **13** includes more than one ferromagnetic layer that are coupled anti-ferromagnetically to each other (e.g., synthetic antiferromagnet). The ferromagnetic reference layer can be formed of any useful material such as, for example, alloys and materials including Co, Fe, and/or Ni. Ternary alloys, such as CoFeB, may be particularly useful because of their lower moment and high polarization ratio, which are desirable for the spin-current switching. The antiferromagnetic reference layer can be formed of any useful material such as, for example, IrMn, FeMn, and/or PtMn.

[26] The ferromagnetic free element **18** can be formed of any useful soft magnetic material that allows a magnetization orientation of the ferromagnetic free element **18** to switch between a first magnetization orientation and an opposing second magnetization orientation. In many embodiments the ferromagnetic free element **18** is formed of a CoFeB material such as, $Co_{65}Fe_{30}B_{15}$ and having a magnetic saturation in a range from 1200 to 500 emu/cc, for example. The first magnetization orientation can be parallel with a magnetization orientation of the first ferromagnetic pinned reference element **14**, forming a low resistance data state or a "0" data state. The second magnetization orientation can be anti-parallel with a magnetization orientation of the first ferromagnetic pinned reference element **14**, forming a high resistance data state or a "1" data state. The ferromagnetic free layer can be formed of any useful material such as, for example, alloys and materials including Co, Fe, and/or Ni. Ternary alloys, such as CoFeB, may be particularly useful because of their lower moment and high

[27] The first and second tunneling or oxide barrier **15**, **16** is an electrically insulating and non-magnetic material. The tunneling or oxide barrier **15**, **16** can be formed of any useful electrically insulating and non-magnetic material such as, AlO, MgO, and/or TiO, for example. In some embodiments, the oxide barrier layers **15**, **16** have a thickness of about 0.5-2 nm.

[28] Electrodes **13**, **19** electrically connect the magnetic tunnel junction cell **10** to a control circuit providing read and write currents through the magnetic tunnel junction cell **10**. Resistance across the magnetic tunnel junction cell **10** is determined by the relative orientation of the magnetization vectors or magnetization orientations of ferromagnetic layers **14**, **18**. The magnetization directions of the ferromagnetic pinned reference layers **14, 13** are pinned in a predetermined direction while the magnetization direction of ferromagnetic free layer **18** is free to rotate under the influence of spin torque when a current flows through the magnetic tunnel junction cell **10**.

[29] Switching the resistance state and hence the data state of magnetic tunnel junction cell **10** via spin-torque transfer occurs when a current, passing through a magnetic layer of magnetic tunnel junction cell **10**, becomes spin polarized and imparts a spin torque on the ferromagnetic free layer **18** of magnetic tunnel junction cell **10**. When a sufficient spin torque is applied (sufficient to overcome the energy barrier **E**) to ferromagnetic free layer **18**, the magnetization orientation of the ferromagnetic free layer **18** can be switched between two opposite directions and accordingly, magnetic tunnel junction cell **10** can be switched between the parallel state (i.e., low resistance state or "0" data state) and anti-parallel state (i.e., high resistance state or "1" data state).

[30] **FIG. 2** is a schematic diagram of an illustrative memory unit including a memory unit **20** and a semiconductor transistor **22**. Memory unit **20** includes a magnetic tunnel junction cell **10**, as

[31] **FIG. 3** is a schematic diagram of an illustrative memory array **30**. Memory array **30** includes a plurality of word lines **WL** and a plurality of bit lines **BL** forming a cross-point array. At each cross-point a memory cell **10**, as described herein, is electrically coupled to word line **WL** and bit line **BL**. A select device (not shown) can be at each cross-point or at each word line **WL** and bit line **BL**.

[32] **FIG. 4** is a schematic side view diagram of another magnetic cell **40** with orthogonal reference layer magnetization orientations. The magnetic tunnel junction cell **40** includes a first ferromagnetic pinned reference layer or element **14** having a first reference magnetization orientation direction, a ferromagnetic free element or layer **18** having a free magnetization orientation direction and a first tunneling barrier **16** separating the first ferromagnetic pinned reference magnetic element **14** from the ferromagnetic free element **18**. A second ferromagnetic pinned reference layer or element **13** has a second reference magnetization orientation direction that is orthogonal to the first reference magnetization orientation direction. The ferromagnetic free layer **18** is between the first ferromagnetic pinned reference layer **14** and the second ferromagnetic pinned reference layer **13**. In many embodiments, a second tunneling barrier **15** separates the second ferromagnetic pinned reference magnetic element **13** from the ferromagnetic free element **18**.

[33] These elements or layers are disposed electrically between a first electrode **13** and a second electrode **19**. While a single magnetic tunnel junction cell **10** is shown, it is understood that a plurality of magnetic tunnel junction cell **10** can be arranged in an array to form a memory array. Other layers, such as seed or capping layers, are not depicted for clarity.

[34] The first ferromagnetic pinned reference layer or element **14** includes a first synthetic anti-ferromagnetic element **SAF1** and a first antiferromagnetic reference (pinning) layer **AFM1**. The first synthetic anti-ferromagnetic element **SAF1** includes two ferromagnetic layers **FM1**, **FM2** anti-ferromagnetically coupled and separated by a non-magnetic and electrically conducting spacer layer **SP1**. The second ferromagnetic pinned reference layer or element **13** includes a second synthetic anti-ferromagnetic element **SAF2** and a second antiferromagnetic reference (pinning) layer **AFM2**. The second synthetic anti-ferromagnetic element **SAF2** includes two ferromagnetic layers **FM3**, **FM4** anti-ferromagnetically coupled and separated by a non-magnetic and electrically conducting spacer layer **SP2**.

[35] In many embodiments the first antiferromagnetic reference (pinning) layer **AFM1** has a different material composition than the second antiferromagnetic reference (pinning) layer **AFM2**. The first antiferromagnetic reference (pinning) layer **AFM1** can have a greater blocking temperature than the second antiferromagnetic reference (pinning) layer **AFM2**. Thus the first ferromagnetic pinned reference layer or element **14** can have its magnetization orientation set at a higher temperature than the later formed second ferromagnetic pinned reference layer or element **13**. Then the second ferromagnetic pinned reference layer or element **13** can have its magnetization orientation set at a lower temperature than the prior formed first ferromagnetic pinned reference layer or element **14**.

[36] **FIG. 5** is a schematic side view diagram of another magnetic cell **50** with orthogonal reference layer magnetization orientations. The magnetic tunnel junction cell **50** includes a first ferromagnetic pinned reference layer or element **14** having a first reference magnetization orientation direction, a ferromagnetic free element or layer **18** having a free magnetization orientation direction and a first tunneling barrier **16** separating the first ferromagnetic pinned reference magnetic element **14** from the ferromagnetic free element **18**. A second ferromagnetic pinned reference layer or element **13** has a second reference magnetization orientation direction that is orthogonal to the first reference magnetization orientation direction. The ferromagnetic free layer **18** is between the first ferromagnetic pinned reference layer **14** and the second ferromagnetic pinned reference layer **13**. In many

[37] These elements or layers are disposed electrically between a first electrode **13** and a second electrode **19**. While a single magnetic tunnel junction cell **10** is shown, it is understood that a plurality of magnetic tunnel junction cell **10** can be arranged in an array to form a memory array. Other layers, such as seed or capping layers, are not depicted for clarity.

[38] The first ferromagnetic pinned reference layer or element **14** includes a first synthetic anti-ferromagnetic element **SAF1** and a antiferromagnetic reference (pinning) layer **AFM**. The first synthetic anti-ferromagnetic element **SAF1** includes two ferromagnetic layers **FM1**, **FM2** anti-ferromagnetically coupled and separated by a non-magnetic and electrically conducting spacer layer **SP1**. The second ferromagnetic pinned reference layer or element **13** includes a second synthetic anti-ferromagnetic element **SAF2** and a permanent magnet **PM**. The second synthetic anti-ferromagnetic element **SAF2** includes two ferromagnetic layers **FM3**, **FM4** anti-ferromagnetically coupled and separated by a non-magnetic and electrically conducting spacer layer **SP2**. The magnetization orientation of the first ferromagnetic pinned reference layer or element **14** can be set with a magnetic set anneal and the magnetization orientation of the second ferromagnetic pinned reference layer or element **13** can be set with the permanent magnet **PM**.

[39] The various structures of this disclosure may be made by thin film techniques such as chemical vapor deposition (CVD), physical vapor deposition (PVD), sputter deposition, and atomic layer deposition (ALD).

[40] Thus, embodiments of the MAGNETIC STACK HAVING REFERENCE LAYERS WITH ORTHOGONAL MAGNETIZATION ORIENTATION DIRECTIONS are disclosed. The implementations described above and other implementations are within the scope of the following claims. One skilled in the art will appreciate that the present disclosure can be practiced with embodiments other than those disclosed. The disclosed embodiments are

[41] The use of numerical identifiers, such as “first”, “second”, etc. in the claims that follow is for purposes of identification and providing antecedent basis. Unless content clearly dictates otherwise, it should not be implied that a numerical identifier refers to the number of such elements required to be present in a device, system or apparatus. For example, if a device includes a first layer, it should not be implied that a second layer is required in that device.

MAGNETIC STACK HAVING REFERENCE LAYERS WITH ORTHOGONAL MAGNETIZATION ORIENTATION DIRECTIONS

What is claimed is:

1. A magnetic cell comprising:
a ferromagnetic free layer having a free magnetization orientation direction;
a first ferromagnetic pinned reference layer having a first reference magnetization orientation direction that is parallel or anti-parallel to the free magnetization orientation direction;
a first oxide barrier layer between the ferromagnetic free layer and the first ferromagnetic pinned reference layer; and
a second ferromagnetic pinned reference layer having a second reference magnetization orientation direction that is orthogonal to the first reference magnetization orientation direction, the ferromagnetic free layer between the first ferromagnetic pinned reference layer and the second ferromagnetic pinned reference layer.

2. The magnetic cell of claim 1 wherein the ferromagnetic free layer, first ferromagnetic pinned reference layer, and second ferromagnetic pinned reference layer, have in-plane magnetic anisotropy.

3. The magnetic cell of claim 1 further comprising a second oxide barrier layer between the ferromagnetic free layer and the second ferromagnetic pinned reference layer.

4. The magnetic cell of claim 1 wherein the first ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element.

5. The magnetic cell of claim 1 wherein the second ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element.

6. The magnetic cell of claim 1 wherein the ferromagnetic free layer switches between a high resistance data state and a low resistance data state due to spin torque transfer induced by a current passing through the magnetic cell.

7. The magnetic cell of claim 4 wherein the second ferromagnetic pinned reference layer comprises a permanent magnetic

8. The magnetic cell of claim 1 wherein the first ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element having a first blocking temperature and the second ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element having a second blocking temperature that is less then the first blocking temperature.

9. The magnetic cell of claim 1 wherein the free magnetization orientation direction is orthogonal to the second reference magnetization orientation direction.

10. A spin torque transfer magnetic cell comprising:

a ferromagnetic free layer having an in-plane free magnetization orientation direction that switches between a high resistance data state and a low resistance data state due to spin torque transfer induced by a current passing through the magnetic cell;

a first ferromagnetic pinned reference layer having a first reference magnetization orientation direction that is parallel or anti-parallel to the free magnetization orientation direction;

a first oxide barrier layer between the ferromagnetic free layer and the first ferromagnetic pinned reference layer;

a second ferromagnetic pinned reference layer having an in-plane second reference magnetization orientation direction that is orthogonal to the free magnetization orientation direction; and

a second oxide barrier layer between the ferromagnetic free layer and the second ferromagnetic pinned reference layer.

11. The spin torque transfer magnetic cell of claim 10 wherein the first ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element.

12. The spin torque transfer magnetic cell of claim 10 wherein the second ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element.

13. The spin torque transfer magnetic cell of claim 11 wherein the second ferromagnetic pinned reference layer comprises a permanent magnetic

14. The spin torque transfer magnetic cell of claim 10 wherein the first ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element having a first blocking temperature and the second ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element having a second blocking temperature that is less then the first blocking temperature.

15. The spin torque transfer magnetic cell of claim 10 wherein the free magnetization orientation direction is orthogonal to the second reference magnetization orientation direction.

16. A spin torque transfer magnetic cell comprising:

a ferromagnetic free layer having an in-plane free magnetization orientation direction that switches between a high resistance data state and a low resistance data state due to spin torque transfer induced by a current passing through the magnetic cell;

a first ferromagnetic pinned reference layer having a first reference magnetization orientation direction that is parallel or anti-parallel to the free magnetization orientation direction;

a first oxide barrier layer between the ferromagnetic free layer and the first ferromagnetic pinned reference layer;

a second ferromagnetic pinned reference layer having an in-plane second reference magnetization orientation direction that is orthogonal to the first reference magnetization orientation direction; and

a second oxide barrier layer between the ferromagnetic free layer and the second ferromagnetic pinned reference layer.

17. The spin torque transfer magnetic cell of claim 16 wherein the first ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element.

18. The spin torque transfer magnetic cell of claim 16 wherein the second ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element.

19. The spin torque transfer magnetic cell of claim 17 wherein the second ferromagnetic pinned reference layer comprises a permanent magnetic

20. The spin torque transfer magnetic cell of claim 16 wherein the first ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element having a first blocking temperature and the second ferromagnetic pinned reference layer comprises a synthetic anti-ferromagnetic element having a second blocking temperature that is less then the first blocking temperature.

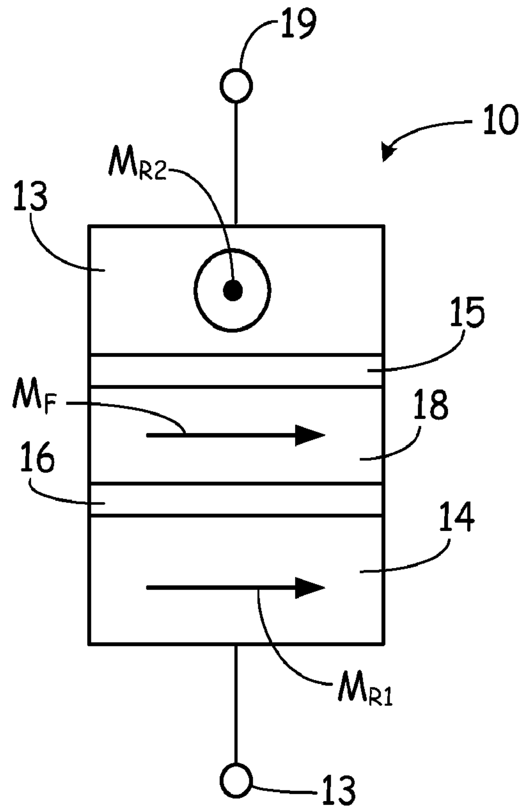

FIG. 1A

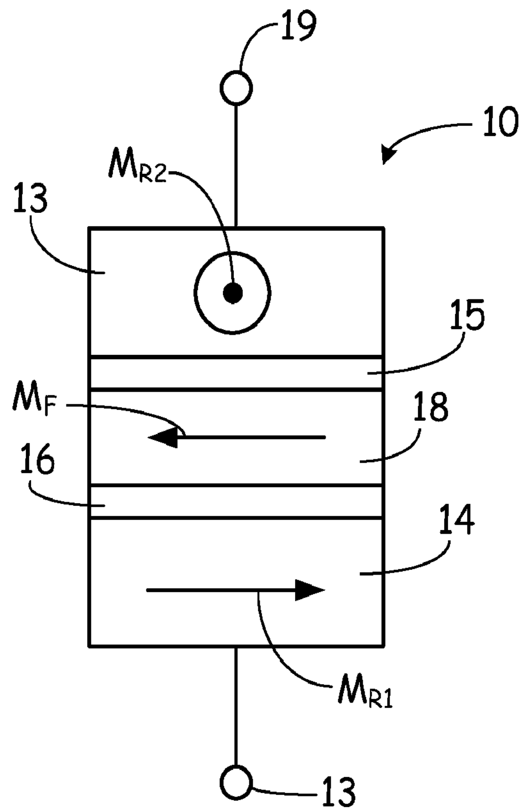

FIG. 1B

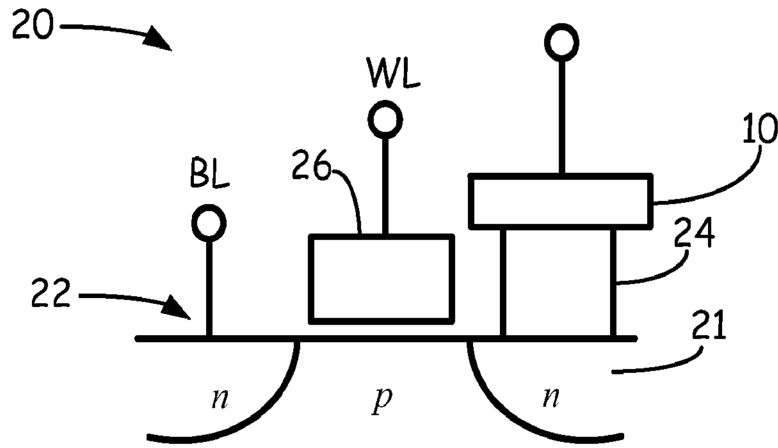

FIG. 2

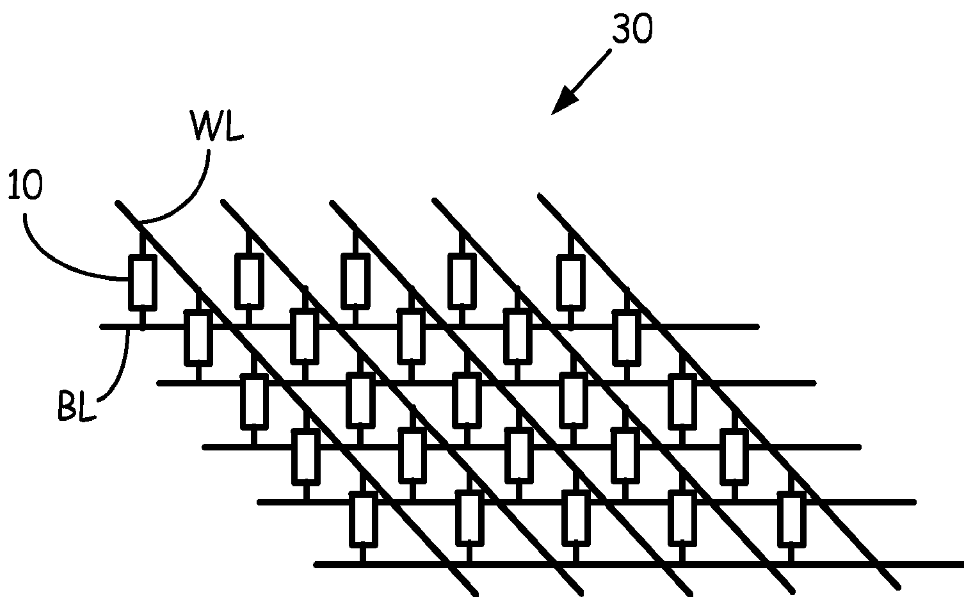

FIG. 3

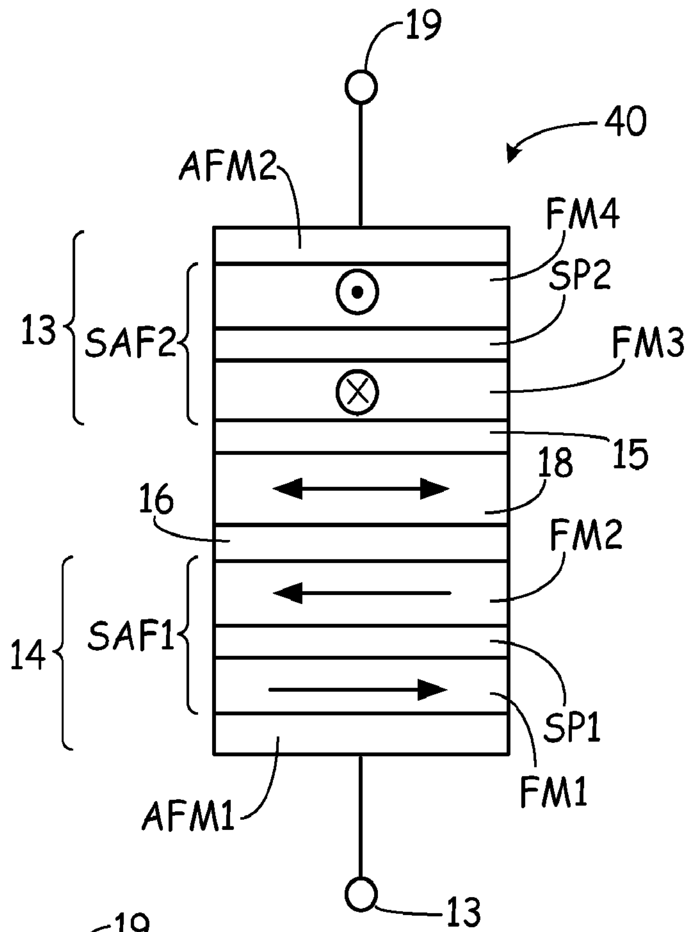

FIG. 4

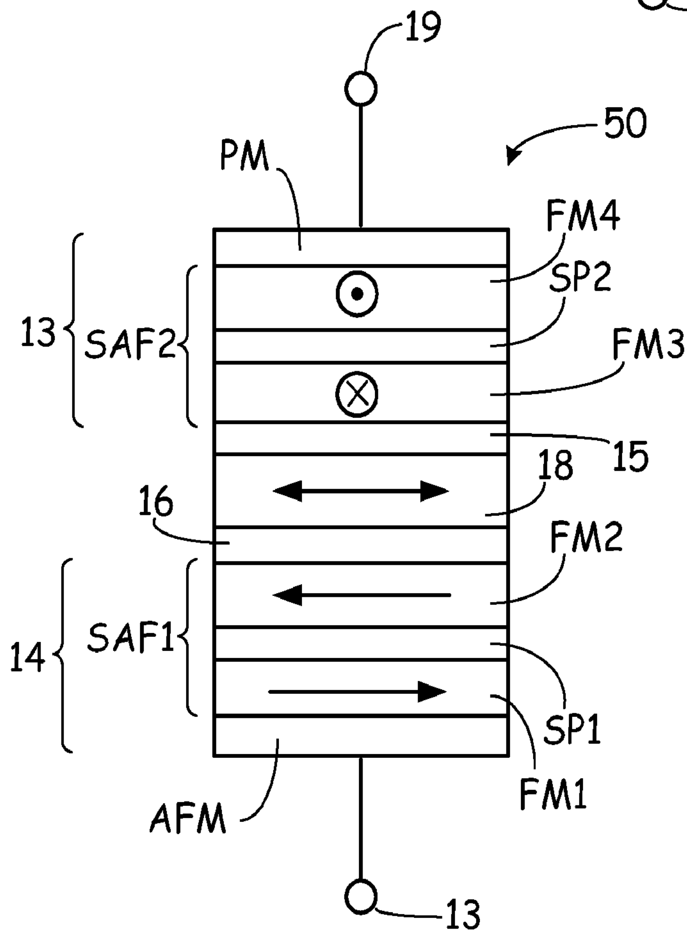

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/041300

A. CLASSIFICATION OF SUBJECT MATTER
INV. G11C11/16 H01L43/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G11C H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/297220 A1 (YOSHIKAWA MASATOSHI [JP] ET AL) 27 December 2007 (2007-12-27) paragraphs [0134] - [0137]; figure 13	1-20
X	US 2008/291721 A1 (APALKOV DMYTRO [US] ET AL) 27 November 2008 (2008-11-27) paragraphs [0050] - [0059]; figure 11	1-20
X	US 2007/002504 A1 (HUAI YIMING [US] ET AL) 4 January 2007 (2007-01-04) paragraphs [0043] - [0048]; figure 5	1-5,7-9

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
3 September 2010	04/10/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Trifonov, Antoniy

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2010/041300

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