

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
27 April 2006 (27.04.2006)

PCT

(10) International Publication Number
WO 2006/044031 A1

(51) International Patent Classification:

H01F 10/32 (2006.01) *H01L 27/22* (2006.01)
G01R 33/09 (2006.01)

(US). **DOOGUE, Michael, C.** [US/US]; 115 N. Adams Street, Manchester, NH 03104 (US).

(21) International Application Number:

PCT/US2005/029982

(74) Agents: **CROWLEY, Judith, C.** et al.; Daly, Crowley, Mofford & Durkee, LLP, Suite 301A, 354A Turnpike Street, Canton, Massachusetts 02021 (US).

(22) International Filing Date: 22 August 2005 (22.08.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/962,889 12 October 2004 (12.10.2004) US

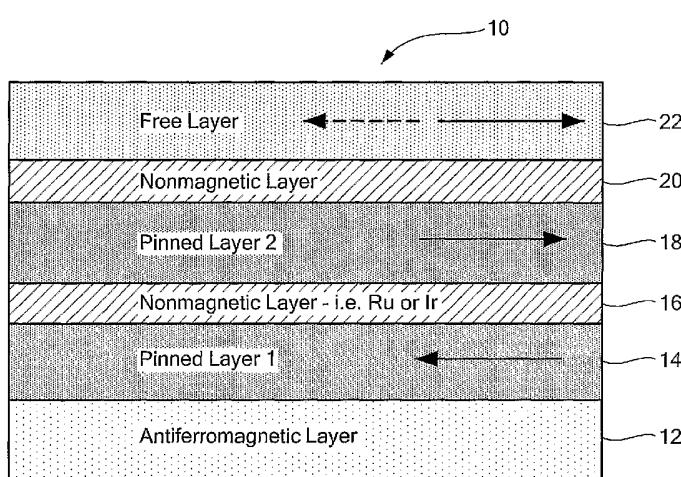
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(71) Applicant (for all designated States except US): **ALLE-GRO MICROSYSTEMS, INC.** [US/US]; 115 Northeast Cutoff, Worcester, Massachusetts 01615-0036 (US).

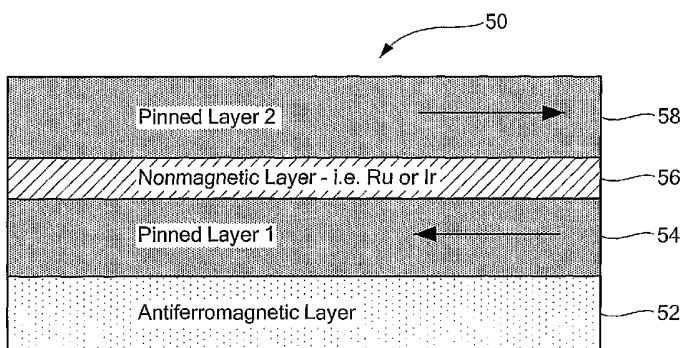
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,

[Continued on next page]

(54) Title: RESISTOR HAVING A PREDETERMINED TEMPERATURE COEFFICIENT



(57) Abstract: A material stack (50) has an electrical resistance generally the same in the presence of a magnetic field and in the presence of no magnetic field. The electrical resistance of the material stack (50) has a temperature coefficient generally the same as a magnetoresistance element (10).



WO 2006/044031 A1



FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

RESISTOR HAVING A PREDETERMINED TEMPERATURE COEFFICIENT

FIELD OF THE INVENTION

5 This invention relates generally to electrical resistors and, in particular, to an electrical resistor having a predetermined temperature coefficient selected in accordance with a temperature coefficient of a magnetoresistance element.

BACKGROUND OF THE INVENTION

10 Magnetoresistance elements are known to be manufactured in a variety of configurations, including, but not limited to giant magnetoresistance (GMR) elements, and anisotropic magnetoresistance (AMR) elements.

15 Referring to FIG. 1, a prior art GMR element 10 is formed having a plurality of layers, including an antiferromagnetic layer 12, a first pinned layer 14, a first non-magnetic layer 16, a second pinned layer 18, a second non-magnetic layer 20, and a free layer 22. In one conventional GMR element, the antiferromagnetic layer 12 comprises PtMn, the first and second pinned layers 14, 18 are comprised of CoFe, the first and second non-magnetic layers 16, 20 are comprised of a selected one of Ir and Ru, and the free layer 22 is 20 comprised of NiFe. However, one of ordinary skill in the art will understand that other layers and materials can be provided in a GMR element.

25 The magnetoresistance element is used in a variety of applications, including, but not limited to current sensors responsive to an electrical current, proximity detectors responsive to proximity of a ferromagnetic object, for example, ferrous gear teeth, and magnetic field sensors responsive to a magnetic field external to the magnetic field sensor.

30 In each of the above applications, one or more magnetoresistance elements can be coupled either in a simple resistor divider or in a Wheatstone bridge arrangement. In either the resistor divider arrangement or in the Wheatstone bridge arrangement, one or more fixed resistors can also be used along with the one or more magnetoresistance elements.

The resistor divider and the Wheatstone bridge arrangement each provide an output voltage signal proportional to a magnetic field experienced by the one or more magnetoresistance elements.

5 The magnetoresistance element has an electrical resistance that changes generally in proportion to a magnetic field in a direction of a maximum response axis of the magnetoresistance element. However, the electrical resistance changes not only in proportion to the magnetic field, but also in proportion to a temperature of the magnetoresistance element. The affect of temperature can be characterized as a
10 temperature coefficient in units of resistance per degree temperature.

It will be recognized that the temperature coefficient of the magnetoresistance element, when used in a resistor divider or in a Wheatstone bridge arrangement, can adversely affect the expected output voltage signal of the resistor divider or the Wheatstone bridge. In particular, if the one or more resistors used in conjunction with the one or more magnetoresistance elements do not have the same temperature coefficient as the one or more magnetoresistance elements, then the output voltage signal of the resistor divider and the Wheatstone bridge arrangement will be responsive not only to a magnetic field, but also to temperature changes.

20 An open loop arrangement of a current sensor, a proximity detector, or a magnetic field sensor is a known circuit arrangement in which one or more magnetic field sensing elements are exposed to a magnetic field generated external to the circuit. A closed loop arrangement of a current sensor, a proximity detector, or a magnetic field sensor is a known circuit arrangement in which one or more magnetic field sensing elements are exposed to both a magnetic field generated external to the circuit and also to an opposing magnetic field generated by the circuit, so as to keep the resulting magnetic field in the vicinity of the one or more magnetic field sensing elements near zero. The closed loop arrangement has certain known advantages over the open loop arrangement, including, but not limited to, improved linearity. Conversely, the open loop arrangement has certain known advantages over the closed loop arrangement, including, but not limited to, improved response time.

SUMMARY OF THE INVENTION

The present invention provides a material stack forming a resistor having a temperature coefficient the same as or similar to the temperature coefficient of a giant magnetoresistance (GMR) element.

In accordance with the present invention, a material stack includes an antiferromagnetic layer, a first pinned layer disposed over the antiferromagnetic layer, a non-magnetic layer disposed over the pinned layer, and a second pinned layer disposed over the non-magnetic layer. The material stack has an electrical resistance generally the same in the presence of a magnetic field and in the presence of no magnetic field, and the electrical resistance has a temperature coefficient generally the same as a temperature coefficient of a magnetoresistance element.

With this particular arrangement, the material stack provides an electrical resistance generally the same as that of a magnetoresistance element even when exposed to temperature variations.

In accordance with another aspect of the present invention, a circuit includes a giant magnetoresistance element and a material stack as described above. In particular embodiments, the circuit can be a voltage divider, a Wheatstone bridge arrangement, a current sensor responsive to an electrical current, a proximity detector responsive to proximity of a ferromagnetic object, and a magnetic field sensor responsive to magnetic fields external to the circuit.

25

With this particular arrangement, the circuit can provide an output signal responsive to a magnetic field but generally unresponsive to temperature changes.

BRIEF DESCRIPTION OF THE DRAWINGS

30 The foregoing features of the invention, as well as the invention itself may be more fully understood from the following detailed description of the drawings, in which:

FIG. 1 is a diagram showing layers of a prior art giant magnetoresistance (GMR) element;

FIG. 2 is a diagram showing layers of a material stack forming a resistor in accordance with the present invention;

5 FIG. 3 is a schematic diagram of a resistor divider having a resistor as in FIG. 2;
FIG. 4 a schematic diagram of a Wheatstone bridge having two resistors as in FIG. 2;
FIG. 5 is a pictorial of a current sensor having two resistors as in FIG. 2; and
FIG. 6 is a pictorial of a magnetic field sensor having two resistors as in FIG. 2.

10 DETAILED DESCRIPTION OF THE INVENTION

Before describing the resistor of the present invention, some introductory concepts and terminology are explained. As used herein, the term "disposed over" is used to refer to a relative placement, without suggesting a requirement for up or down orientation. For example, a first layer in combination with a second layer disposed over the first layer is not 15 meant to require that the second layer be above the first layer. Merely by flipping the above-described combination, it can be seen that the second layer can be either above or below the first layer. The term "disposed over" also does not suggest a requirement for physical contact. For example, the above-described first and second layers need not be touching.

20 Referring to FIG. 2, an exemplary resistor 50 having a predetermined temperature coefficient is provided as a material stack including an antiferromagnetic layer 52, a first pinned layer 54, a non-magnetic layer 56, and a second pinned layer 58. The antiferromagnetic layer 52 comprises PtMn, the first and second pinned layers 54, 58 are 25 comprised of CoFe, and the non-magnetic layer 56 comprises a selected one of Ir and Ru. It will be recognized that the resistor 50 has most of the layers of the magnetoresistance element 10 of FIG. 1. However, the second non-magnetic layer 20 and the free layer 22 of FIG. 1 are not present in the resistor 50. Therefore, the resistor 50 is not responsive to a magnetic field. However, the resistor 50 has a temperature coefficient the same as or 30 similar to the temperature coefficient of a magnetoresistance element such as the magnetoresistance element 10 of FIG. 1. In an alternate embodiment, a non-magnetic layer

(not shown) is provided on top of the second pinned layer 58.

If the resistor 50 has the same width and depth dimensions as the magnetoresistance element 10, the resistor 50 may have a nominal resistance that is different than the nominal 5 resistance of the magnetoresistance element 10 at any particular temperature, while having a temperature coefficient that is generally the same as that of the magnetoresistance element 10. However, in other embodiments, it will be recognized that that the width and the depth of the resistor 50 can be made to be different than the width and depth of the magnetoresistance element 10 in order to achieve a nominal resistance that is generally the 10 same as that of the magnetoresistance element, while also retaining a temperature coefficient that is generally the same as that of the magnetoresistance element 10. However, in other embodiments, the width and the depth to the resistor 50 can be made to have any dimensions within manufacturing capabilities to achieve any desired resistance.

15 While the particular material stack 50 having particular layers formed from particular materials is described, it should be recognized that other material stacks can be provided to match other GMR structures, other than the GMR element 10 of FIG. 1, merely by eliminating the associated free layer and an associated non-magnetic layer from the GMR structure in much the same way as provided by the material stack 50.

20 It should be recognized that, in other embodiments, the non-magnetic layer 56 can be comprised of a plurality of non-magnetic layers, each of the plurality of non-magnetic layers formed from the same or a different material. Thus, as used herein, the term "non-magnetic layer" is used to refer to both a single non-magnetic layer and also to a plurality 25 of non-magnetic layers.

In another embodiment, a second non-magnetic layer (not shown) can be provided adjacent to the second pinned layer 58. The second non-magnetic layer can be the same as or similar to the second non-magnetic layer 20 of FIG. 1. In this case, it should be 30 recognized that other material stacks can be provided to match other GMR structures, other than the GMR element 10 of FIG. 1, merely by eliminating the associated free layer from

the GMR structure.

In other embodiments, one or more other layers (not shown) can be interposed between the layers 52-58.

5

Referring now to FIG. 3, a voltage divider circuit 70 includes a resistor 72 and a magnetoresistance element 74. The resistor 72 is provided as a material stack as shown, for example, as the resistor 50 of FIG. 2.

10

Since the resistor 72 has the same temperature coefficient as the magnetoresistance element 74, an output voltage, V_{out} , of the resistor divider 70 is generally not responsive to temperature. However, the output voltage, V_{out} , is responsive to a magnetic field in the vicinity of the magnetoresistance element 74.

15

Referring now to FIG. 4, a Wheatstone bridge circuit 100 includes first and second resistors 102, 104, respectively and first and second magnetoresistance elements 106, 108, respectively. The first and second resistors 102, 104 are each provided as a respective material stack as shown, for example, as the resistor 50 of FIG. 2.

20

Since the resistors 102, 104 have the same temperature coefficient as the magnetoresistance elements 106, 108, an output voltage difference between V_{out+} and V_{out-} of the Wheatstone bridge circuit 100 is generally not responsive to temperature. However, the output voltage difference is responsive to a magnetic field in which the magnetoresistance elements 106, 108 are placed.

25

Referring now to FIG. 5, an electronic circuit 150 in the form of a closed loop current sensor is shown. The current sensor 150 contains first and second magnetoresistance elements 152, 155, respectively, and first and second resistors 168, 165, respectively. The resistors 168, 165 are each fabricated as a material stack in accordance with the resistor 50 of FIG. 2. The magnetoresistance elements 152, 155 and resistors 168, 165 are disposed over a surface 154a of a silicon substrate 154. A secondary conductor

164 is also disposed over the surface 154a of the silicon substrate 154 proximate to the magnetoresistance elements 152, 155. A further, primary, conductor 158 is isolated from the silicon substrate 154 by a dielectric 156, as shown.

5 In operation, a primary current 160 flows through the primary conductor 158, thereby generating a primary magnetic field 162. A secondary current 166 flows through the secondary conductor 164, thereby generating a secondary magnetic field 165 at the conductor portion 164a. Because the secondary current 166 passes through the secondary conductor portion 164a in a direction opposite to the primary current 160 passing through 10 the primary conductor 158, the secondary magnetic field 165 is opposite in direction to the primary magnetic field 162.

A first voltage source 174, here integrated in the silicon substrate 154, provides a current through the first resistor 168 and the first magnetoresistance element 152 and, 15 therefore, generates a voltage at node 170 having a magnitude related to the magnetic field experienced by the first magnetoresistance element 152. Similarly, a second voltage source 159, also here integrated in the silicon substrate 154, provides a current through the second magnetoresistance element 155 and the second resistor 165 and, therefore, generates a voltage at node 171 having a magnitude related to the magnetic field experienced by the 20 second magnetoresistance element 155. In one particular embodiment, the first and the second voltage sources 174, 159 supply the same voltage and are provided by a single voltage source. An amplifier 172, coupled to the nodes 170, 171, provides the secondary current 166 to the secondary conductor 164 in response to the voltage difference between the nodes 170 and 171.

25 The first magnetoresistance element 152 has a response axis 153, and the second magnetoresistance element 155 has a response axis 157. The magnetoresistance elements 152, 155 are polarized in the same direction. The secondary current 166 passes by the first and second magnetoresistance elements 152, 155 in the same direction. Therefore, when 30 exposed to the secondary magnetic field 165 the voltages at nodes 170, 171 move in response to the magnetic field in opposite directions.

In the particular arrangement shown, the node 170 is coupled to a negative input of the amplifier 172 and the node 171 is coupled to a positive input of the amplifier 172. The amplifier 172 generates the secondary current 166 in proportion to the voltage difference 5 between nodes 170 and 171. The voltage at the node 171 tends to increase in response to the primary magnetic field 162 and the voltage at the node 170 tends to decrease.

However, as described above, the secondary magnetic field 165 tends to oppose the primary magnetic field 162.

10 The magnetic field experienced by the first magnetoresistance element 152 is the sum of the secondary magnetic field 165 and the primary magnetic field 162 along the response axis 153. Similarly, the magnetic field experienced by the second magnetoresistance element 155 is the sum of the secondary magnetic field 165 and the primary magnetic field 162 along the response axes 157. Since the secondary magnetic 15 field 165 is opposite in direction to the primary magnetic field 162, the secondary magnetic field 165 tends to cancel the primary magnetic field 162.

20 The amplifier 172 provides the secondary current 166 at a level necessary to generate the secondary magnetic field 165 sufficient to cancel the primary magnetic field 162 along the response axes 153, 157 so that the total magnetic field experienced by the first and second magnetoresistance elements 152, 155 is substantially zero gauss.

25 The secondary current 166 passes through a resistor 176, thereby generating an output voltage, V_{out} , between output terminals 178, 180 in proportion to the secondary current 166. With this arrangement, the output voltage, V_{out} , is proportional to the secondary magnetic field 165, and is thus proportional to the primary current 160, as desired.

30 It will be understood that the resistor 176 has a resistance with a temperature coefficient. One of ordinary skill in the art will recognize techniques that can be used to reduce the affect of this temperature coefficient. For example, an operational amplifier

circuit with a properly matched feedback compensation network can be used to reduce the affect.

The two magnetoresistance elements 152, 155 and the two resistors 168, 165
5 provide a Wheatstone bridge circuit as shown, for example, in FIG. 4. It should be appreciated that, since the resistors 168, 165 are provided as material stacks in accordance with the resistor 50 of FIG. 2, having a temperature coefficient essentially the same as the temperature coefficients of the magnetoresistance elements 152, 155, the voltage difference between the nodes 170, 171 will be essentially unaffected by temperature changes, and
10 therefore, the output voltage, V_{out} , will be similarly unaffected.

It will be appreciated by those of ordinary skill in the art that while the closed loop current sensor 150 has two magnetoresistance elements 152, 155, and two resistors 168, 125, alternative closed loop current sensors can be provided with more than two or fewer
15 than two magnetoresistance elements and more than two or fewer than two resistors.

While the silicon substrate 154 is shown, it will also be apparent that other substrate materials, including but not limited to, SiGe, GaAs, or InGaAs can be used in place of the silicon substrate 154 without departing from the present invention. Also, in an
20 alternate embodiment, the silicon substrate 154 can be replaced by another substrate (not shown) comprised of a ceramic material, including but not limited to Al_2O_3 . In this particular embodiment, a magnetoresistance element and a resistor formed as a material stack in accordance with the resistor 50 of FIG. 2 can be fabricated on the ceramic substrate. Circuitry similar to the amplifier 171 can be formed, for example, on a separate
25 substrate (not shown), for example, on a silicon substrate, which can be coupled with wire bonds or the like to the ceramic substrate.

Referring now to FIG. 6, an electronic circuit 200 in the form of a magnetic field sensor includes a silicon substrate 204, first and second magnetoresistance elements 202, 205, respectively and first and second resistors 218, 215, respectively, disposed over a surface 204a of the silicon substrate 204. A conductor 214 is also disposed over the

surface 204a of the silicon substrate 204 proximate to the magnetoresistance elements. The first and second resistors 218, 215 are provided as material stacks in accordance with the material stack 50 of FIG. 2. The magnetic field sensor 200 is adapted to sense an external magnetic field 240 and to provide an output signal, V_{out} , proportional to the magnetic field 240.

5 In operation, a current 216 flows through a first portion 214a of conductor 214, thereby generating a magnetic field 217. The magnetic field 217 is in the opposite direction with respect to the external magnetic field 240. Thus, the magnetic field 217 10 tends to cancel the external magnetic field 240.

A first voltage source 224, here integrated in the silicon substrate 204, provides a current through the first resistor 218 and the first magnetoresistance element 202, and therefore, generates a voltage at node 220 having a magnitude related to the magnetic field 15 experienced by the first magnetoresistance element 202. Similarly, a second voltage source 209, also here integrated in the silicon substrate 204, provides a current through the second magnetoresistance element 205 and the second resistor 215, and therefore, generates a voltage at node 221 having a magnitude related to the magnetic field experienced by the second magnetoresistance element 205. In one embodiment, the first and the second 20 voltage sources 224, 209 supply the same voltage and are provided by a single voltage source. An amplifier 221 provides the secondary current 216 to the secondary conductor 214 in response to a voltage difference between the nodes 220 and 221.

25 The first magnetoresistance element 202 has a response axis 203 and the second magnetoresistance element 205 has a response axis 207. The first and second magnetoresistance elements 202, 205 are polarized in the same direction. The current 216 passes by the first and second magnetoresistance elements 202, 205, in the same direction. Therefore, when exposed to the magnetic field 217, the voltage at the node 220 moves in one voltage direction and the voltage at the node 221 moves in the other voltage direction.

30

In the particular arrangement shown, the node 220 is coupled to a negative input of

the amplifier 222 and the node 221 is coupled to a positive input of the amplifier 222. The voltage at the node 221 tends to increase while the voltage at the node 220 tends to decrease in response to the external magnetic field 240. However, as described above, the magnetic field 217 tends to oppose the external magnetic field 240.

5

The first and second magnetoresistance elements 202, 205 are oriented such that the response axes 203, 207 are aligned with the external magnetic field 240 and also with the magnetic field 217. The magnetic field experienced by the first and second magnetoresistance elements 202, 205 is the sum of the magnetic field 217 and the external magnetic field 240 along the response axes 203, 207 respectively. Since the magnetic field 217 is opposite in direction to the external magnetic field 240 along the response axes 203, 207 the magnetic field 217 tends to cancel the external magnetic field 240. The amplifier 221 generates the current 216 in proportion to the voltage difference between the node 220 and the node 221. Thus, the amplifier 222 provides the current 216 at a level necessary to generate the magnetic field 217 sufficient to cancel the external magnetic field 240 along the response axes 203, 207 so that the total magnetic field experienced by each of the magnetoresistance elements 202, 205 is substantially zero gauss.

20 The current 216 passes through a resistor 226 thereby generating an output voltage, Vout, between output terminals 228, 230 in proportion to the current 216. With this arrangement, the output voltage, Vout, is proportional to the magnetic field 217 necessary to cancel the external magnetic field 240, and is thus proportional to the external magnetic field 240, as desired.

25 The two magnetoresistance elements 202, 205 and the two resistors 218, 215 provide a Wheatstone bridge circuit as shown, for example, in FIG. 4. It should be appreciated that, since the resistors 218, 215 are provided as material stacks in accordance with the resistor 50 of FIG. 2, having a temperature coefficient essentially the same as the temperature coefficients of the magnetoresistance elements 202, 205, the voltage difference 30 between the nodes 220, 221 will be essentially unaffected by temperature changes, and therefore, the output voltage, Vout, will be similarly unaffected.

It should be recognized that while the closed loop magnetic field sensor 200 is shown having two magnetoresistance elements 202, 205 and two resistors 218, 215, in an alternate arrangement, a closed loop magnetic field sensor can have more than two or fewer 5 than two magnetoresistance elements and more than two or fewer than two resistors.

While the silicon substrate 204 is shown, it will also be apparent that other substrate materials, including but not limited to, SiGe, GaAs, or InGaAs can be used in place of the silicon substrate 204 without departing from the present invention. Also, in an 10 alternate embodiment, the silicon substrate 204 can be replaced by another substrate (not shown) comprised of a ceramic material, including but not limited to Al_2O_3 . In this particular embodiment, a magnetoresistance element and a resistor formed as a material stack in accordance with the resistor 50 of FIG. 2 can be fabricated on the ceramic substrate. Circuitry similar to the amplifier 222 can be formed, for example, on a separate 15 substrate (not shown), for example, on a silicon substrate, which can be coupled with wire bonds or the like to the ceramic substrate.

While a closed loop current sensor 150 is shown in FIG. 5 and a closed loop magnetic field sensor 200 is shown in FIG. 6, it will be recognized that open loop 20 arrangements can be provided having resistors formed as material stacks in accordance with the material stack 50 of FIG. 2. Furthermore, a proximity detector, either closed loop or open loop, which is responsive to an external magnetic field generated, for example, by ferrous gear teeth, can also be provided having resistors formed as material stacks in accordance with the material stack 50 of FIG. 2.

25

All references cited herein are hereby incorporated herein by reference in their entirety.

Having described preferred embodiments of the invention, it will now become 30 apparent to one of ordinary skill in the art that other embodiments incorporating their concepts may be used. It is felt therefore that these embodiments should not be limited to

disclosed embodiments, but rather should be limited only by the spirit and scope of the appended claims.

What is claimed is:

CLAIMS

1. A material stack comprising:
 - an antiferromagnetic layer;
 - 5 a first pinned layer disposed over the antiferromagnetic layer;
 - a non-magnetic layer disposed over the pinned layer; and
 - 10 a second pinned layer disposed over the non-magnetic layer, wherein the material stack has an electrical resistance generally the same in the presence of a magnetic field and in the presence of no magnetic field, and wherein the electrical resistance has a temperature coefficient generally the same as a temperature coefficient of a magnetoresistance element.
2. The material stack of Claim 1, wherein the electrical resistance of the material stack also has generally the same resistance as an electrical resistance of the magnetoresistance element.
15
3. The material stack of Claim 1, wherein the antiferromagnetic layer comprises PtMn, the first and second pinned layers are comprised of CoFe, and the non-magnetic layer comprises a selected one of Ir and Ru.
20
4. A circuit comprising:
 - a magnetoresistance element; and
 - a material stack coupled to the magnetoresistance element, comprising:
 - an antiferromagnetic layer;
 - 25 a first pinned layer disposed over the antiferromagnetic layer;
 - a non-magnetic layer disposed over the pinned layer; and
 - a second pinned layer disposed over the non-magnetic layer, wherein the material stack has an electrical resistance generally the same in the presence of a magnetic field and in the presence of no magnetic field, and wherein the electrical resistance has a temperature coefficient generally the same as a temperature coefficient of a magnetoresistance element.

5. The circuit of Claim 4, wherein the electrical resistance of the material stack also has generally the same resistance as an electrical resistance of the magnetoresistance element.

5

6. The circuit of Claim 4, wherein the antiferromagnetic layer comprises PtMn, the first and second pinned layers are comprised of CoFe, and the non-magnetic layer comprises a selected one of Ir and Ru.

10 7. The circuit of Claim 4, wherein the circuit provides a selected one of a voltage divider and a Wheatstone bridge.

15 8. The circuit of Claim 4, wherein the circuit is provided in a selected one of a current sensor, a proximity detector, and a magnetic field sensor, wherein the current sensor is responsive to an electrical current, the proximity detector is responsive to proximity of a ferromagnetic article and the magnetic field sensor is responsive to a magnetic field external to the magnetic field sensor.

9. The circuit of Claim 4, wherein the circuit is provided in a current sensor
20 responsive to an electrical current.

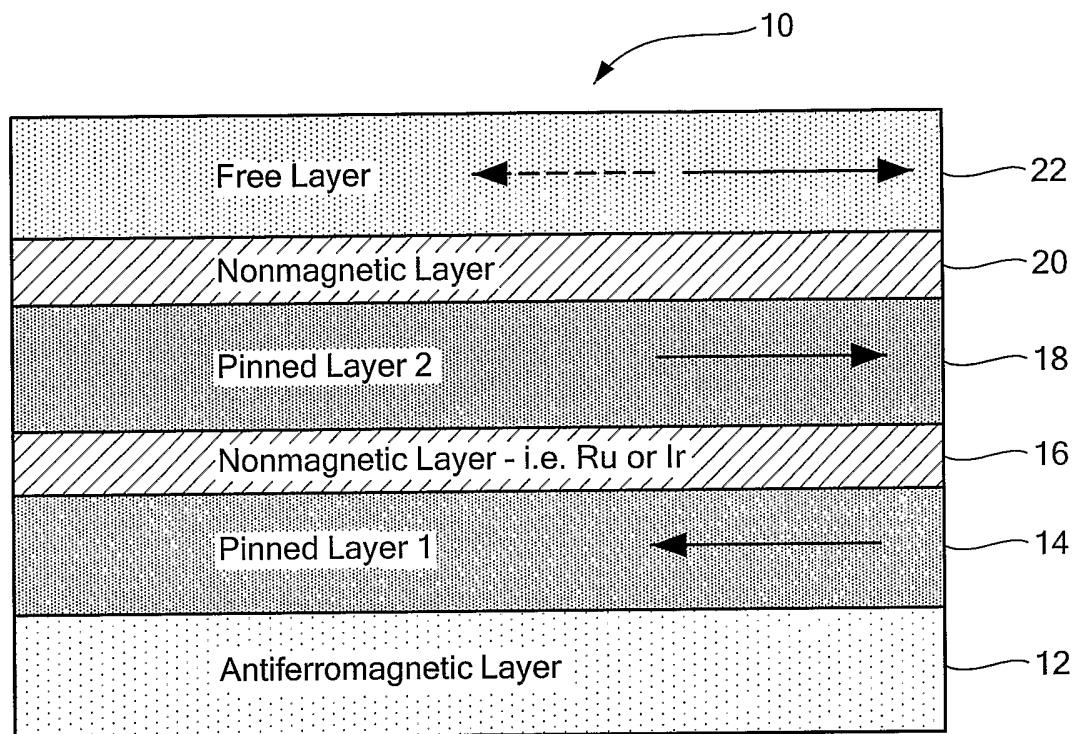
10. The circuit of Claim 4, wherein the circuit is provided in a magnetic field sensor responsive to a magnetic field external to the magnetic field sensor.

25 11. The circuit of Claim 4, wherein the circuit is provided in a proximity detector responsive to proximity of a ferromagnetic article.

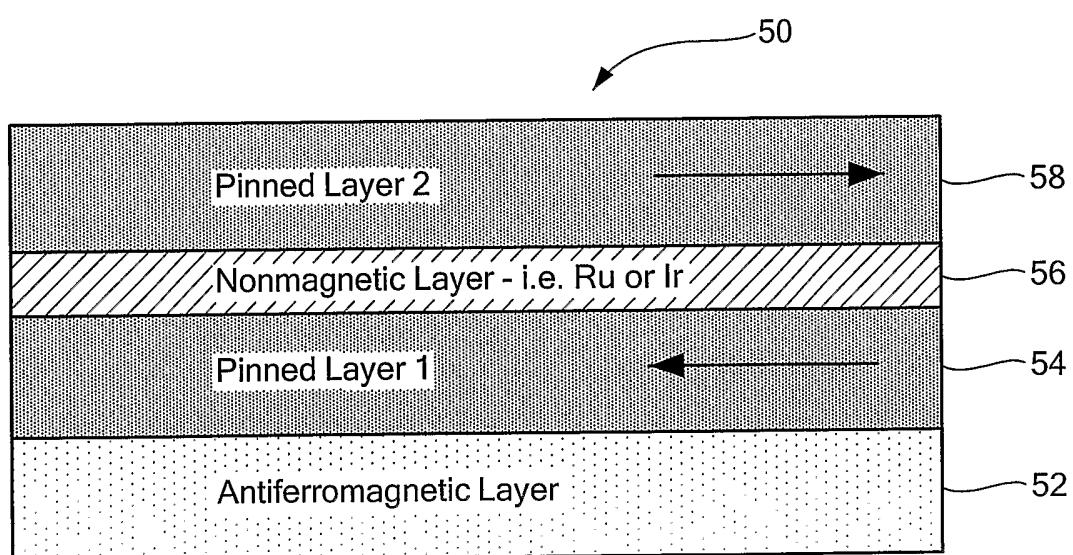
12. The circuit of Claim 4, wherein the magnetoresistance element is provided as a giant magnetoresistance (GMR) element.

30

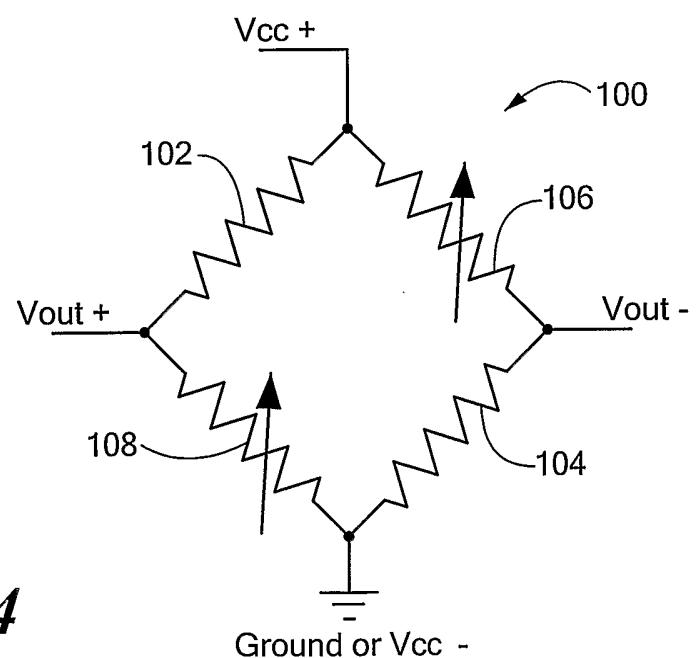
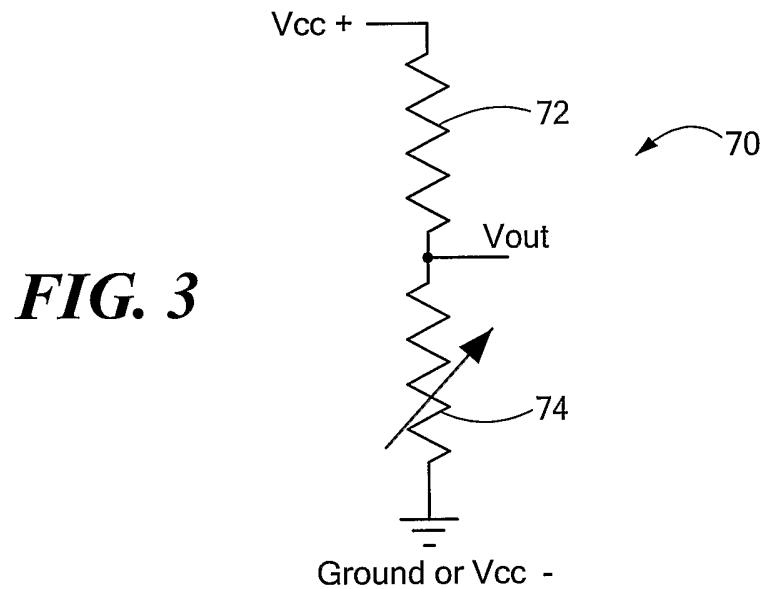
1/4

**FIG. 1**

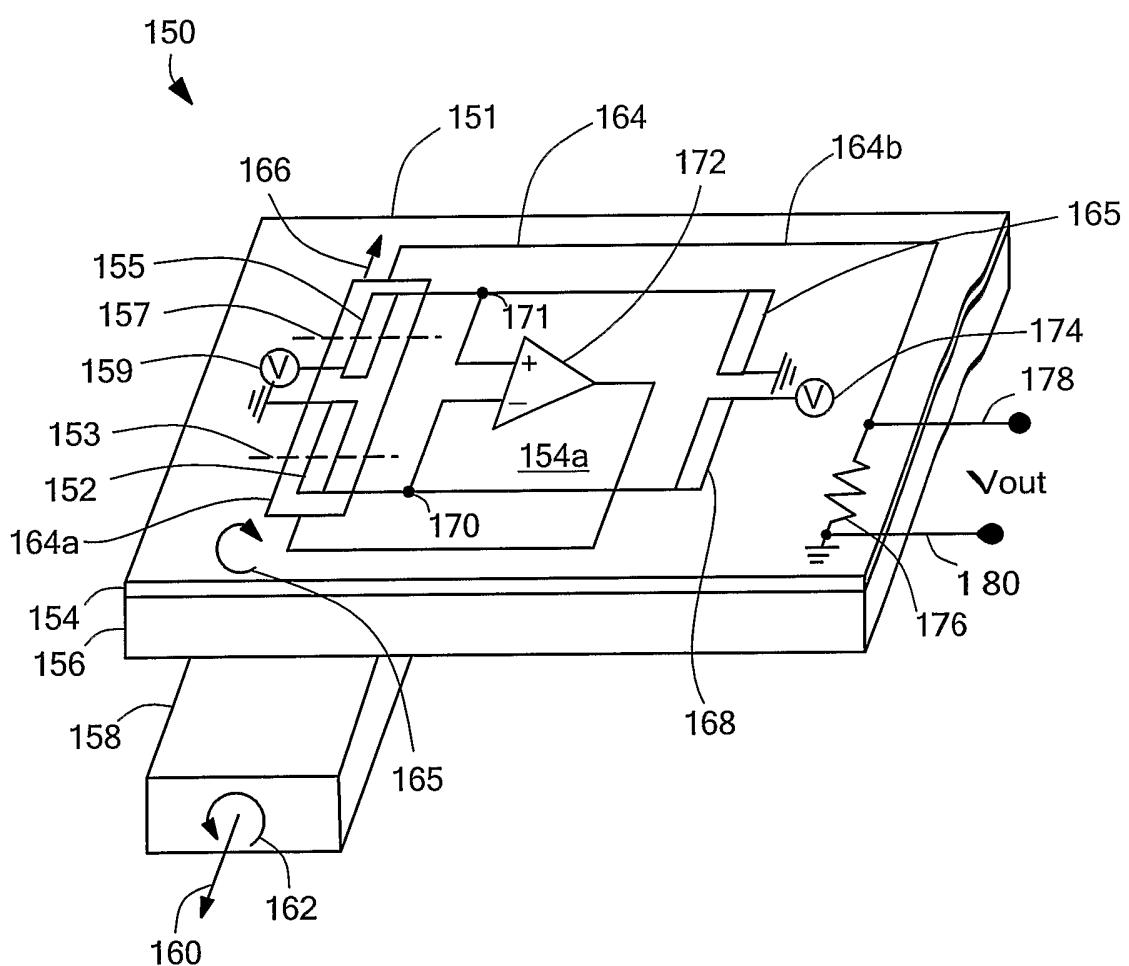
PRIOR ART

**FIG. 2**

2/4



3/4

**FIG. 5**

4/4

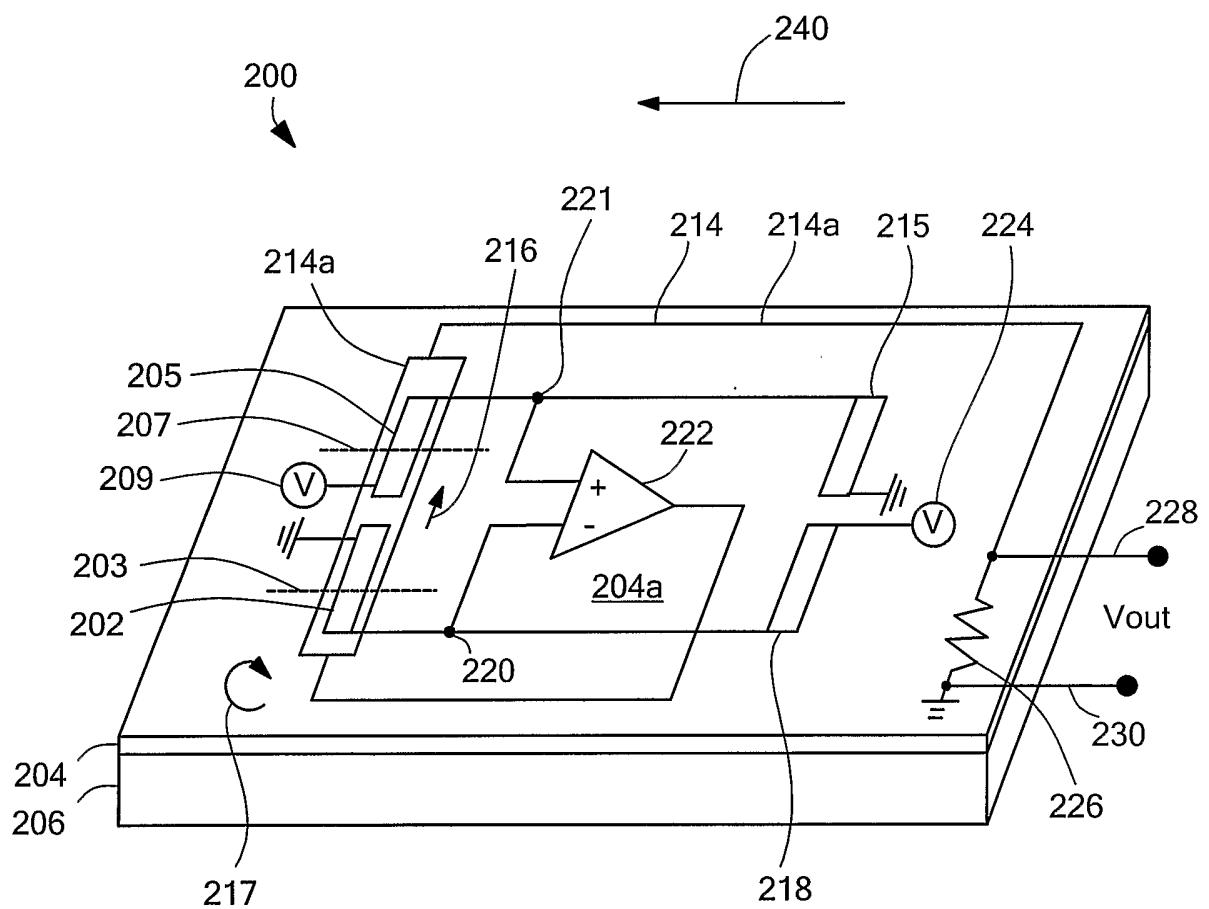


FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No

. . . /US2005/029982

A. CLASSIFICATION OF SUBJECT MATTER
 H01F10/32 G01R33/09 H01L27/22

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)
 H01F G01R 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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002/180433 A1 (VAN ZON JOANNES BAPTIST ADRIANUS DIONISIUS ET AL) 5 December 2002 (2002-12-05) claim 20 paragraphs '0011!, '0057!, '0062! figures 1,2 -----	1-12
X	US 6 501 678 B1 (LENSSEN KARS-MICHIEL HUBERT ET AL) 31 December 2002 (2002-12-31) claims 1,4,5 column 1, line 50 - line 56 column 2, line 8 - line 15 column 11, line 53 - line 57 column 13, line 51 - line 65 figures 1,4 ----- -/-	1-12

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority, claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

& document member of the same patent family

Date of the actual completion of the international search

10 January 2006

Date of mailing of the international search report

18/01/2006

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Stichauer, L

INTERNATIONAL SEARCH REPORT

National Application No

/US2005/029982

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/023064 A1 (EHRESMANN ARNO ET AL) 5 February 2004 (2004-02-05) claim 1 paragraphs '0001!, '0009!, '0022! figure 6 -----	1-8,10, 12
P,X	WO 2004/109725 A (KONINKLIJKE PHILIPS ELECTRONICS N.V; RUIGROK, JACOBUS, J., M; VAN ZON,) 16 December 2004 (2004-12-16) claims 1,6-8,11,12,14 page 8, line 13 - line 30 page 9, line 21 - line 23; table 1 page 10, line 22 - line 25 -----	1-8,10, 12

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

.~./US2005/029982

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
US 2002180433	A1	05-12-2002	CN WO JP	1513120 A 02099451 A2 2004533120 T		14-07-2004 12-12-2002 28-10-2004
US 6501678	B1	31-12-2002	WO JP	0079298 A2 2003502876 T		28-12-2000 21-01-2003
US 2004023064	A1	05-02-2004	DE WO EP	10028640 A1 0194963 A2 1287372 A2		20-12-2001 13-12-2001 05-03-2003
WO 2004109725	A	16-12-2004		NONE		