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(54) METHOD FOR MANUFACTURING MAGNETIC SENSOR AND MAGNETIC SENSOR

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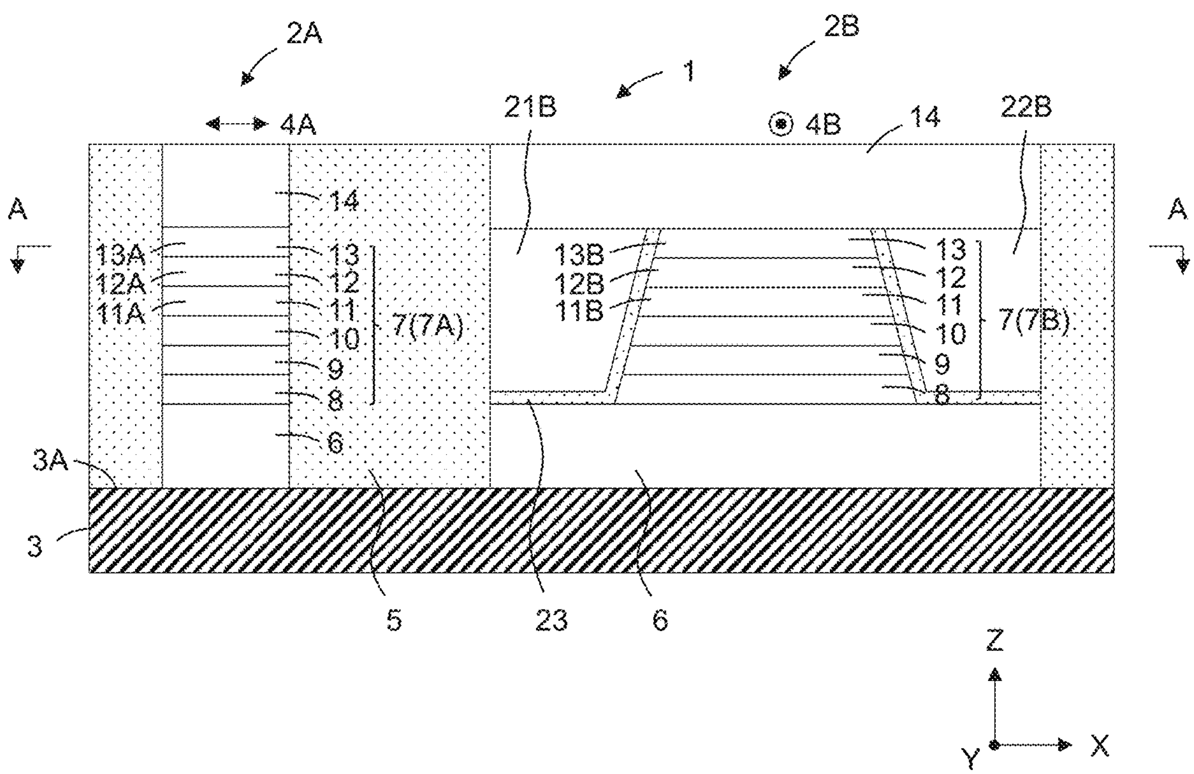
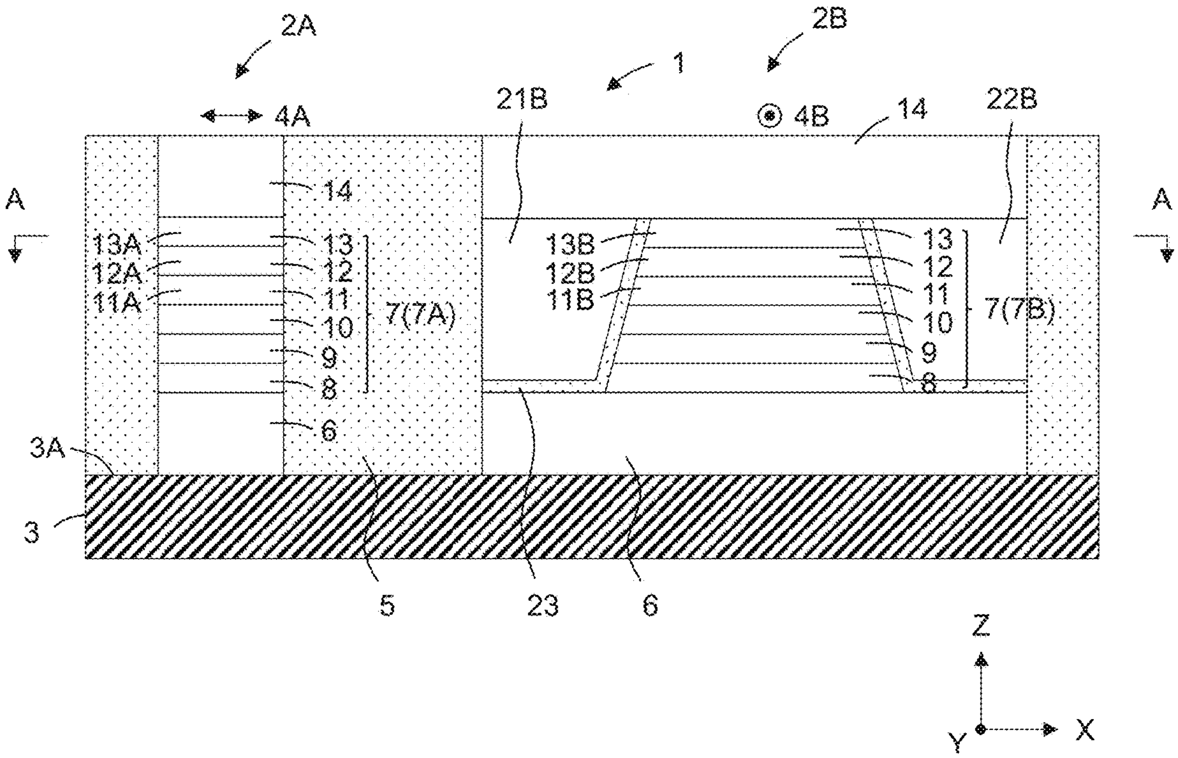
(57) **ABSTRACT**

A magnetic sensor comprises: a first magnetic field sensing element that includes a magnetic field sensing axis parallel to a first direction, two first magnet layers that are arranged in a second direction perpendicular to the first direction, and a first soft magnetic layer that is sandwiched between the two first magnet layers in the second direction; a second magnetic field sensing element that includes a magnetic field sensing axis parallel to the second direction, two second magnet layers that are arranged in the first direction, and a second soft magnetic layer that is sandwiched between the two second magnet layers in the first direction; and a substrate that supports the first and second magnetic field sensing elements. The first and second magnet layers are magnetized by applying an external magnetic field from a direction that is at approximately equal angles to each of the first and second directions.

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4A
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11A
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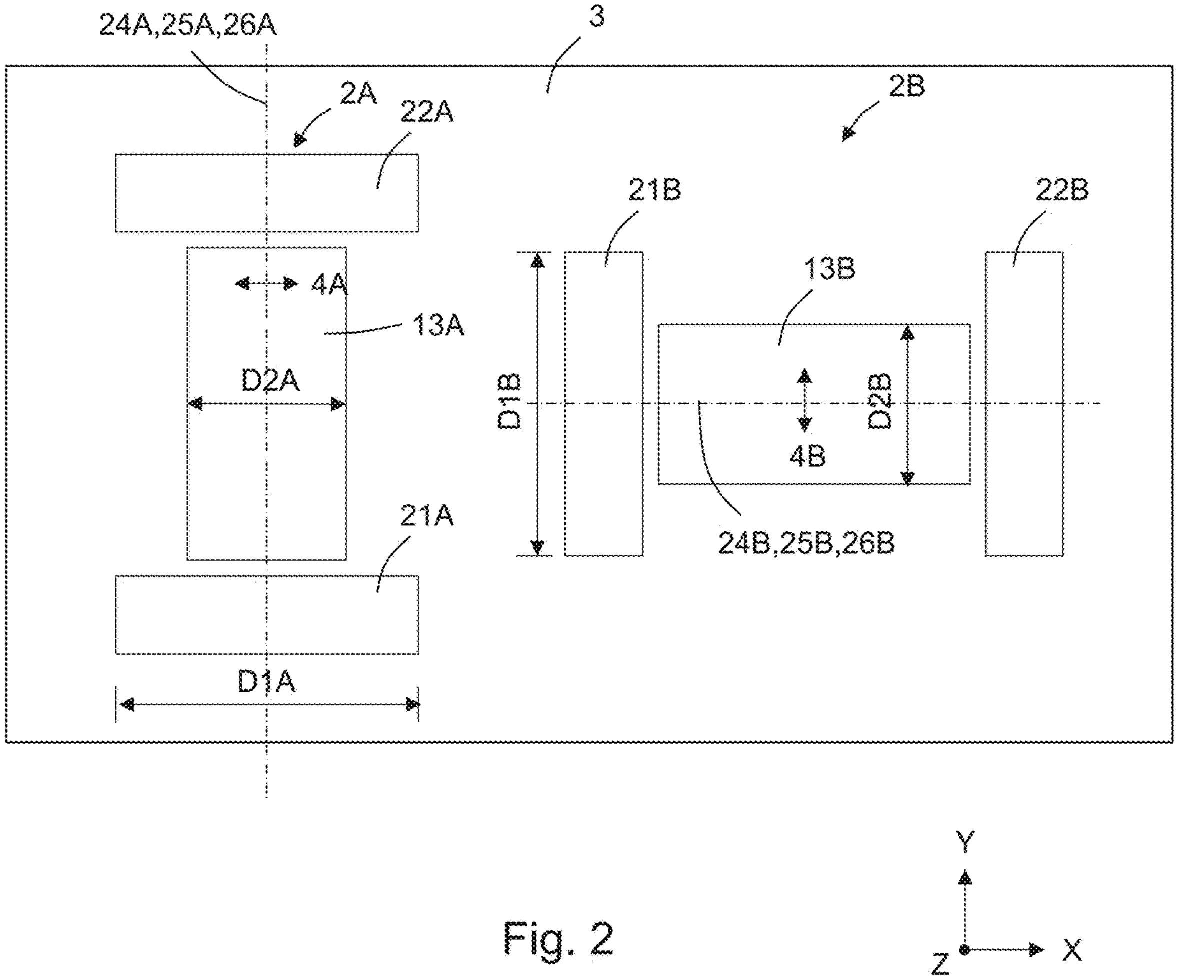
8
6
7(7A)
13B
12B
11B
13
12
11
10
9
8
7(7B)
3A
3
5
23
6
Z
Y
X

Fig. 1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2A
22A
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21B
22B
4A
13B
13A
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D1B
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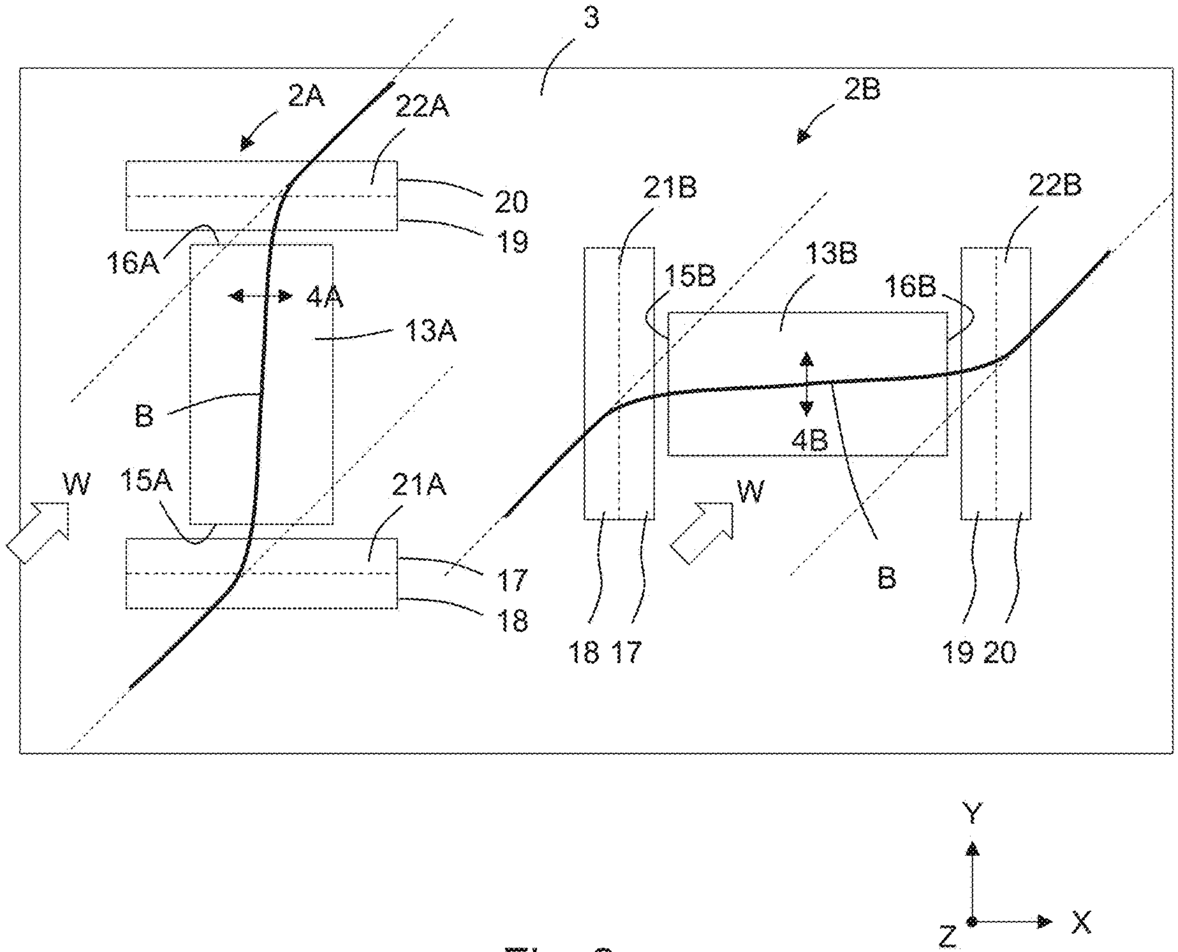
21A
24B,25B,26B
D1A
Y
Z
X

Fig. 2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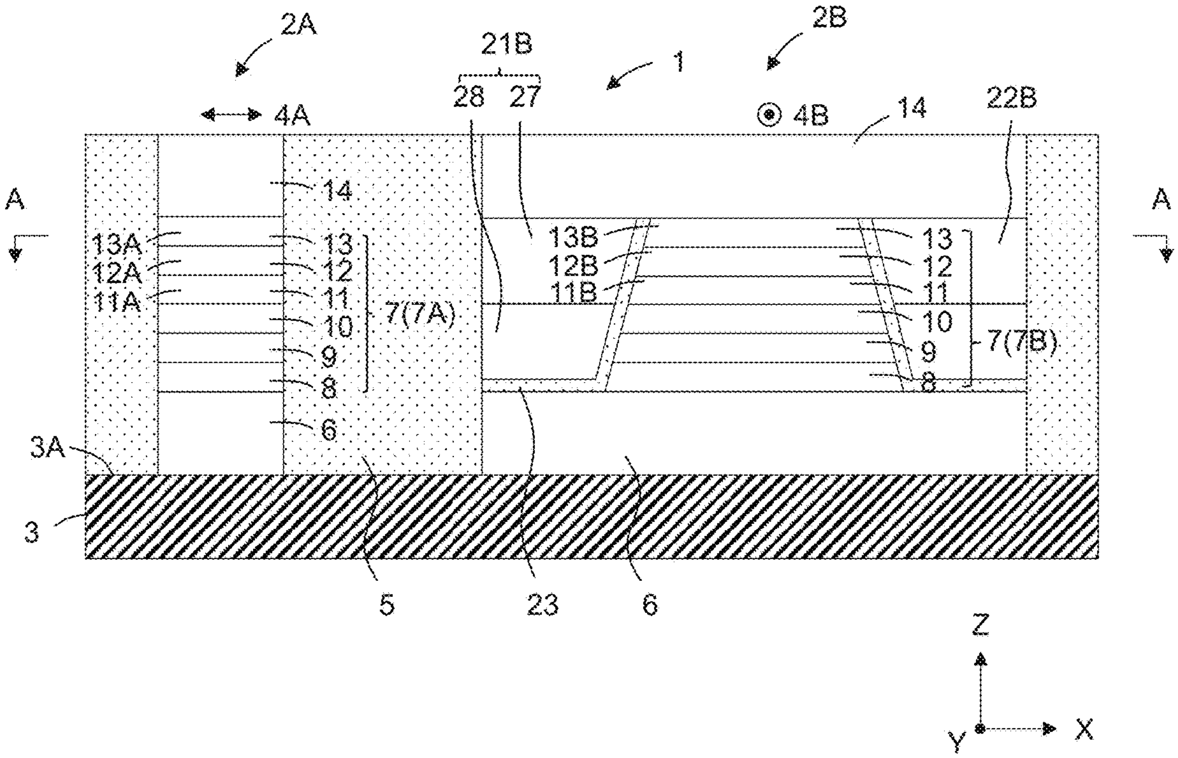
22A
20
19
16A
4A
13A
B
W
15A
21A
17
18
2B
21B
22B
15B
13B
16B
4B
W
B
18 17
19 20
Y
Z
X

Fig. 3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2B
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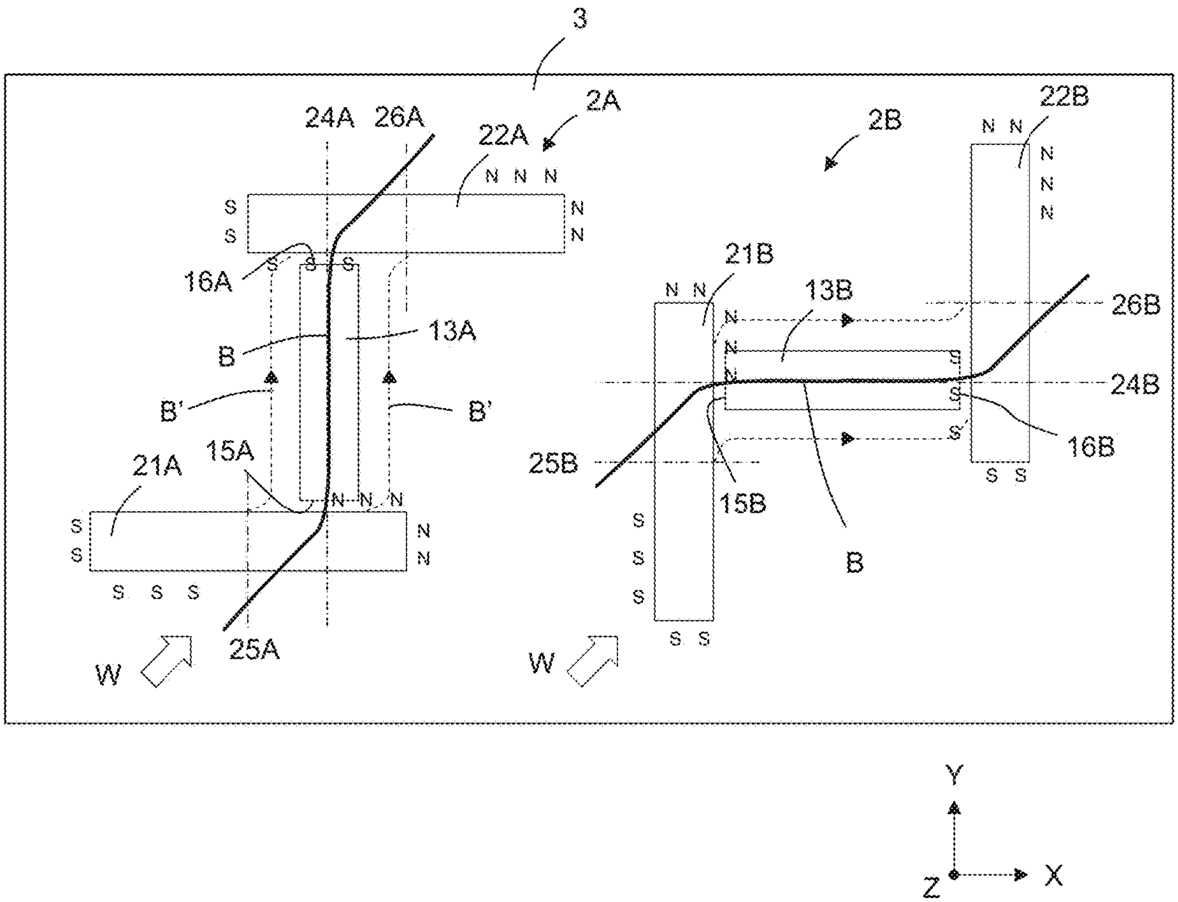
27
4A
4B
14
22B
A
A
14
13A
12A
11A
13
12
11
10
9
8
6
7(7A)
13B
12B
11B
13
12
11
10
9
8
7(7B)
3A
3
5
23
6
Z
Y
X

Fig. 4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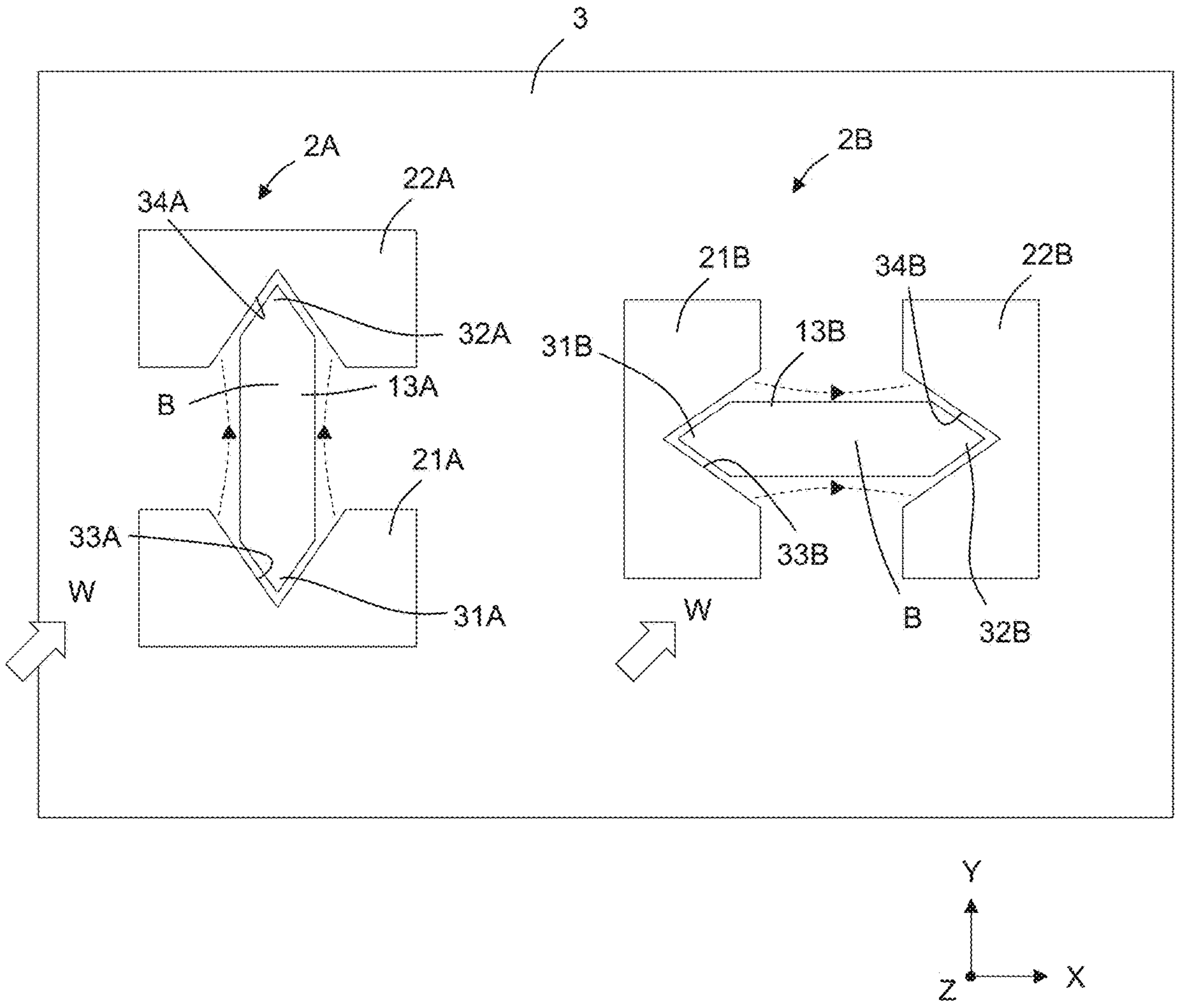
2A
2B
24A
26A
22A
22B
21A
21B
13A
13B
15A
15B
16A
16B
B
B'
24B
25A
25B
26B
W
N
S
Y
X
Z

Fig. 5



3
2A
22A
34A
32A
13A
B
21A
33A
31A
W
2B
21B
34B
22B
31B
13B
33B
B
32B
W
Y
Z
X

Fig. 6

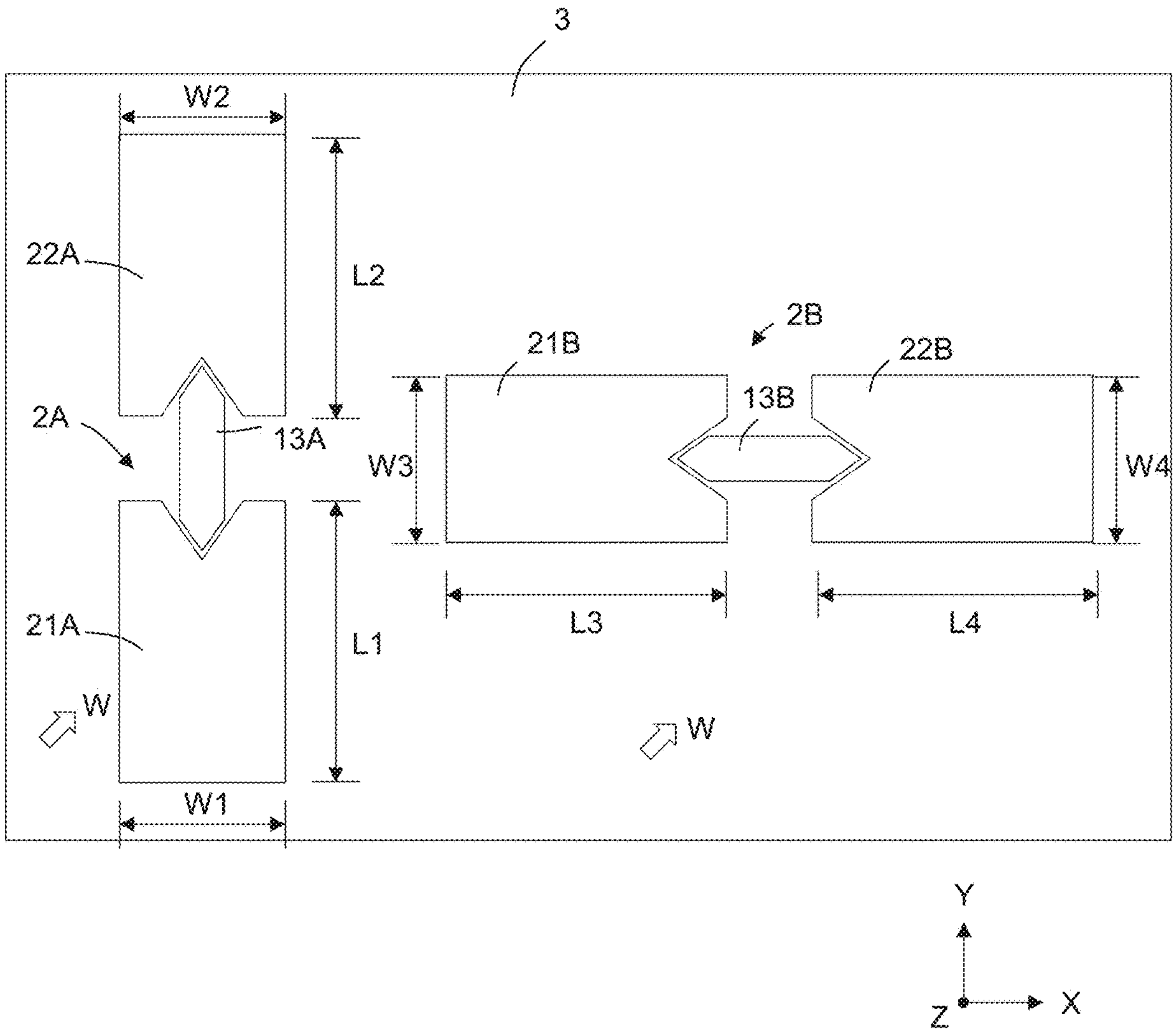


Fig. 7

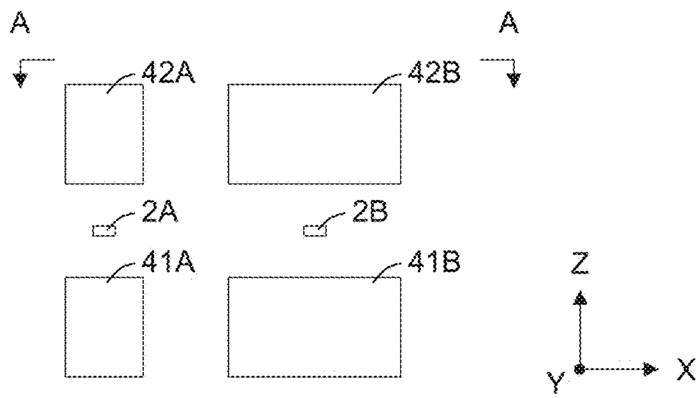

A
A
42A
42B
2A
2B
41A
41B
Z
Y
X

Fig. 8A

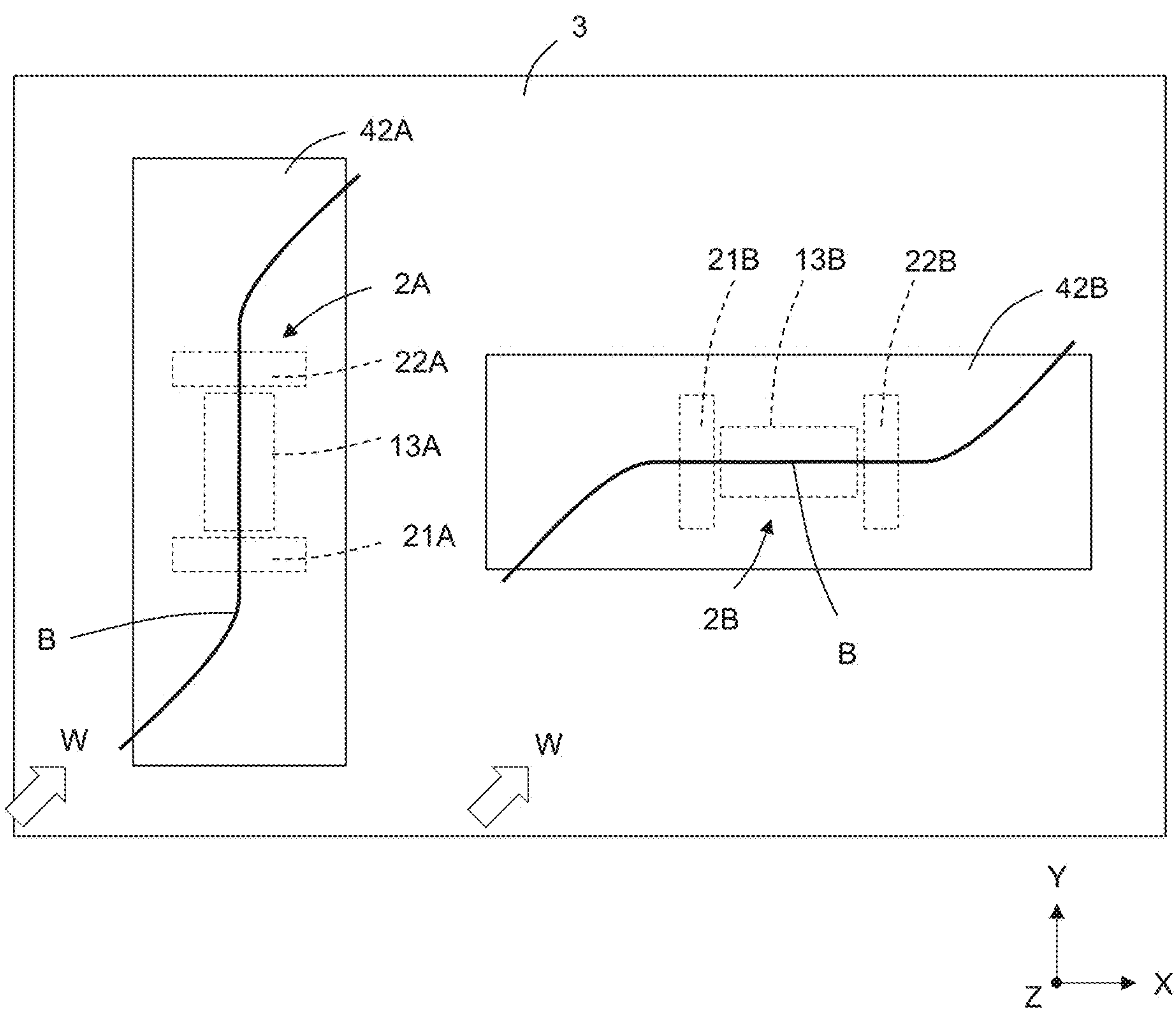

3
42A
2A
22A
13A
21A
B
W
W
21B
13B
22B
42B
2B
B
Y
Z
X

Fig. 8B

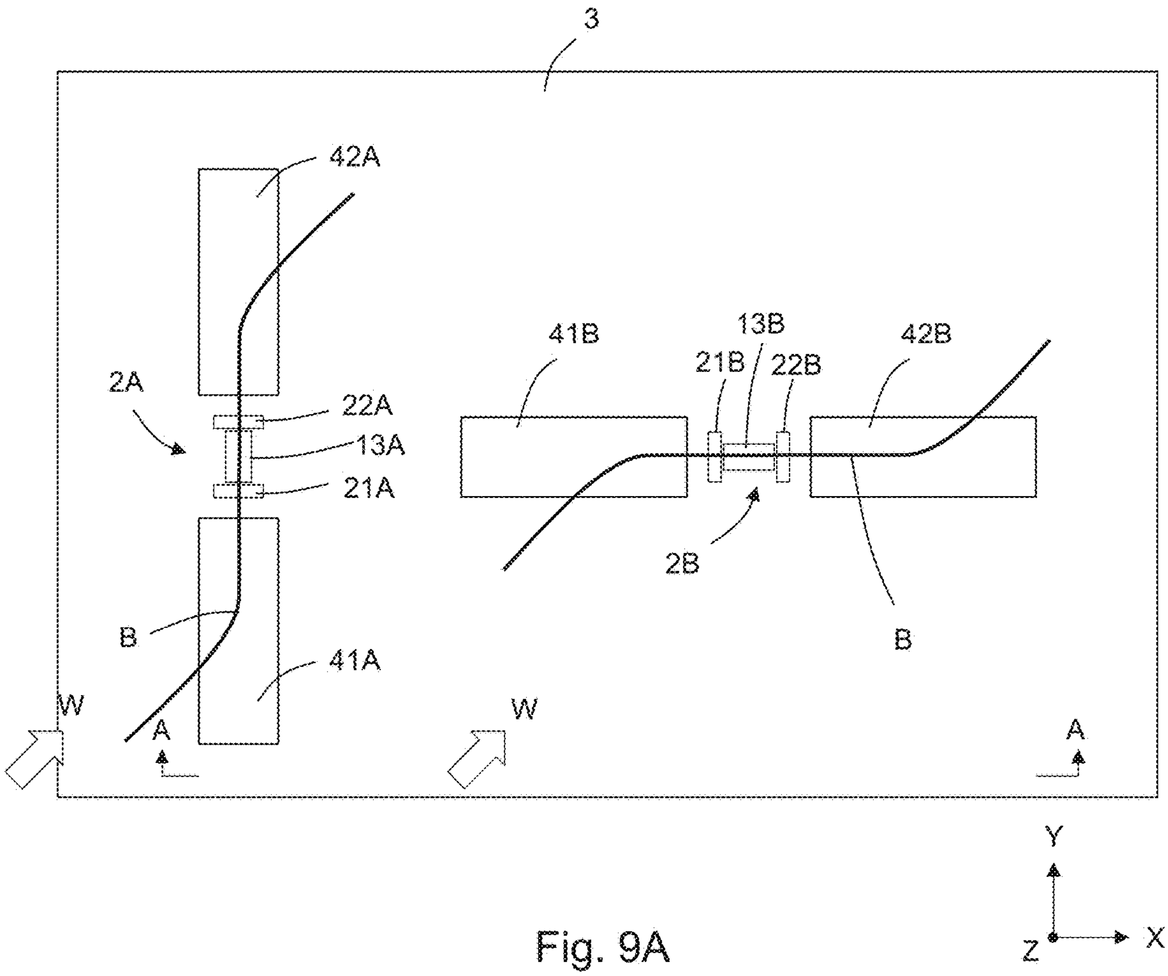

3
42A
41B
13B
21B
22B
42B
2A
22A
13A
21A
2B
B
B
41A
W
A
W
A
Y
Z
X

Fig. 9A

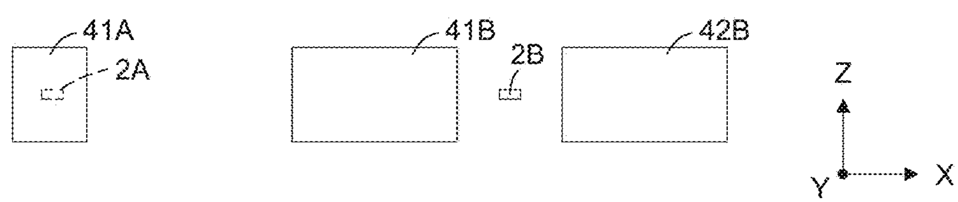

41A
2A
41B
2B
42B
Z
Y
X

Fig. 9B

METHOD FOR MANUFACTURING MAGNETIC SENSOR AND MAGNETIC SENSOR

FIELD

[0001] This application claims the benefit of Japanese Priority Patent Application No. JP 2024-024599 filed on Feb. 21, 2024, the entire contents of which are incorporated herein by reference.

[0002] The present invention relates to a method for manufacturing a magnetic sensor and the magnetic sensor.

BACKGROUND

[0003] Magnetic sensors that can detect magnetic fields in a plurality of directions are known. JP 2014-515470 A describes a magnetic sensor in which two types of sensor bridges are supported on a substrate. The two types of sensor bridges detect two orthogonal magnetic field components. A plurality of magnets is mounted on the substrate to apply a bias magnetic field to each of the sensor bridges, and the magnets are magnetized in the same direction. Each sensor bridge is made up of four elements, and the long axes of two elements are perpendicular to the long axes of the other two elements.

SUMMARY

[0004] In the magnetic sensor described in JP 2014-515470 A, a plurality of magnets can be magnetized in a single process. In addition, a bias magnetic field is applied to stabilize the magnetization state of the elements of the magnetic sensor and to improve the linearity and symmetry of the output. Because the bias field is parallel to the long axis of one set of elements but parallel to the short axis of the other set of elements, stabilizing the magnetization state of the other set of elements is difficult. The magnets may be magnetized so that the magnets each have a different magnetization state according to the orientation of the elements.

[0005] The present disclosure relates to a method for manufacturing a magnetic sensor. The magnetic sensor comprises: a first magnetic field sensing element that includes a magnetic field sensing axis approximately parallel to a first direction, two first magnet layers that are arranged in a second direction approximately perpendicular to the first direction, and a first soft magnetic layer that is sandwiched between the two first magnet layers in the second direction; a second magnetic field sensing element that includes a magnetic field sensing axis approximately parallel to the second direction, two second magnet layers arranged in the first direction, and a second soft magnetic layer that is sandwiched between the two second magnet layers in the first direction; and a substrate that supports the first magnetic field sensing element and the second magnetic field sensing element. The method for manufacturing the magnetic sensor comprises a step of applying an external magnetic field from a direction at an angle that is approximately equal to each the first direction and the second direction while the two first magnet layers, the two second magnet layers, the first soft magnetic layer, and the second soft magnetic layer are supported on a substrate, thereby magnetizing the two first magnet layers and the two second magnet layers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The accompanying drawings are included to provide a further understanding of the disclosure and are incorporated in and constitute a part of this specification. The drawings illustrate example embodiments and, together with the specification, serve to explain the principles of the technology.

[0007] FIG. **1** is a schematic configuration diagram of a magnetic sensor according to a first embodiment of the present disclosure;

[0008] FIG. **2** is a plan view of a magnetization free layer and a magnet layer shown in FIG. **1**;

[0009] FIG. **3** is a conceptual diagram showing a method of magnetizing a magnet layer;

[0010] FIG. **4** is a schematic configuration diagram of a magnetic sensor according to a modification of the first embodiment;

[0011] FIG. **5** is a conceptual diagram showing a method for magnetizing a magnet layer of a magnetic sensor according to a second embodiment of the present disclosure;

[0012] FIG. **6** is a conceptual diagram showing a method for magnetizing a magnet layer of a magnetic sensor according to a third embodiment of the present disclosure;

[0013] FIG. **7** is a conceptual diagram showing a method for magnetizing a magnet layer of a magnetic sensor according to a fourth embodiment of the present disclosure;

[0014] FIGS. **8**A and **8**B are conceptual diagrams showing a method for magnetizing a magnet layer of a magnetic sensor according to a fifth embodiment of the present disclosure; and

[0015] FIGS. **9**A and **9**B are conceptual diagrams showing a method for magnetizing a magnet layer of a magnetic sensor according to a sixth embodiment of the present disclosure.

DETAILED DESCRIPTION

[0016] In the following explanation, some example embodiments and modifications of the technology are described in detail with reference to the accompanying drawings. Note that the following description is directed to illustrative examples of the disclosure and is not to be construed as limiting the technology. Factors including, without limitation, numerical values, shapes, materials, components, positions of the components, and the manner in which components are combined with each other are illustrative only and not to be construed as limiting the technology. Further, elements in the following example embodiments that are not recited in a most-generic independent claim of the disclosure are optional and may be provided on an as-needed basis. The drawings are schematic and are not intended to be drawn to scale. Like elements are denoted with the same reference numerals to avoid redundant descriptions.

[0017] An object of the present disclosure is to provide a method for manufacturing a magnetic sensor, the method being capable of magnetizing a plurality of magnet layers to different magnetization states in a single process.

[0018] Embodiments of a magnetic sensor according to the present disclosure will be described with reference to the drawings. In the following description and drawings, first direction X is approximately parallel to the magnetic sensing direction of first magnetic field sensing element **2**A, and second direction Y is approximately parallel to the magnetic sensing direction of second magnetic field sensing element 2B. Third direction Z coincides with the stacking direction of a laminated body, which will be described later. First direction X and second direction Y are parallel to element mounting surface 3A of substrate 3. First direction X, second direction Y, and third direction Z are approximately perpendicular to one another.

First Embodiment

[0019] FIG. **1** is a cross-sectional view showing a schematic configuration of magnetic sensor **1** according to the first embodiment, and FIG. **2** is a plan view of a magnetization free layer and magnet layers taken along line AA in FIG. **1**. Referring to FIG. **1**, magnetic sensor **1** comprises first magnetic field sensing element **2**A, second magnetic field sensing element **2**B, and substrate **3** that supports first magnetic field sensing element **2**A and second magnetic field sensing element **2**B. First magnetic field sensing element **2**A has magnetic field sensing axis (magnetic field sensing direction) **4**A parallel to first direction X, and second magnetic field sensing element **2**B has magnetic field sensing axis (magnetic field sensing direction) **4**B parallel to second direction Y. First magnetic field sensing element **2**A and second magnetic field sensing element **2**B have the same configuration, and first (or second) magnetic field sensing element **2**A (**2**B) rotated 90 degrees on the XY plane corresponds to second (or first) magnetic field sensing element **2**B (**2**A). Insulating layer **5** that is made of Al_2O_3 is provided between first magnetic field sensing element **2**A and second magnetic field sensing element **2**B.

[0020] First magnetic field sensing element **2**A and second magnetic field sensing element **2**B each comprise lower electrode layer **6**, laminated body **7**, and upper electrode layer **14**. Laminated body **7** includes antiferromagnetic layer **8**, outer magnetization fixed layer **9**, nonmagnetic intermediate layer **10**, inner magnetization fixed layer **11**, spacer layer **12**, and magnetization free layer **13**. These layers are stacked in the above order in third direction Z from lower electrode layer **6** to upper electrode layer **14**. Inner magnetization fixed layer **11** may be referred to as magnetization fixed layer **11**. A sense current flows in laminated body **7** in third direction Z by including lower electrode layer **6** and upper electrode layer **14**. In the following explanation, laminated body **7**, inner magnetization fixed layer **11**, spacer layer **12**, and magnetization free layer **13** of first magnetic field sensing element **2**A may also be referred to as first laminated body **7**A, first magnetization fixed layer **11**A, first spacer layer **12**A, and first magnetization free layer **13**A, respectively. Laminated body **7**, inner magnetization fixed layer **11**, spacer layer **12** and magnetization free layer **13** of second magnetic field sensing element **2**B may also be referred to as second laminated body **7**B, second magnetization fixed layer **11**B, second spacer layer **12**B, and second magnetization free layer **13**B, respectively. First magnetization free layer **13**A may also be referred to as first soft magnetic layer **13**A, and second magnetization free layer **13**B may also be referred to as second soft magnetic layer **13**B.

[0021] Magnetization free layer **13** is a soft magnetic layer in which the magnetization direction is caused to rotate by an external magnetic field, and can be made of, for example, NiFe. Spacer layer **12** is a nonmagnetic layer located between magnetization free layer **13** and magnetization fixed layer **11**. Spacer layer **12** may be formed of a nonmagnetic insulator such as Al_2O_3 or MgO, or of a nonmagnetic conductor such as Cu. When spacer layer **12** is a nonmagnetic insulator, first and second magnetic field sensing elements **2**A and **2**B function as tunneling magnetoresistance (TMR) elements, and when spacer layer **12** is a nonmagnetic conductor, first and second magnetic field sensing elements **2**A and **2**B function as giant magnetoresistance (GMR) elements. A TMR element has a larger MR change rate than a GMR element, and the output voltage of magnetic sensor **1** can be increased.

[0022] Inner magnetization fixed layer **11** is a ferromagnetic layer that is sandwiched between outer magnetization fixed layer **9** and spacer layer **12**. Inner magnetization fixed layer **11** is antiferromagnetically coupled to outer magnetization fixed layer **9** via nonmagnetic intermediate layer **10** that is made of, for example, Ru or Rh. Outer magnetization fixed layer **9** is a ferromagnetic layer that is exchange-coupled to antiferromagnetic layer **8**. Antiferromagnetic layer **8** can be made of PtMn, IrMn, NiMn, or the like. The magnetization directions of inner magnetization fixed layer **11** and outer magnetization fixed layer **9** are fixed and are antiparallel to each other. The magnetization direction of first magnetization fixed layer **11**A is fixed in first direction X, and the magnetization direction of second magnetization fixed layer **11**B is fixed in second direction Y. The magnetization direction (first direction X) of first magnetization fixed layer **11**A coincides with magnetic field sensing axis **4**A of first magnetic field sensing element **2**A, and the magnetization direction (second direction Y) of second magnetization fixed layer **11**B coincides with magnetic field sensing axis **4**B of second magnetic field sensing element **2**B.

[0023] As shown in FIG. **2**, first magnetic field sensing element **2**A comprises two first magnet layers **21**A and **22**A arranged in second direction Y. First magnet layers **21**A and **22**A sandwich first magnetization free layer **13**A in second direction Y. First magnet layers **21**A and **22**A apply a bias magnetic field in second direction Y to first magnetization free layer **13**A. Second magnetic field sensing element **2**B has two second magnet layers **21**B and **22**B arranged in first direction X. Second magnet layers **21**B and **22**B sandwich second magnetization free layer **13**B in first direction X. Second magnet layers **21**B and **22**B apply a bias magnetic field in first direction X to second magnetization free layer **13**B. First magnet layers **21**A and **22**A and second magnet layers **21**B and **22**B have the same configuration and shape.

[0024] First and second magnet layers **21**A, **22**A, **21**B, and **22**B are made of a hard-magnetic material such as CoPt or CoCrPt. As shown in FIG. **1**, second magnet layers **21**B and **22**B are provided over almost the entire area in third direction Z of second laminated body **7**B. Second magnet layers **21**B and **22**B may be provided at least on the sides in first direction X of second magnetization free layer **13**B. Although not shown, first magnet layers **21**A and **22**A are provided over almost the entire area in third direction Z of first laminated body **7**A. First magnet layers **21**A and **22**A need only be provided on at least the sides in second direction Y of first magnetization free layer **13**A. Insulating layers **23** made of Al_2O_3 or the like are provided between first magnet layers **21**A and **22**A and first laminated body **7**A and between second magnet layers **21**B and **22**B and second laminated body **7**B. Insulating layer **23** prevents the sense current flowing through laminated body **7** from leaking to magnet layers **21**A, **22**A, **21**B, and **22**B, and in particular prevents a short circuit between magnetization free layer **13** and magnetization fixed layer **11**. Insulating layer **23** is omitted in FIG. **2**.

[0025] As shown in FIG. **2**, first magnetization free layer **13**A is formed longer in second direction Y and narrower in first direction X. Therefore, the magnetization direction of first magnetization free layer **13**A is easily oriented to second direction Y by the shape anisotropy effect. As described above, a bias magnetic field is applied to first magnetization free layer **13**A in second direction Y by first magnet layers **21**A and **22**A. For the above reasons, first magnetization free layer **13**A is magnetized in second direction Y when no external magnetic field is applied (hereinafter, referred to as a zero magnetic field). Similarly, second magnetization free layer **13**B is formed longer in first direction X than in second direction Y. Therefore, the magnetization direction of second magnetization free layer **13**B is easily oriented to first direction X by the shape anisotropy effect. As described above, a bias magnetic field is applied to second magnetization free layer **13**B in first direction X by second magnet layers **21**B and **22**B. For the above reasons, second magnetization free layer **13**B is magnetized in first direction X in a zero magnetic field. However, the shapes of first magnetization free layer **13**A and second magnetization free layer **13**B are not limited to those described above. For example, first magnetization free layer **13**A may be square when viewed from third direction Z, or may be formed so that first direction X is longer than second direction Y. The same applies to second magnetization free layer **13**B.

[0026] First magnetization fixed layer **11**A is magnetized in first direction X. When an external magnetic field is applied in first direction X, the magnetization direction of first magnetization free layer **13**A in FIG. **2** rotates clockwise or counterclockwise depending on the strength of the external magnetic field. This rotation changes the relative angle between the magnetization direction of first magnetization fixed layer **11**A and the magnetization direction of first magnetization free layer **13**A and thus changes the electrical resistance of first magnetic field sensing element **2**A to the sense current. Based on this change in electrical resistance, first magnetic field sensing element **2**A detects the strength of the external magnetic field in the magnetic field sensing direction (first direction X). Second magnetic field sensing element **2**B also detects the strength of the external magnetic field in the magnetic field sensing direction (second direction Y) by a similar principle.

[0027] Next, a method for manufacturing the above-described magnetic sensor **1** will be described. First, lower electrode layers **6**, laminated bodies **7**, and upper electrode layers **14** are formed on substrate **3** for each of first magnetic field sensing element **2**A and second magnetic field sensing element **2**B. First magnetization fixed layer **11**A of first laminated body **7**A and second magnetization fixed layer **11**B of second laminated body **7**B can be magnetized by, for example, a method that combines application of a magnetic field and local heating. Specifically, while applying an external magnetic field from first direction X, first magnetic field sensing element **2**A (first magnetization fixed layer **11**A) is irradiated with laser light to heat first magnetic field sensing element **2**A (first magnetization fixed layer **11**A). Next, while applying an external magnetic field from second direction Y, second magnetic field sensing element **2**B (second magnetization fixed layer **11**B) is irradiated with laser light to heat second magnetic field sensing element **2**B (second magnetization fixed layer **11**B). By this method, first magnetization fixed layer **11**A and second magnetization fixed layer **11**B that are supported by the same substrate **3** can be magnetized in different directions.

[0028] Next, first magnet layers **21**A and **22**A and the second magnet layers **21**B and **22**B are formed. Subsequently, first magnet layers **21**A and **22**A and second magnet layers **21**B and **22**B are magnetized. As shown in FIG. **3**, an external magnetic field is applied from direction W that is at approximately the same angle to each of first direction X and second direction Y to magnetize first magnet layers **21**A and **22**A and second magnet layers **21**B and **22**B. This process is performed with first magnet layers **21**A and **22**A and second magnet layers **21**B and **22**B supported on substrate **3** such that first magnet layers **21**A and **22**A and second magnet layers **21**B and **22**B can be magnetized simultaneously. Thereafter, upper electrode layers **14** of first magnetic field sensing element **2**A and second magnetic field sensing element **2**B are formed. Direction W may be inclined at 45 degrees from each of first direction X and second direction Y, but direction W may vary within a slight range (for example, from about 43 to 47 degrees).

[0029] In FIG. **3**, magnetic flux generated by a magnetic field application device (not shown) such as an electromagnet flows from the lower left to the upper right (in direction W). First magnet layer **21**A on the lower side in the drawing is located on the upstream side in terms of the direction in which the external magnetic field is applied, and first magnet layer **22**A on the upper side in the drawing is located on the downstream side in terms of the direction in which the external magnetic field is applied. Therefore, first magnet layer **21**A on the lower side in the figure is referred to as first upstream magnet layer **21**A, and first magnet layer **22**A on the upper side in the figure is referred to as first downstream magnet layer **22**A. Also, a part of magnetic flux B that enters lower first magnet layer **21**A in the figure passes through first magnetization free layer **13**A and upper first magnet layer **22**A and exits from upper first magnet layer **22**A. Therefore, the lower end of first magnetization free layer **13**A is referred to as first upstream end **15**A in the application direction of the external magnetic field, and the upper end is referred to as first downstream end **16**A in the application direction of the external magnetic field. First upstream magnet layer **21**A faces first upstream end **15**A of first magnetization free layer **13**A, and first downstream magnet layer **22**A faces first downstream end **16**A of first magnetization free layer **13**A. The same applies to second magnet layers **21**B and **22**B. Second upstream magnet layer **21**B faces second upstream end **15**B of second magnetization free layer **13**B, and second downstream magnet layer **22**B faces second downstream end **16**B of second magnetization free layer **13**B.

[0030] As shown in FIG. **3**, magnetic flux B that passes through first upstream magnet layer **21**A, first magnetization free layer **13**A, and first downstream magnet layer **22**A bends inside first upstream magnet layer **21**A and slants in second direction Y, proceeds in roughly second direction Y in first magnetization free layer **13**A, and bends again in first downstream magnet layer **22**A to be directed in the application direction W of the external magnetic field. In other words, since first magnetization free layer **13**A has a magnetic flux collecting function or a function as a yoke, the path of magnetic flux B is bent to follow first magnetization free layer **13**A.

[0031] By utilizing this phenomenon, first magnet layers **21**A and **22**A can be magnetized at an angle closer to second direction Y than to the application direction W of the external magnetic field. When first upstream magnet layer **21**A is divided in second direction Y into half-portion **17** that is close to first magnetization free layer **13**A and another half-portion **18** that is more distant from first magnetization free layer **13**A, the average magnetization direction of half-portion **17** is inclined more toward second direction Y than the average magnetization direction of the other half-portion **18**. The average magnetization direction means the average of the magnetization directions of the individual grains of first magnet layer **21**A. Similarly, when first downstream magnet layer **22**A is divided in second direction Y into half-portion **19** that is close to first magnetization free layer **13**A and another half-portion **20** that is more distant from first magnetization free layer **13**A, the average magnetization direction of half-portion **19** is inclined more toward second direction Y than the average magnetization direction of the other half-portion **20**. As a result, the angle between the average magnetization direction of each of two first magnet layers **21**A and **22**A and second direction Y is between more than 0 degrees and less than 45 degrees. Regarding the direction of the bias magnetic field applied to first magnetization free layer **13**A, the contribution of the magnetization direction of half-portion **17** of first upstream magnet layer **21**A and half-portion **19** of first downstream magnet layer **22**A is relatively large. Therefore, according to this embodiment, a bias magnetic field that is oriented in second direction Y can be applied to first magnetization free layer **13**A. The same applies to second magnetization free layer **13**B.

[0032] As shown in FIG. **2**, centerline **24**A of first magnetization free layer **13**A that is parallel to second direction Y coincides with centerlines **25**A and **26**A of first magnet layers **21**A and **22**A that are parallel to second direction Y. This arrangement allows the bias magnetic field applied to first magnetization free layer **13**A to be directed more along second direction Y. Dimension D1A in first direction X of first magnet layers **21**A and **22**A may be greater than dimension D2A in first direction X of first magnetization free layer **13**A. This arrangement enables the application of a bias magnetic field oriented in second direction Y across the entire width in first direction X of first magnetization free layer **13**A.

[0033] The same arrangement applies to second magnet layers **21**B and **22**B. In each of second magnet layers **21**B and **22**B, the magnetization directions of half-portions **17** and **19** that are close to second magnetization free layer **13**B are inclined toward first direction X relative to the magnetization direction of other half-portions **18** and **20** that are more distant from second magnetization free layer **13**B. The angle between the average magnetization direction of each of second magnet layers **21**B and **22**B and first direction X is between more than 0 degrees and less than 45 degrees. As shown in FIG. **2**, centerline **24**B of second magnetization free layer **13**B that is parallel to first direction X coincides with centerlines **25**B and **26**B of second magnet layers **21**B and **22**B that are parallel to first direction X. Dimension D1B in second direction Y of second magnet layers **21**B and **22**B is greater that dimension D2B in second direction Y of second magnetization free layer **13**B.

[0034] FIG. **4** is a cross-sectional view showing a schematic configuration of magnetic sensor **1** according to another modification of the first embodiment. Description of configurations and effects that are the same those of the first embodiment is here omitted. As shown in FIG. **4**, two second magnet layers **21**B and **22**B each have ferromagnetic layer **27** and antiferromagnetic layer **28**, and ferromagnetic layers **27** face second magnetization free layer **13**B in first direction X. Although not shown, first magnet layers **21**A and **22**A also each have ferromagnetic layer **27** and antiferromagnetic layer **28**, and ferromagnetic layers **27** face first magnetization free layer **13**A in second direction Y. Ferromagnetic layer **27** is made of CoFe. Antiferromagnetic layer **28** is made of an alloy such as IrMn, Fe-Mn, Ni-Mn, Pt-Mn, or Pd-Pt-Mn, and is strongly exchange-coupled with adjacent ferromagnetic layer **27**. Ferromagnetic layer **27** applies a bias magnetic field to magnetization free layer **13**, as do first and second magnet layers **21**A, **22**A, **21**B, and **22**B in the first embodiment. The magnetization direction of ferromagnetic layer **27** is firmly fixed by antiferromagnetic layer **28** and thus reduces hysteresis in first and second magnet layers **21**A, **22**A, **21**B, and **22**B in a zero magnetic field. The exchange coupling between antiferromagnetic layer **28** and ferromagnetic layer **27** is achieved by locally heating ferromagnetic layer **27** and antiferromagnetic layer **28** in a state in which an external magnetic field is applied. In other words, each of ferromagnetic layers **27** is magnetized by locally heating each of two first magnet layers **21**A and **22**A and two second magnet layers **21**B and **22**B while the external magnetic field is applied.

Second Embodiment

[0035] FIG. **5** is a view similar to FIG. **2** of magnetic sensor **1** according to the second embodiment and shows a plan view of the magnetization free layers and the magnet layers. Description of configurations and effects that are the same as those of the first embodiment is here omitted. In this embodiment, first magnetic field sensing element **2**A and second magnetic field sensing element **2**B have the same configuration, and first (or second) magnetic field sensing element **2**A (**2**B) that is rotated 90 degrees on the XY plane corresponds to second (or first) magnetic field sensing element **2**B (**2**A). Therefore, the following description will mainly focus on first magnetic field sensing element **2**A.

[0036] In this embodiment, centerline **24**A of first magnetization free layer **13**A is parallel to second direction Y and centerlines **25**A and **26**A of first magnet layers **21**A and **22**A are parallel to second direction Y but are offset from each other in first direction X. Specifically, centerline **24**A of first magnetization free layer **13**A is located between centerline **25**A of first upstream magnet layer **21**A and centerline **26**A of first downstream magnet layer **22**A, and centerline **25**A of first upstream magnet layer **21**A is located to precede centerline **26**A of first downstream magnet layer **22**A in application direction W of the external magnetic field. Since magnetic flux B is applied from the lower left and toward the upper right in FIG. **5**, first upstream magnet layer **21**A and first downstream magnet layer **22**A are magnetized with south pole at the lower left and north pole at the upper right, respectively. Therefore, the N-pole of first upstream magnet layer **21**A and the S-pole of first downstream magnet layer **22**A are roughly opposite each other in second direction Y, and magnetic field B' that is directed in second direction Y is formed around first magnetization free layer **13**A. As a result, first magnetization free layer **13**A is magnetized in a direction closer to second direction Y. In addition, in first direction X, only one of centerlines **25**A and **26**A may deviate from centerline **24**A.

[0037] Similarly, centerline **24**B of second magnetization free layer **13**B that is parallel to first direction X and centerlines **25**B and **26**B of second magnet layers **21**B and **22**B that are parallel to first direction X are offset from each other in second direction Y. Specifically, centerline **24**B of second magnetization free layer **13**B is located between centerline **25**B of second upstream magnet layer **21**B and centerline **26**B of second downstream magnet layer **22**B, and centerline **25**B of second upstream magnet layer **21**B is located to precede centerline **26**B of second downstream magnet layer **22**B in application direction W of the external magnetic field. In addition, only one of centerlines **25**B and **26**B may deviate in second direction Y from centerline **24**B.

Third Embodiment

[0038] FIG. **6** is a view similar to FIG. **2** of magnetic sensor **1** according to the third embodiment and shows a plan view of the magnetization free layers and the magnet layers. Description of configurations and effects that are the same as those of the first embodiment is here omitted. In this embodiment, first magnetic field sensing element **2**A and second magnetic field sensing element **2**B have the same configuration, and first (or second) magnetic field sensing element **2**A (**2**B) that is rotated 90 degrees on the XY plane corresponds to second (or first) magnetic field sensing element **2**B (**2**A). Therefore, the following description will mainly focus on first magnetic field sensing element **2**A.

[0039] First magnetization free layer **13**A includes triangular first upstream end region **31**A that faces first upstream magnet layer **21**A and triangular first downstream end region **32**A that faces first downstream magnet layer **22**A. First upstream magnet layer **21**A includes first upstream recess **33**A that accommodates first upstream end region **31**A, and first downstream magnet layer **22**A includes first downstream recess **34**A that accommodates first downstream end region **32**A. Similarly, second magnetization free layer **13**B includes triangular second upstream end region **31**B that faces second upstream magnet layer **21**B, and triangular second downstream end region **32**B that faces second downstream magnet layer **22**B. Second upstream magnet layer **21**B includes second upstream recess **33**B that accommodates second upstream end region **31**B, and second downstream magnet layer **22**B includes second downstream recess **34**B that accommodates second downstream end region **32**B.

[0040] When first magnetization free layer **13**A has a rectangular shape when viewed from third direction Z, a demagnetizing field is generated at the end of first magnetization free layer **13**A that face first magnet layers **21**A and **22**A. Because of the effect of the demagnetizing field, oblique magnetization may remain at the ends of first magnetization free layer **13**A that face first magnet layers **21**A and **22**A even when the external magnetic field disappears, and this oblique magnetization causes hysteresis in the output of magnetic sensor **1**. In this embodiment, in contrast, end regions **31**A and **32**A of first magnetization free layer **13**A that face first magnet layers **21**A and **22**A are formed with a triangular shape that therefore reduces the effect of the demagnetizing field and thus reduces hysteresis. The same effect applies to second magnetic field sensing element **2**B.

Fourth Embodiment

[0041] FIG. **7** is a view similar to FIG. **6** of magnetic sensor **1** according to the fourth embodiment and shows a plan view of the magnetization free layer and the magnet layers. Description of configurations and effects that are the same as those of the third embodiment is here omitted. The configurations and effects of which description has been omitted are the same as those of the third embodiment. In this embodiment, first magnetic field sensing element **2**A and second magnetic field sensing element **2**B have the same configuration, and first (or second) magnetic field sensing element **2**A (**2**B) that is rotated 90 degrees on the XY plane corresponds to second (or first) magnetic field sensing element **2**B (**2**A). In this embodiment, dimension L**1** in second direction Y of first upstream magnet layer **21**A of first magnetic field sensing element **2**A is greater than dimension W**1** in first direction X, and dimension L**2** in second direction Y of first downstream magnet layer **22**A is greater than dimension W**2** in first direction X. This arrangement causes the effect of shape anisotropy of first upstream magnet layer **21**A and first downstream magnet layer **22**A to be exerted in a direction that aligns with second direction Y, and first magnetization free layer **13**A is therefore magnetized in a direction closer to second direction Y. Similarly, dimension L**3** in first direction X of first upstream magnet layer **21**B of second magnetic field sensing element **2**B is greater than dimension W**3** in second direction Y, and dimension L**4** in first direction X of second downstream magnet layer **22**B is greater than dimension W**4** in second direction Y. This arrangement causes the effect of shape anisotropy of second upstream magnet layer **21**B and second downstream magnet layer **22**B to be exerted in a direction that aligns with first direction X, and second magnetization free layer **13**B is therefore magnetized in a direction closer to first direction X. Although not shown in the drawings, this embodiment can be combined with the first to third embodiments and the fifth and sixth embodiments.

Fifth Embodiment

[0042] FIGS. **8**A and **8**B show the configuration of magnetic sensor **1** according to the fifth embodiment. Description of configurations and effects that are the same as those of the first embodiment is here omitted. FIG. **8**A is a side view of magnetic sensor **1** as viewed from second direction Y. FIG. **8**B is a diagram similar to FIG. **2** and shows a plan view of the magnetization free layer and the magnet layers taken along line AA in FIG. **8**A. In this embodiment, first magnetic field sensing element **2**A and second magnetic field sensing element **2**B have the same configuration, and first (or second) magnetic field sensing element **2**A (**2**B) that is rotated 90 degrees on the XY plane corresponds to second (or first) magnetic field sensing element **2**B (**2**A). Therefore, the following description will mainly focus on first magnetic field sensing element **2**A.

[0043] In this embodiment, at least one (two in this embodiment) first shield layer **41**A and **42**A is provided to shield first magnetic field sensing element **2**A, and at least one (two in this embodiment) second shield layer **41**B and **42**B is provided to shield second magnetic field sensing element **2**B. First shield layers **41**A and **42**A are elongated in second direction Y, and second shield layers **41**B and **42**B are elongated in first direction X. First shield layers **41**A and **42**A sandwich first magnetic field sensing element **2**A in third direction Z, and second shield layers **41**B and **42**B sandwich second magnetic field sensing element **2**B in third direction Z. First shield layers **41**A and **42**A and second shield layers **41**B and **42**B are made of a soft magnetic material such as NiFe.

[0044] In general, a soft magnetic material having an elongated shape has a property such that magnetization is easily saturated in the longitudinal direction but not easily saturated in the lateral direction. Therefore, first shield layers **41**A and **42**A shield against an external magnetic field in first direction X while magnetization in second direction Y is easily saturated, whereby first shield layers **41**A and **42**A no longer function as a shield. When the external magnetic field is too strong, the shielding effect in first direction X is also reduced. The external magnetic field may have strength at least in first direction X that does not cause magnetic saturation of first shield layers **41**A and **42**A. As a result, the component of the external magnetic field in second direction Y predominates around first shield layers **41**A and **42**A, and as shown in FIG. **8**B, the external magnetic field applied to first magnetic field sensing element **2**A tends to be oriented in second direction Y. The same effect applies to second magnetic field sensing element **2**B. Although FIG. **8**B shows first and second magnetic field sensing elements **2**A and **2**B of the first embodiment, this embodiment can also be combined with the second or third embodiment.

Sixth Embodiment

[0045] FIGS. **9**A and **9**B show the configuration of magnetic sensor **1** according to the sixth embodiment. Description of configurations and effects that are the same as those of the fifth embodiment is here omitted. FIG. **9**A is similar to FIG. **2** and shows a plan view of magnetic sensor **1** as viewed from third direction Z. FIG. **9**B shows a side view of the magnetization free layer and the magnet layers taken along line AA in FIG. **9**A. In this embodiment, first magnetic field sensing element **2**A and second magnetic field sensing element **2**B have the same configuration, and first (or second) magnetic field sensing element **2**A (**2**B) that is rotated 90 degrees on the XY plane corresponds to second (or first) magnetic field sensing element **2**B (**2**A).

[0046] The configurations of first shield layers **41**A and **42**A and second shield layers **41**B and **42**B are the same as in the fifth embodiment, but two first shield layers **41**A and **42**A sandwich first magnetic field sensing element **2**A in second direction Y, and two second shield layers **41**B and **42**B sandwich second magnetic field sensing element **2**B in first direction X. In this configuration as well, the component of the external magnetic field in second direction Y predominates around first shield layers **41**A and **42**A, whereby the same effect can be obtained. In addition, in the fifth and sixth embodiments, one first shield layer **41**A or **42**A may be arranged near first magnetic field sensing element **2**A, and one second shield layer **41**B or **42**B may be arranged near second magnetic field sensing element **2**B. In other words, one of first shield layers **41**A or **42**A and one of second shield layers **41**B or **42**B in the fifth and sixth embodiments may be omitted.

[0047] According to the present disclosure, a manufacturing method can be provided for a magnetic sensor that allows a plurality of magnet layers to be magnetized to different magnetization states in a single process.

LIST OF REFERENCE NUMERALS

[0048] **1** magnetic sensor
[0049] **2**A first magnetic field sensing element
[0050] **2**B second magnetic field sensing element
[0051] **3** substrate
[0052] **11**A first magnetization fixed layer
[0053] **11**B second magnetization fixed layer
[0054] **12**A first spacer layer
[0055] **12**B second spacer layer
[0056] **13**A first magnetization free layer (first soft magnetic layer)
[0057] **13**B second magnetization free layer (second soft magnetic layer)
[0058] **15**A first upstream end
[0059] **15**B second upstream end
[0060] **16**A first downstream end
[0061] **16**B second downstream end
[0062] **21**A first upstream magnet layer
[0063] **21**B second upstream magnet layer
[0064] **22**A first downstream magnet layer
[0065] **22**B second downstream magnet layer
[0066] **24**A centerline of the first magnetic free layer
[0067] **24**B centerline of the second magnetic free layer
[0068] **25**A centerline of the first upstream magnet layer
[0069] **25**B centerline of the second upstream magnet layer
[0070] **26**A centerline of the first downstream magnet layer
[0071] **26**B centerline of the second downstream magnet layer
[0072] **27** ferromagnetic layer
[0073] **28** antiferromagnetic layer
[0074] **31**A first upstream end region
[0075] **31**B second upstream end region
[0076] **32**A first downstream end region
[0077] **32**B second downstream end region
[0078] **33**A first upstream recess
[0079] **33**B second upstream recess
[0080] **34**A first downstream recess
[0081] **34**B second downstream recess
[0082] **41**A, **42**A first shield layer
[0083] **41**B, **42**B second shield layer
[0084] X first direction
[0085] Y second direction
[0086] Z third direction

1. A method for manufacturing a magnetic sensor comprising:

a first magnetic field sensing element that includes a magnetic field sensing axis approximately parallel to a first direction, two first magnet layers arranged in a second direction approximately perpendicular to the first direction, and a first soft magnetic layer that is sandwiched between the two first magnet layers in the second direction;

a second magnetic field sensing element that includes a magnetic field sensing axis approximately parallel to the second direction, two second magnet layers arranged in the first direction, and a second soft magnetic layer sandwiched between the two second magnet layers in the first direction; and

a substrate that supports the first magnetic field sensing element and the second magnetic field sensing element, the method comprising a step of:

applying an external magnetic field from a direction that is at approximately equal angles to each of the first direction and the second direction while the two first magnet layers, the two second magnet layers, the first soft magnetic layer, and the second soft magnetic layer are supported on the substrate, thereby magnetizing the two first magnet layers and the two second magnet layers.

2. The method for manufacturing a magnetic sensor according to claim **1**, wherein:

the first magnetic field sensing element comprises a first magnetization free layer in which magnetization direction is caused to rotate by an external magnetic field, a first magnetization fixed layer in which magnetization direction is fixed in the first direction, and a nonmagnetic first spacer layer located between the first magnetization free layer and the first magnetization fixed layer;

the second magnetic field sensing element comprises a second magnetization free layer in which magnetization direction is caused to rotate by an external magnetic field, a second magnetization fixed layer in which magnetization direction is fixed in the second direction, and a nonmagnetic second spacer layer located between the second magnetization free layer and the second magnetization fixed layer; and

the first magnetization free layer is the first soft magnetic layer, and the second magnetization free layer is the second soft magnetic layer.

3. The method for manufacturing a magnetic sensor according to claim **2**, wherein:

a centerline of the first magnetization free layer parallel to the second direction coincides with centerlines of the two first magnet layers parallel to the second direction; and

a centerline of the second magnetization free layer parallel to the first direction coincides with centerlines of the two second magnet layers parallel to the first direction.

4. The method for manufacturing a magnetic sensor according to claim **2**, wherein:

the first magnetization free layer includes a first upstream end region and a first downstream end region in the application direction of the external magnetic field;

the two first magnet layers include a first upstream magnet layer that faces the first upstream end region, and a first downstream magnet layer that faces the first downstream end region;

a centerline of the first magnetization free layer parallel to the second direction is between centerlines of the two first magnet layers parallel to the second direction;

a centerline of the first upstream magnet layer parallel to the second direction is on the upstream side in the application direction of the external magnetic field with respect to a centerline of the first downstream magnet layer parallel to the second direction;

the second magnetization free layer includes a second upstream end region and a second downstream end region in the application direction of the external magnetic field;

the two second magnet layers include a second upstream magnet layer that faces the second upstream end region and a second downstream magnet layer that faces the second downstream end region;

a centerline of the second magnetization free layer parallel to the first direction is between centerlines of the two second magnet layers parallel to the first direction; and

a centerline of the second upstream magnet layer parallel to the first direction is the upstream of a centerline of the second downstream magnet layer parallel to the first direction in the application direction of the external magnetic field.

5. The method for manufacturing a magnetic sensor according to claim **2**, wherein:

a dimension of the first magnet layer in the first direction is greater than a dimension of the first magnetization free layer in the first direction; and

a dimension of the second magnet layer in the second direction is greater than a dimension of the second magnetization free layer in the second direction.

6. The method for manufacturing a magnetic sensor according to claim **2**, wherein:

the first magnetic free layer includes two triangular first end regions that each face a respective one of the two first magnet layers; and

the second magnetization free layer includes two triangular second end regions that each face a respective one of the two second magnet layers.

7. The method for manufacturing a magnetic sensor according to claim **6**, wherein:

the two first magnet layers each include a first recess that accommodates a respective one of the first end regions; and

the two second magnet layers each include a second recess that accommodates a respective one of the second end regions.

8. The method for manufacturing a magnetic sensor according to claim **2**, further comprising steps of:

after forming the first magnetization fixed layer, heating the first magnetization fixed layer while applying a magnetic field in the first direction to magnetize the first magnetization fixed layer; and

after forming the second magnetization fixed layer, heating the second magnetization fixed layer while applying a magnetic field in the second direction to magnetize the second magnetization fixed layer.

9. The method for manufacturing a magnetic sensor according to claim **1**, wherein:

the dimensions of each of the two first magnet layers in the second direction are greater than the dimensions of each of the two first magnet layers in the first direction; and

the dimensions of each of the two second magnet layers in the first direction are greater than the dimensions of each of the two second magnet layers in the second direction.

10. The method for manufacturing a magnetic sensor according to claim **1**, the magnetic sensor further comprising:

at least one first shield layer that is elongated in the second direction and that shields the first magnetic field sensing element; and

at least one second shield layer that is elongated in the first direction and that shields the second magnetic field sensing element.

11. The method for manufacturing a magnetic sensor according to claim **10**, wherein:

the at least one first shield layer includes two first shield layers that sandwich the first magnetic field sensing element in a third direction perpendicular to the first direction and the second direction; and

the at least one second shield layer includes two second shield layers that sandwich the second magnetic field sensing element in the third direction.

12. The method for manufacturing a magnetic sensor according to claim **10**, wherein:

the at least one first shield layer includes two first shield layers that sandwich the first magnetic field sensing element in the second direction; and

the at least one second shield layer includes two second shield layers that sandwich the second magnetic field sensing element in the first direction.

13. The method for manufacturing a magnetic sensor according to claim **1**, wherein

each of the two first magnet layers and the two second magnet layers are made of a hard-magnetic material.

14. The method for manufacturing a magnetic sensor according to claim **1**, wherein

each of the two first magnet layers and the two second magnet layers includes a ferromagnetic layer and an antiferromagnetic layer, and each of the ferromagnetic layers is magnetized by locally heating each of the two first magnet layers and the two second magnet layers while the external magnetic field is applied.

15. A magnetic sensor, comprising:

a first magnetic field sensing element that includes a magnetic field sensing axis parallel to a first direction;

a second magnetic field sensing element that includes a magnetic field sensing axis parallel to a second direction approximately perpendicular to the first direction; and

a substrate that supports the first magnetic field sensing element and the second magnetic field sensing element, wherein:

the first magnetic field sensing element includes a first magnetization free layer in which magnetization direction is caused to rotate by an external magnetic field, a first magnetization fixed layer in which magnetization direction is fixed in the first direction, a nonmagnetic first spacer layer located between the first magnetization free layer and the first magnetization fixed layer, and two first magnet layers that are arranged in the second direction and that sandwich the first magnetization free layer in the second direction; and

the second magnetic field sensing element includes a second magnetization free layer in which magnetization direction is caused to rotate by an external magnetic field, a second magnetization fixed layer in which magnetization direction is fixed in the second direction, a nonmagnetic second spacer layer located between the second magnetization free layer and the second magnetization fixed layer, and two second magnet layers that are arranged in the first direction and that sandwich the second magnetization free layer in the first direction.

16. The magnetic sensor according to claim **15**, wherein:

in each of the two first magnet layers, a magnetization direction of a half-portion close to the first magnetization free layer is more inclined toward the second direction than a magnetization direction of a remaining half-portion that is more distant from the first magnetization free layer; and

in each of the two second magnet layers, the magnetization direction of a half-portion close to the second magnetization free layer is more inclined toward the first direction than the magnetization direction of a remaining half-portion that is more distant from the second magnetization free layer.

17. The magnetic sensor according to claim **15**, wherein:

an angle between an average magnetization direction of the two first magnet layers and the second direction is between 0 degrees and less than 45 degrees; and

an angle between an average magnetization direction of the two second magnet layers and the first direction is between more than 0 degrees and less than 45 degrees.

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