US009791341B2

(12) **United States Patent**
Fuji et al.

(10) **Patent No.: US 9,791,341 B2**
(45) **Date of Patent: Oct. 17, 2017**

(54) **PRESSURE SENSOR, MICROPHONE, BLOOD PRESSURE SENSOR, AND TOUCH PANEL**

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(72) Inventors: **Yoshihiko Fuji**, Kawasaki (JP); **Hideaki Fukuzawa**, Kawasaki (JP); **Michiko Hara**, Yokohama (JP); **Tomohiko Nagata**, Yokohama (JP); **Akio Hori**, Kawasaki (JP); **Shiori Kaji**, Kawasaki (JP); **Yoshihiro Higashi**, Komatsu (JP); **Akiko Yuzawa**, Kawasaki (JP)

(73) Assignee: **Kabushiki Kaisha Toshiba**, Minato-ku (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 532 days.

(21) Appl. No.: **14/469,876**

(22) Filed: **Aug. 27, 2014**

(65) **Prior Publication Data**

US 2015/0088008 A1 Mar. 26, 2015

(30) **Foreign Application Priority Data**

Sep. 20, 2013 (JP) 2013-196065

(51) **Int. Cl.**
G01L 9/16 (2006.01)
A61B 5/021 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01L 9/16*** (2013.01); ***A61B 5/021*** (2013.01); ***A61B 5/02141*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G01L 9/0001; G01L 9/16; G01L 9/0041; G01L 1/125
See application file for complete search history.

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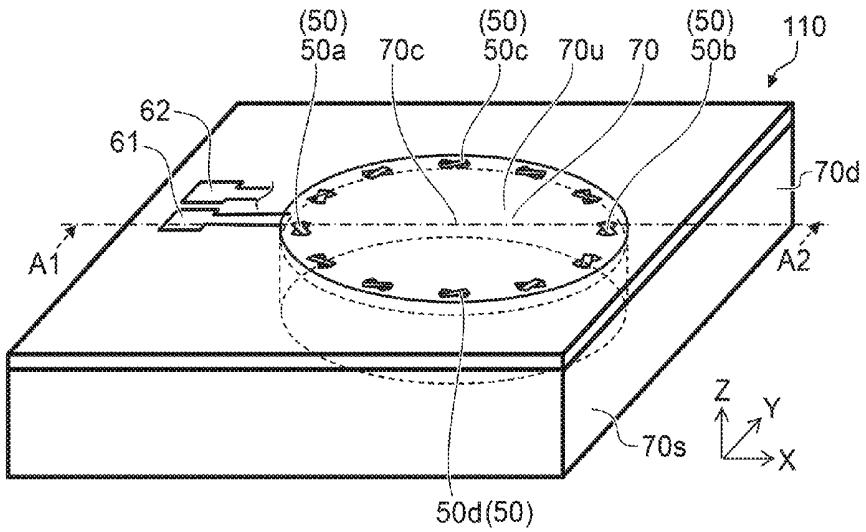
Primary Examiner — Erika J Villaluna
(74) *Attorney, Agent, or Firm* — Oblon, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

According to one embodiment, a pressure sensor includes a support, a film unit supported by the support, having an upper surface, and capable of being deformed, and a first sensing element provided on the upper surface. The first sensing element includes a first magnetic layer, a second magnetic layer provided apart from the first magnetic layer and a first intermediate unit including a first intermediate layer including a portion provided between the first and second magnetic layers. The first magnetic layer extends in a first direction parallel to the upper surface, and a first major axis length of the first magnetic layer is longer than a first minor axis length. The second magnetic layer extends in a second direction parallel to the upper surface and crossing the first direction, and a second major axis length of the second magnetic layer is longer than a second minor axis length.

30 Claims, 27 Drawing Sheets



(51) **Int. Cl.**

G01L 9/00	(2006.01)
G06F 3/041	(2006.01)
H04R 19/00	(2006.01)
H04R 19/04	(2006.01)
H04R 31/00	(2006.01)
A61B 5/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G01L 9/0001*** (2013.01); ***G06F 3/0414*** (2013.01); ***H04R 19/005*** (2013.01); ***H04R 19/04*** (2013.01); ***H04R 31/00*** (2013.01); *A61B 5/6824* (2013.01); *A61B 2562/0247* (2013.01)

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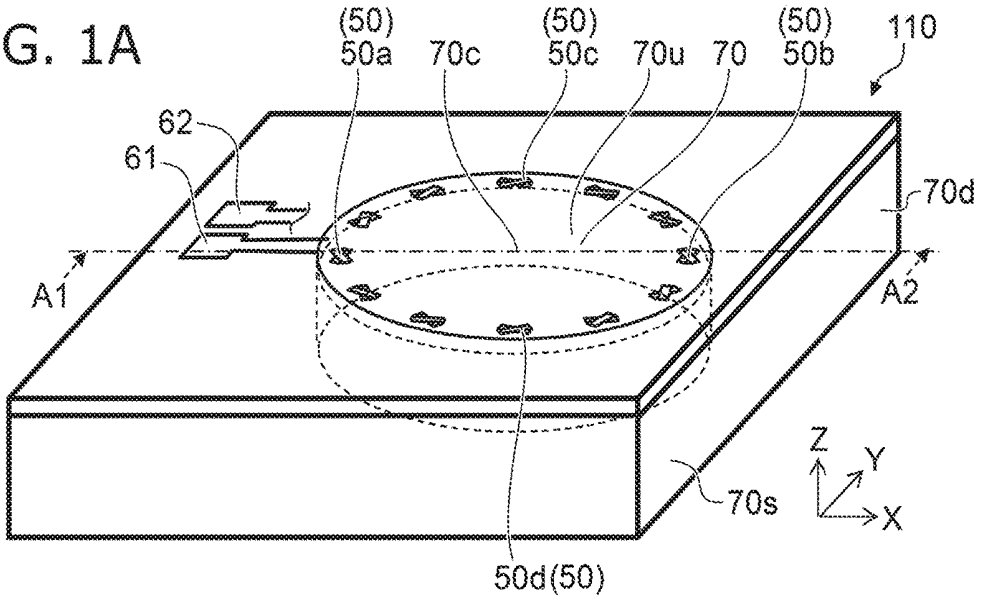
FIG. 1A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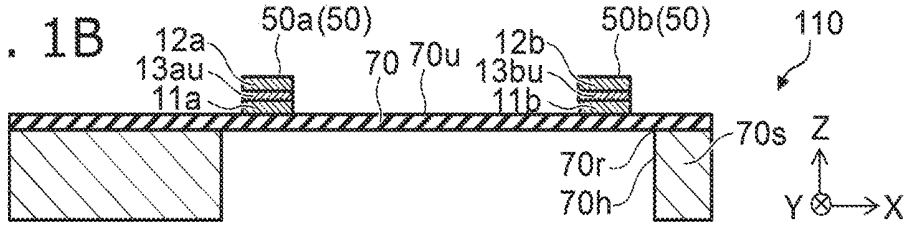
50d(50)

FIG. 1B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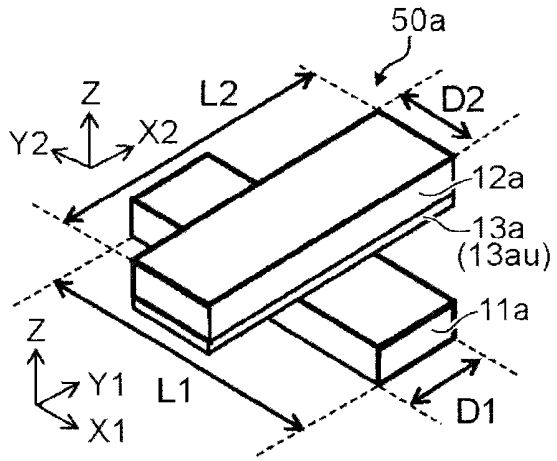


FIG. 2A

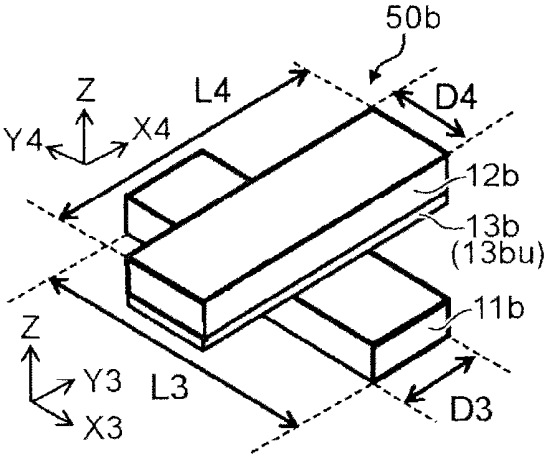


FIG. 2B

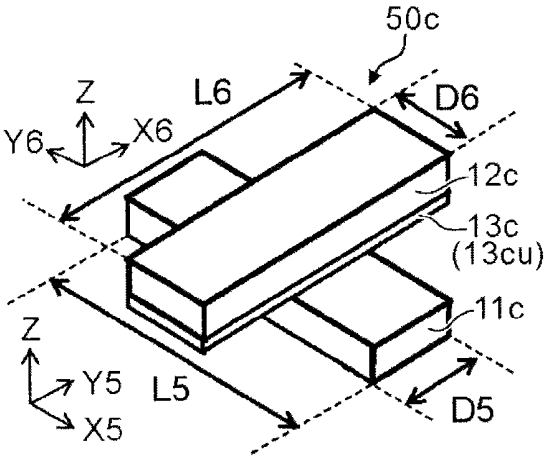


FIG. 2C

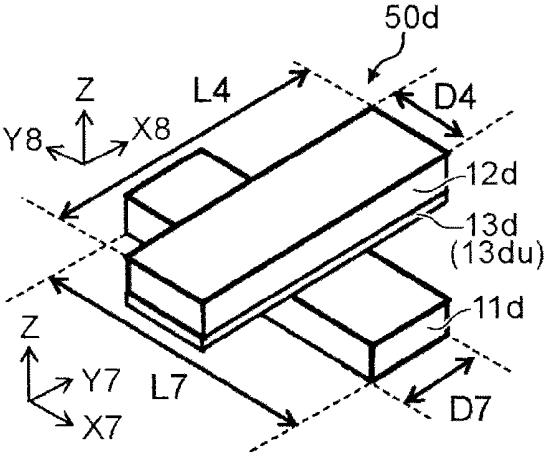


FIG. 2D

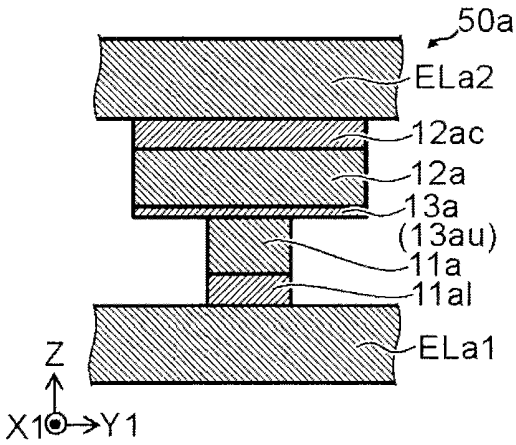


FIG. 3A

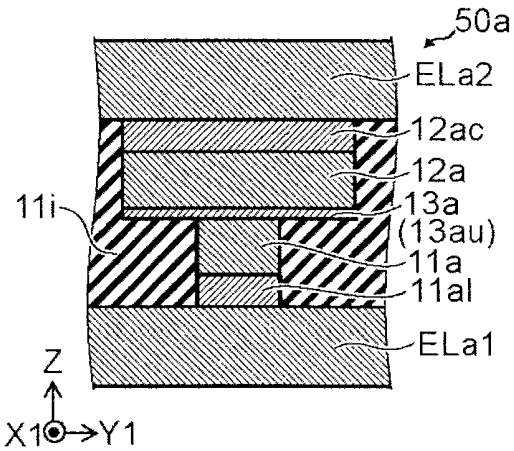


FIG. 3B

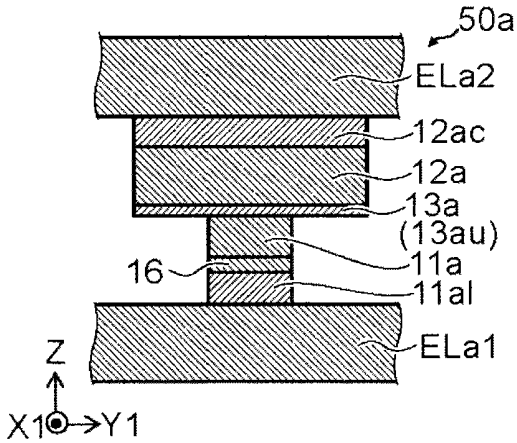


FIG. 3C

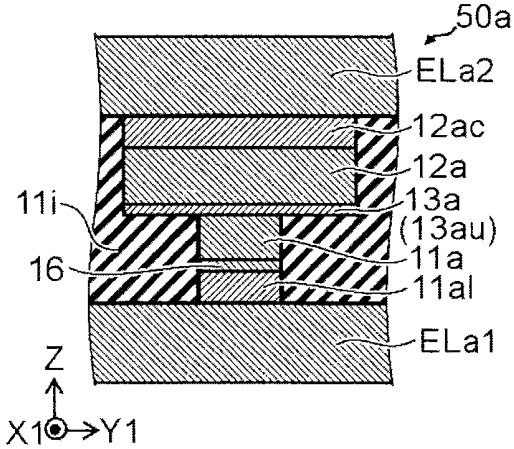


FIG. 3D

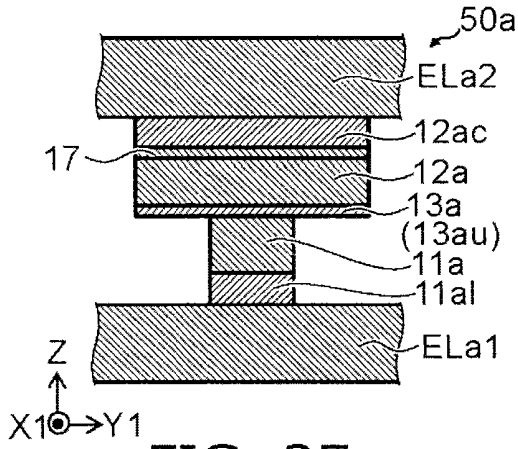


FIG. 3E

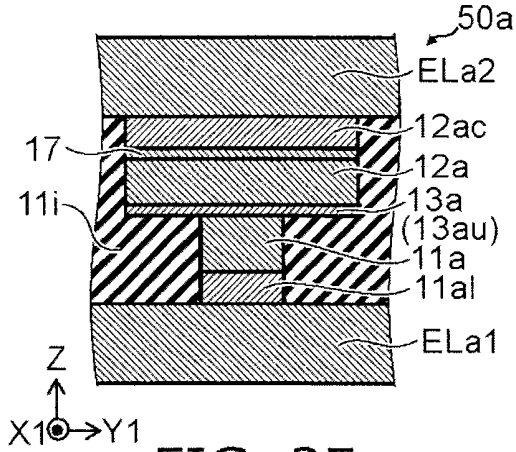


FIG. 3F

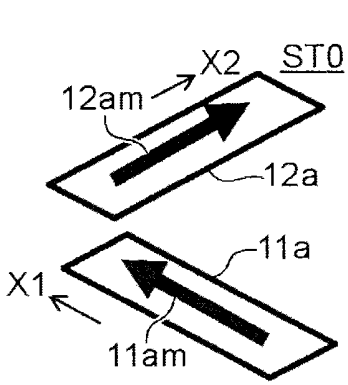


FIG. 4A

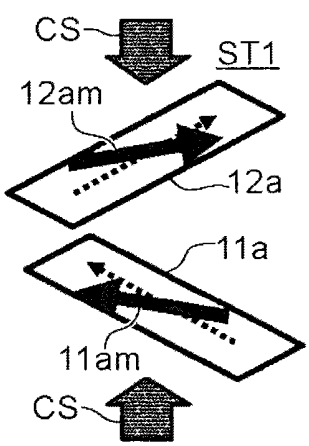


FIG. 4B

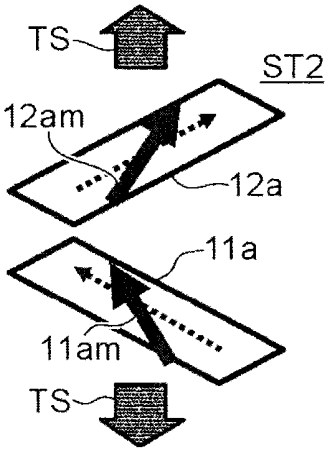


FIG. 4C

FIG. 4D

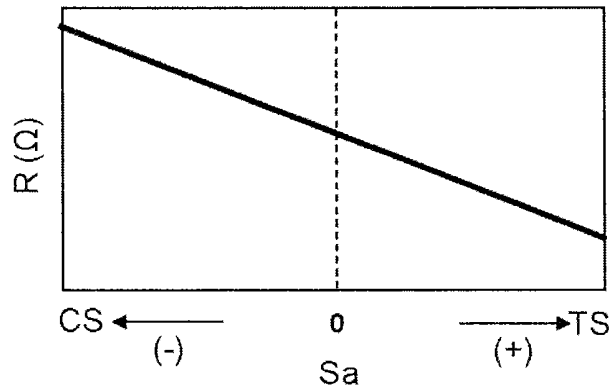
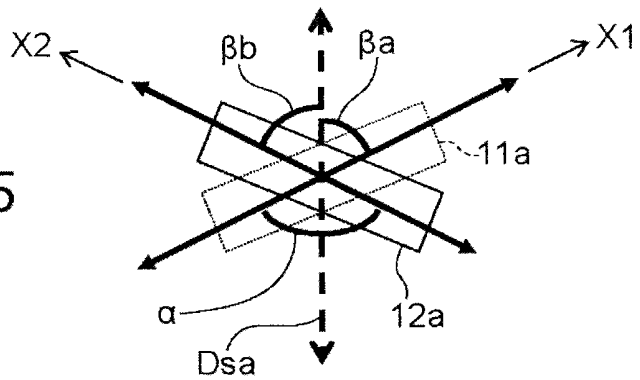


FIG. 5



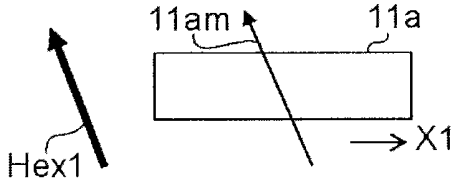


FIG. 6A

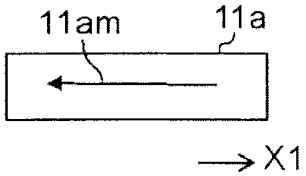


FIG. 6B

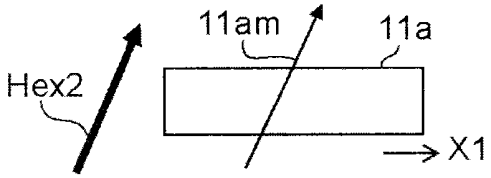


FIG. 6C

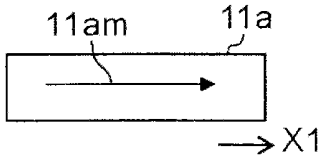


FIG. 6D

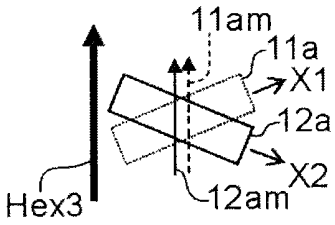


FIG. 7A

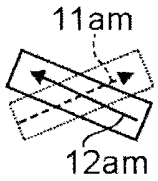


FIG. 7B

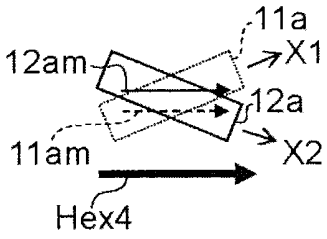
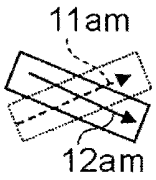


FIG. 7C



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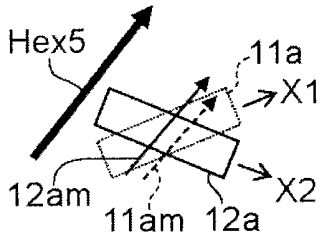


FIG. 7E

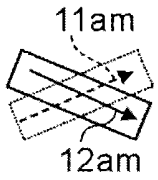


FIG. 7F

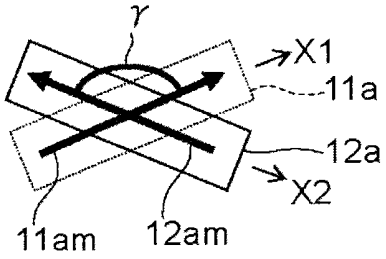
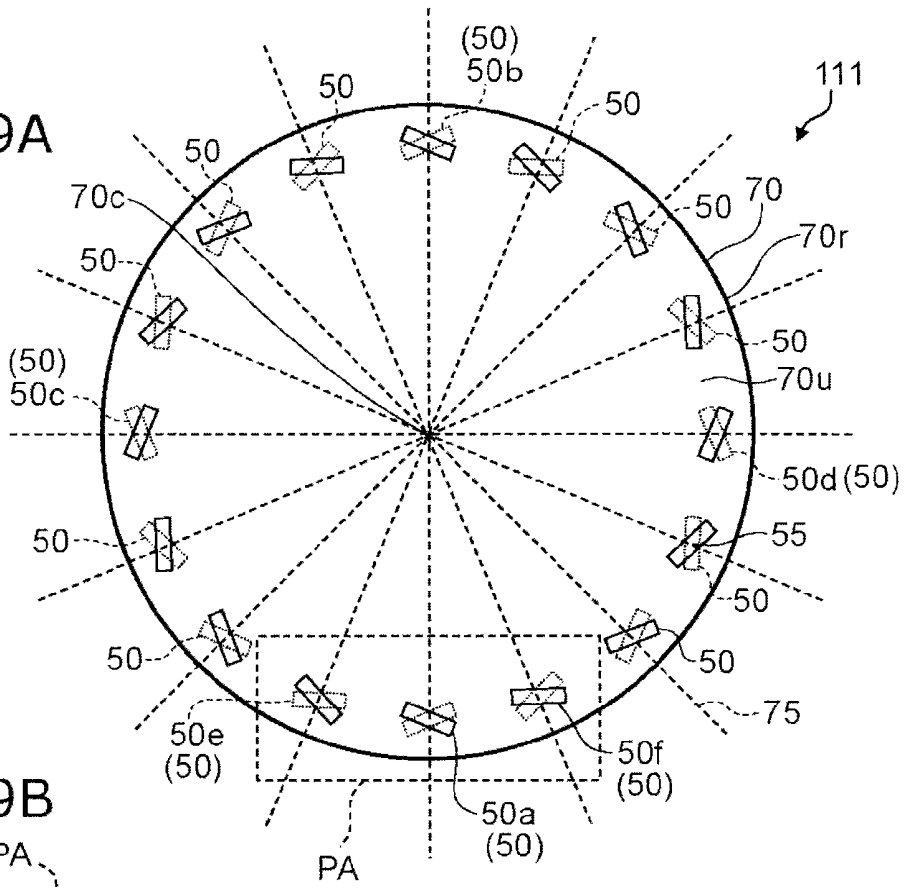


FIG. 8

FIG. 9A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70r
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(50)
50c
70u
50d (50)
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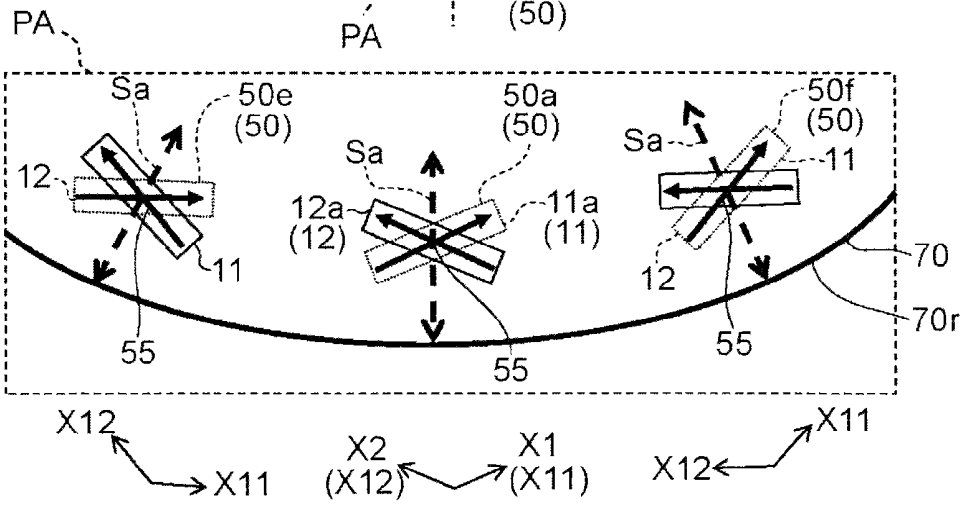
(50)
50f
(50)
50a
(50)
PA
PA

FIG. 9B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(50)
Sa
Sa
50f
(50)
12
11
12a
(12)
11a
(11)
11
12
70
70r
55
55
55
X12
X11
X2
(X12)
X1
(X11)
X12
X11

FIG. 10A

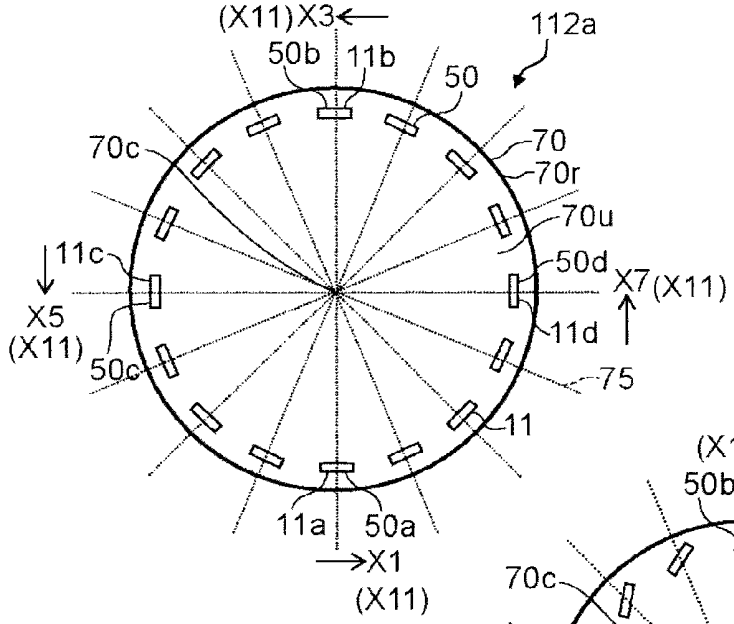


FIG. 10B

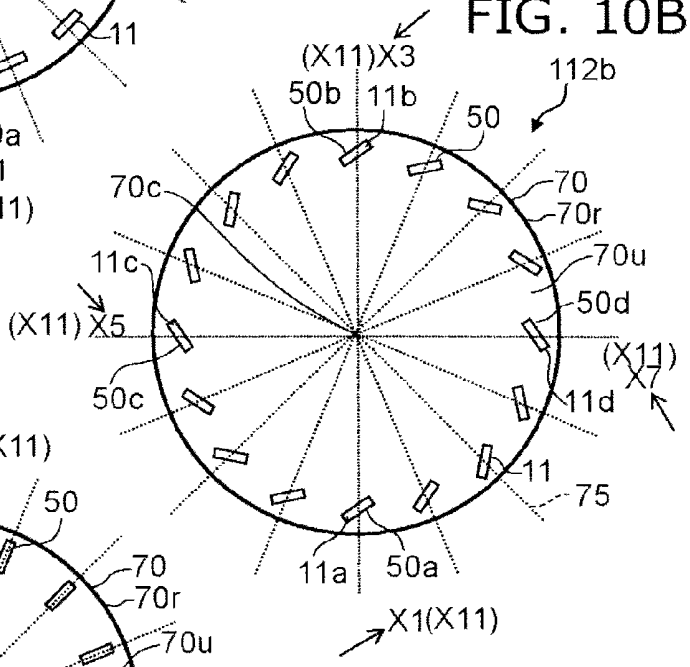
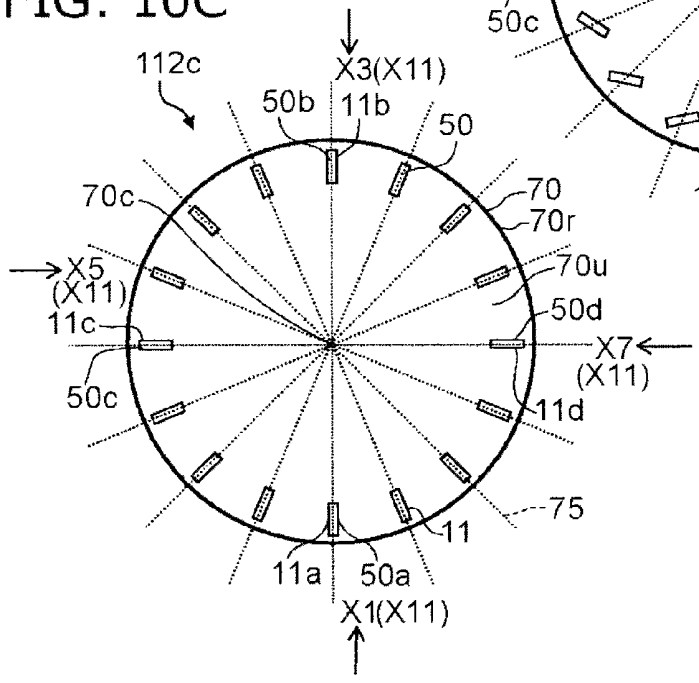
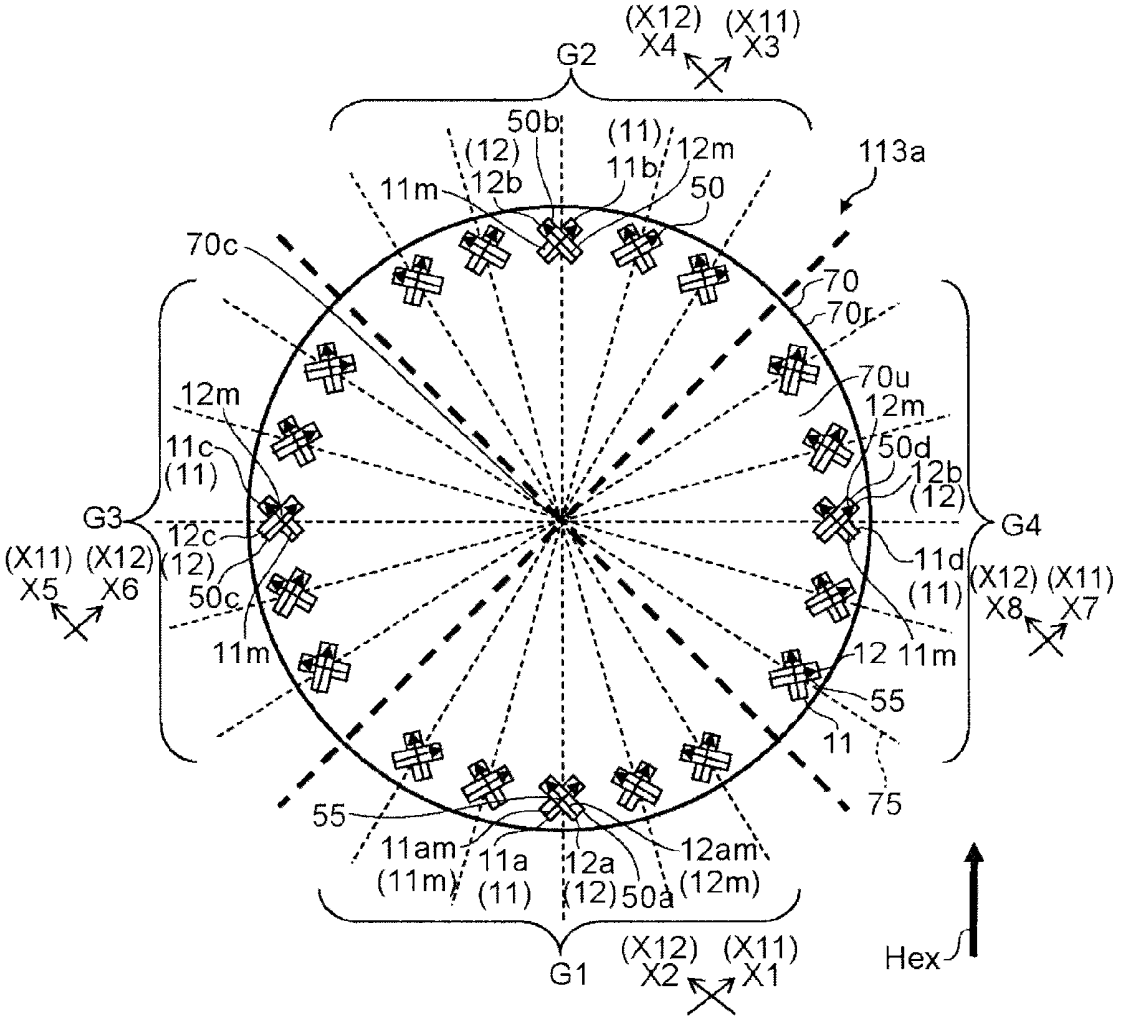


FIG. 10C

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G2
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(11) 11b
12m
50
113a
11m
70c
70
70r
70u
12m
50d
12b (12)
G4
11d (11)
(X12) X8
(X11) X7
12 11m
55
11
75
12m
11c (11)
G3
12c (12)
50c
11m
(X11) X5
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(X12) X2
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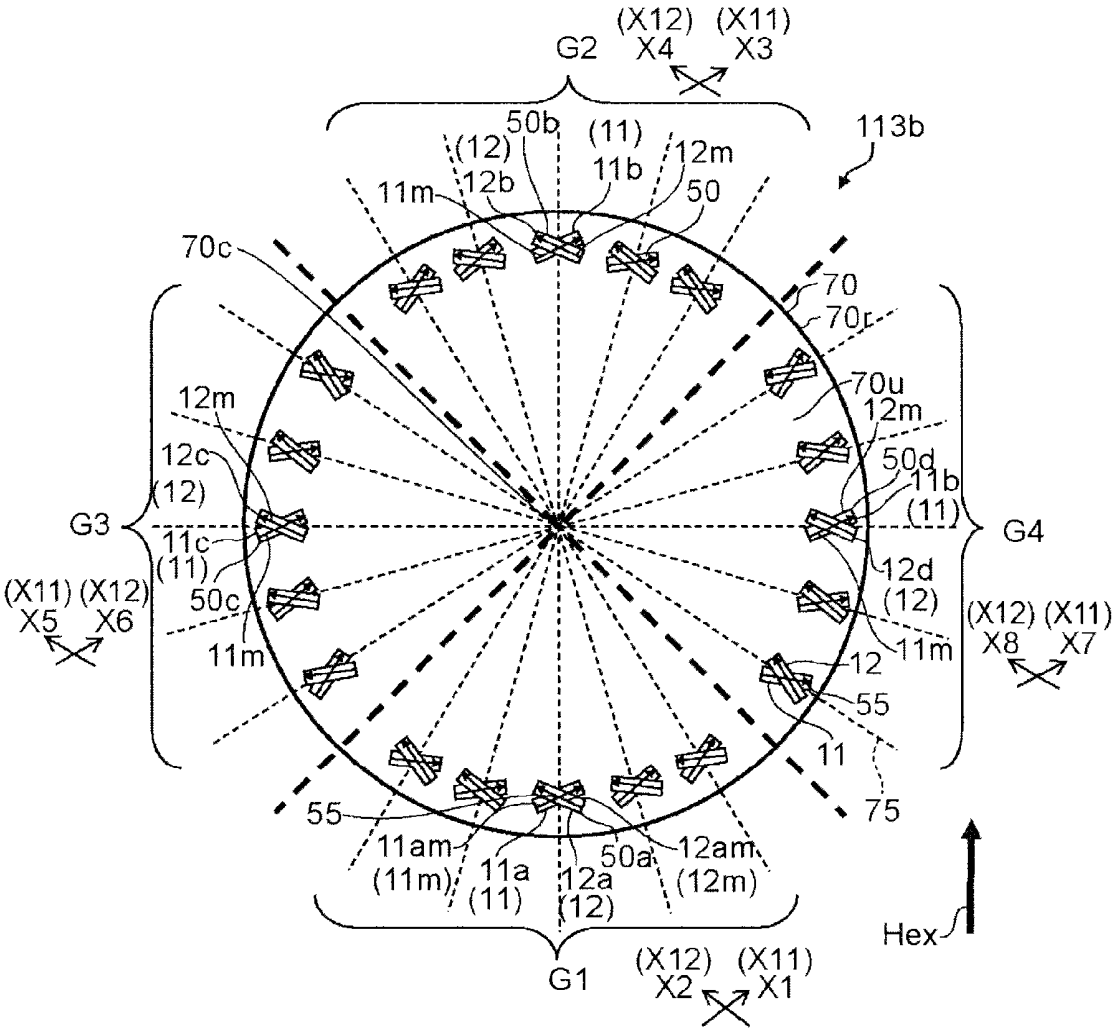
Hex

FIG. 11


G2
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(12)
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(11)
11b
12m
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11m
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70
70r
70u
12m
50d
11b
(11)
G4
12d
(12)
11m
12
55
11
75
(X12) (X11)
X8 X7
G3
12m
12c
(12)
11c
(11)
50c
11m
(X11) (X12)
X5 X6
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11am
(11m)
11a
(11)
12a
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50a
12am
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Hex
G1
(X12) (X11)
X2 X1

FIG. 12

FIG. 13A

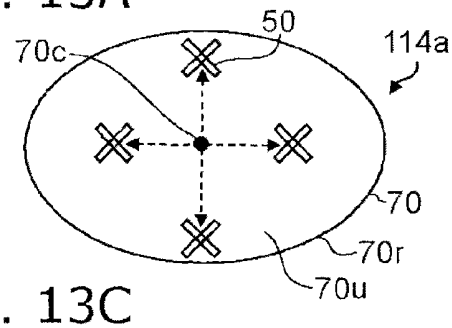


FIG. 13B

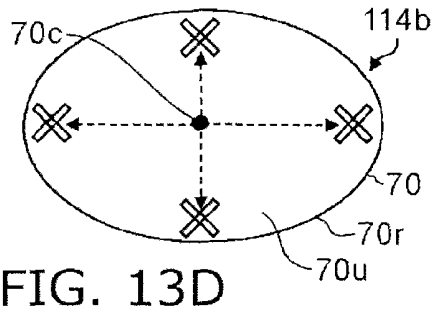


FIG. 13C

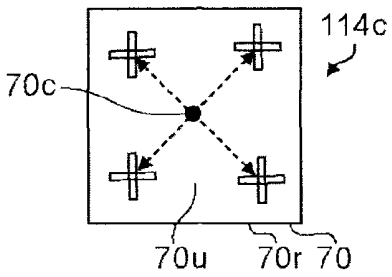


FIG. 13D

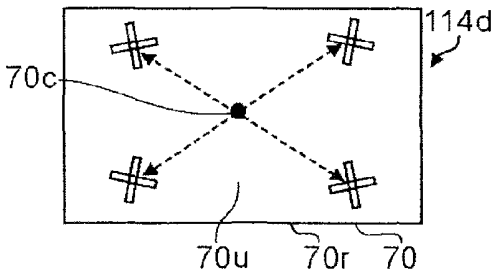


FIG. 14A

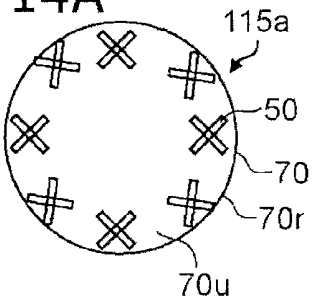


FIG. 14B

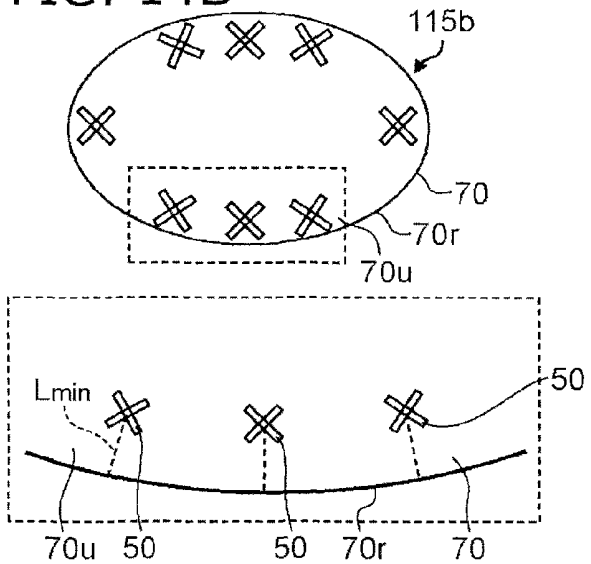


FIG. 14C

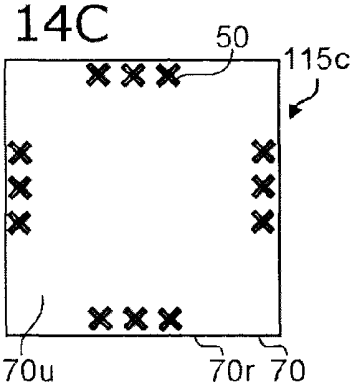


FIG. 14D

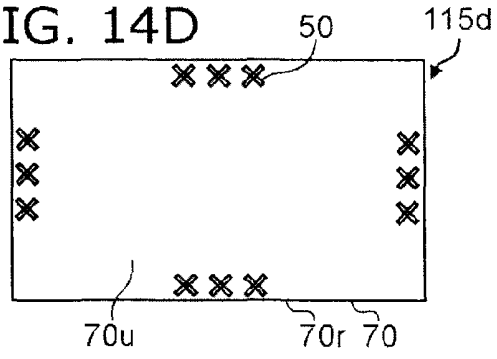


FIG. 15A

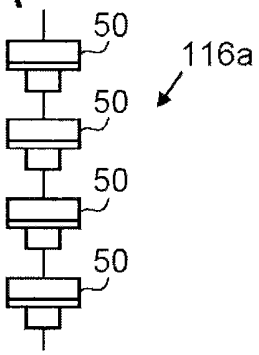


FIG. 15B

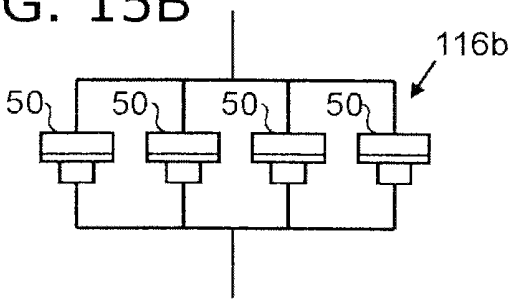
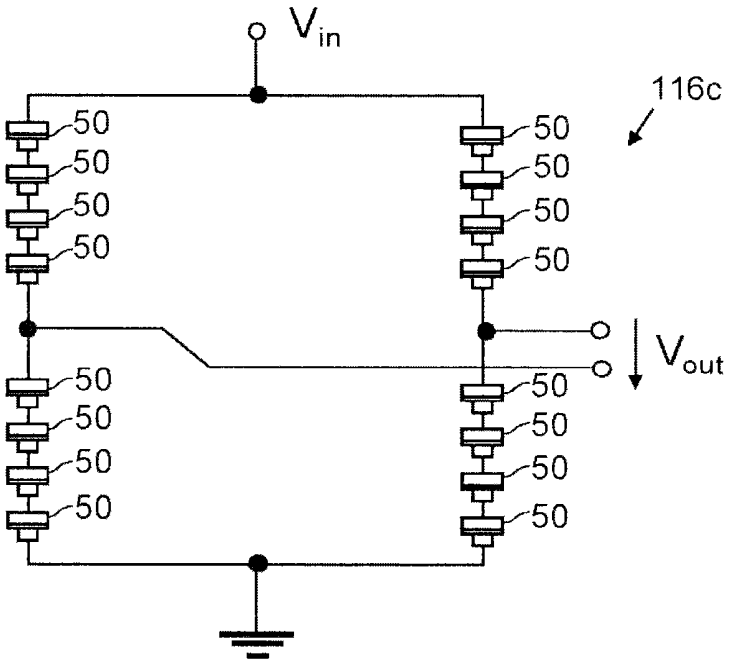


FIG. 15C



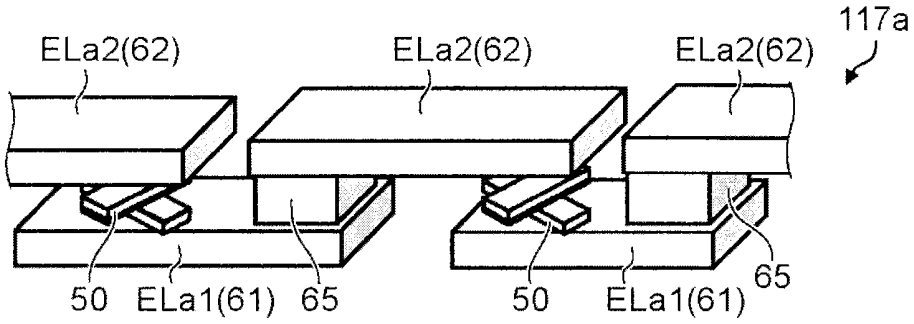


FIG. 16A

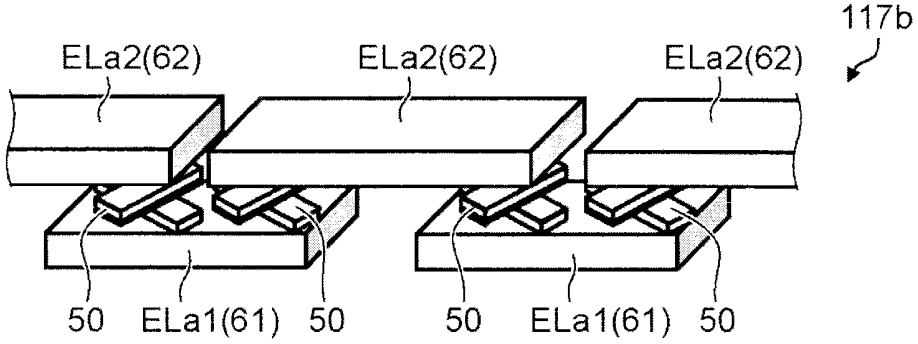


FIG. 16B

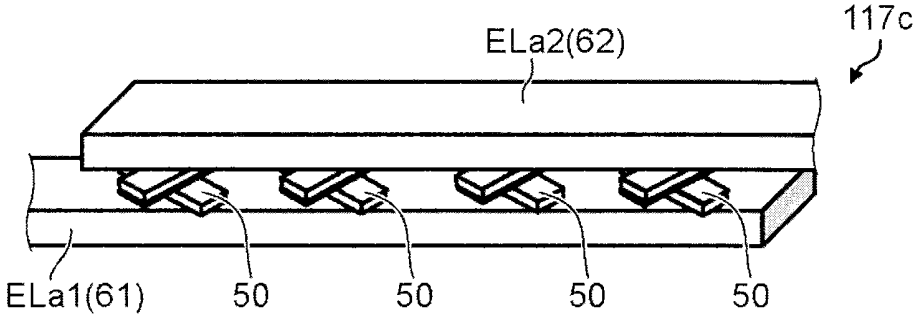


FIG. 16C

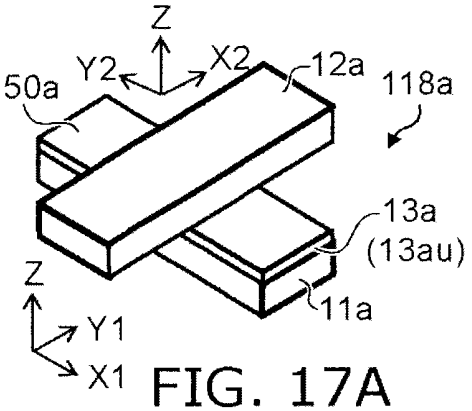


FIG. 17A

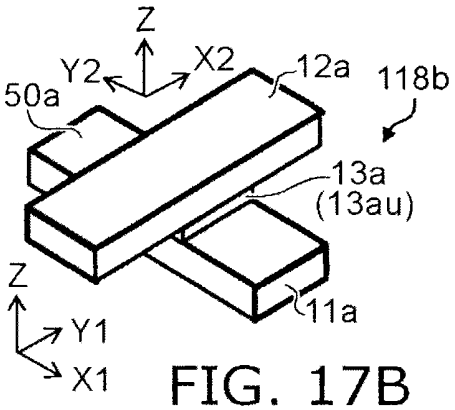


FIG. 17B

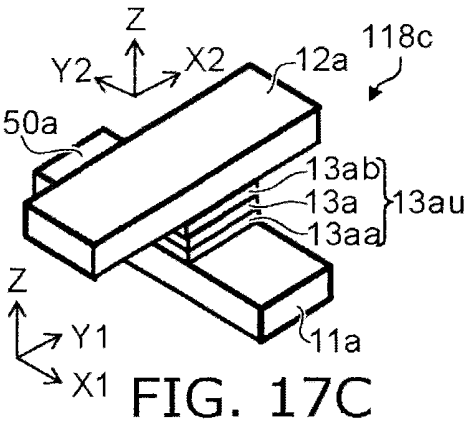


FIG. 17C

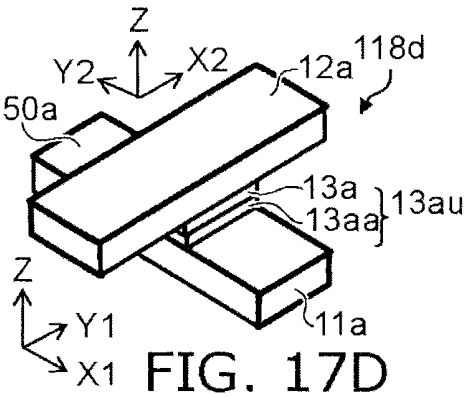


FIG. 17D

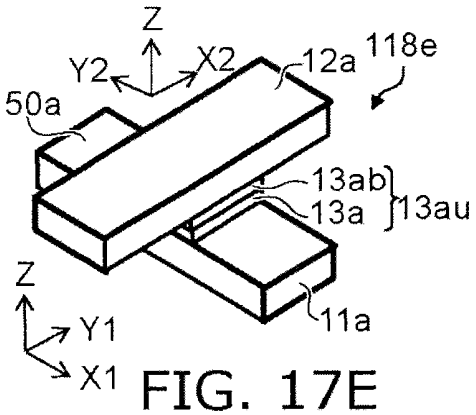


FIG. 17E

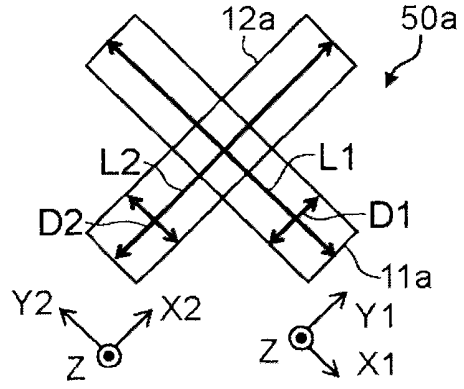


FIG. 18A

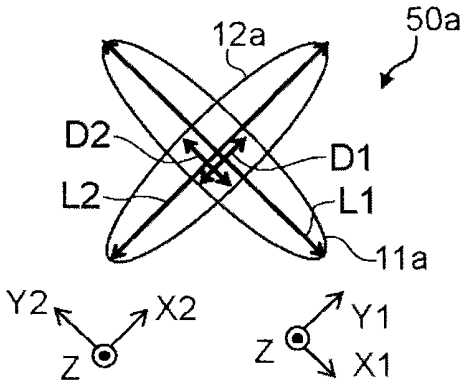


FIG. 18B

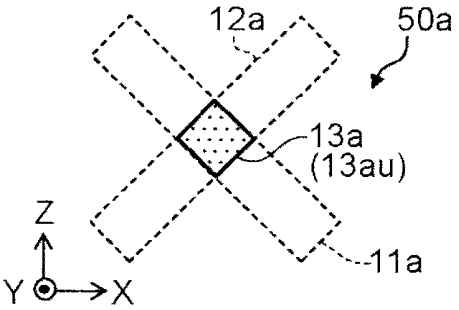


FIG. 19A

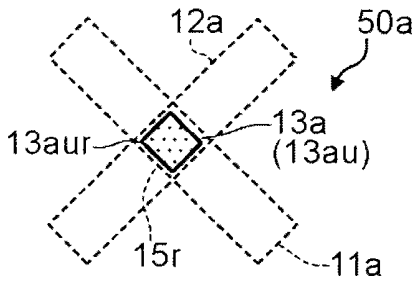


FIG. 19B

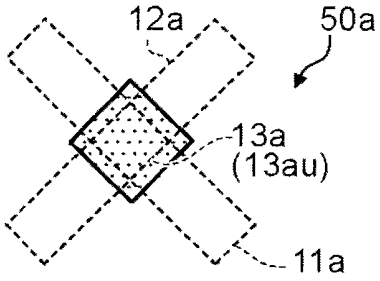


FIG. 19C

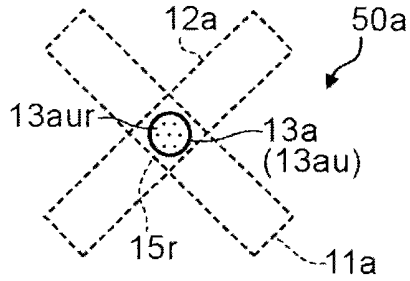


FIG. 19D

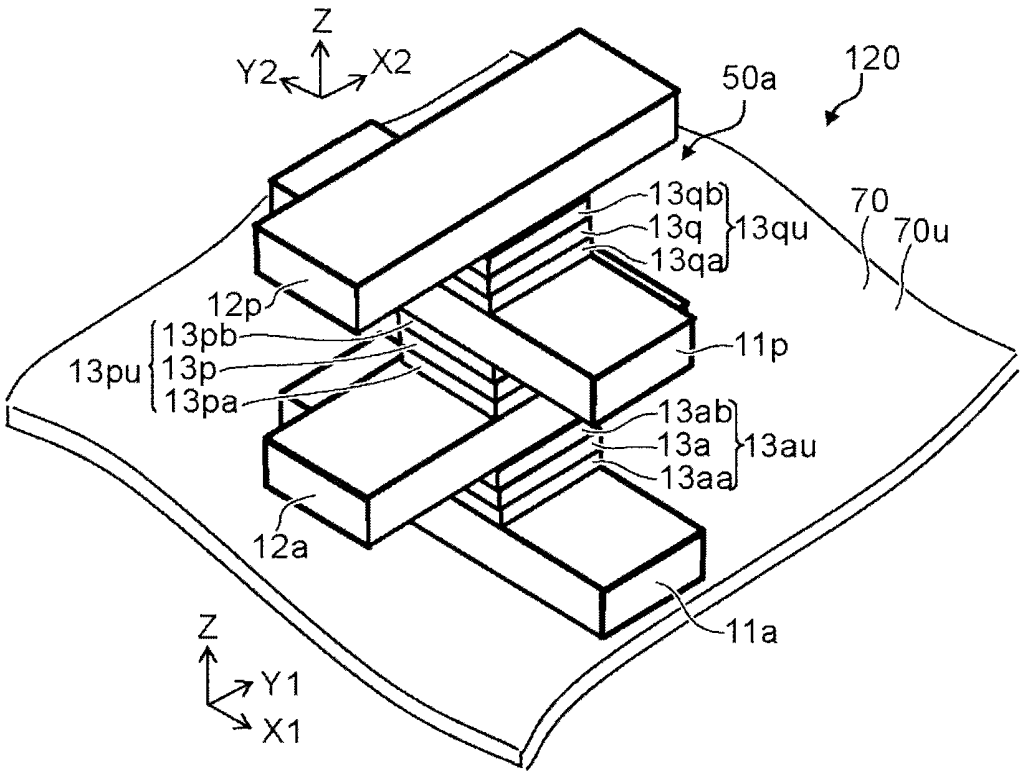


FIG. 20

FIG. 21A

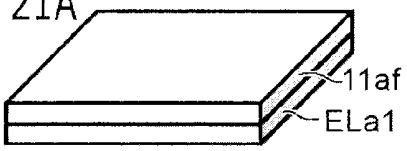


FIG. 21B

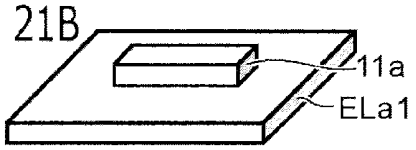


FIG. 21C

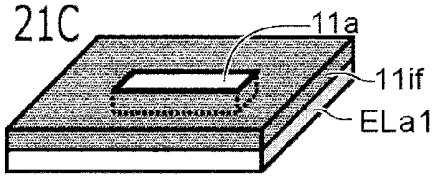


FIG. 21D

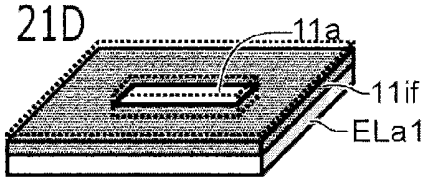


FIG. 21E

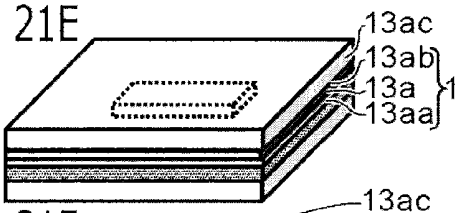


FIG. 21F

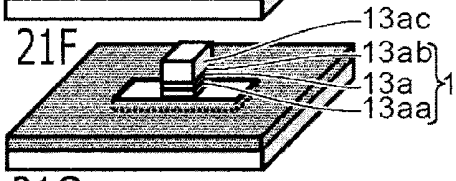


FIG. 21G

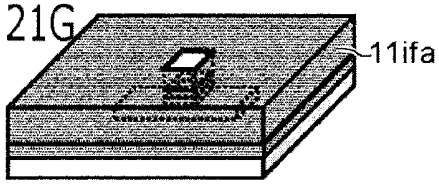


FIG. 21H

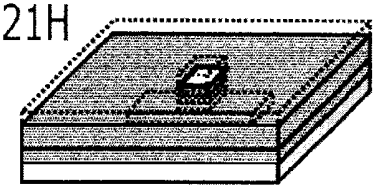


FIG. 21I

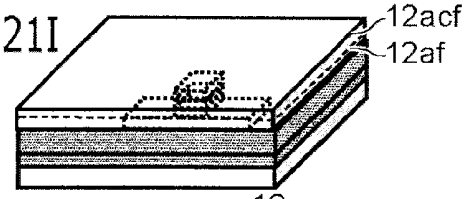


FIG. 21J

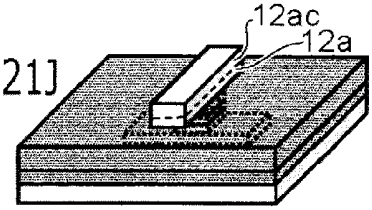


FIG. 21K

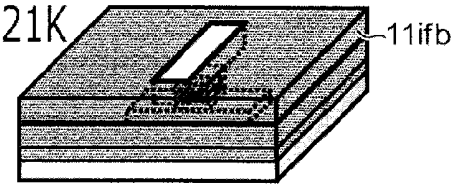


FIG. 21L

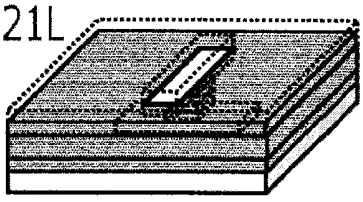


FIG. 21M

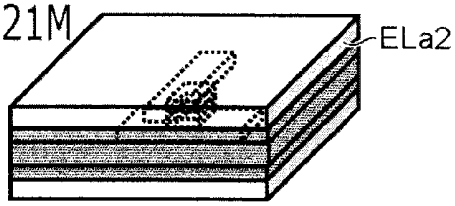


FIG. 22A

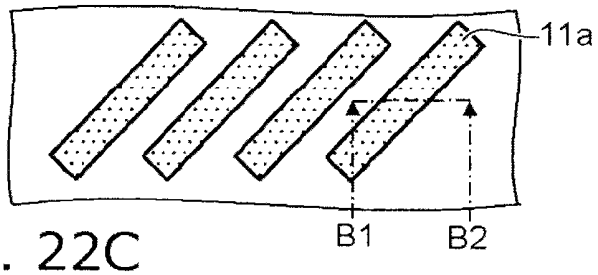


FIG. 22B

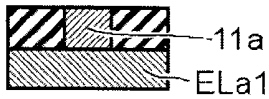


FIG. 22C

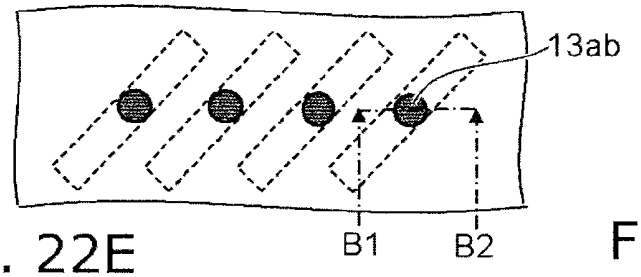


FIG. 22D

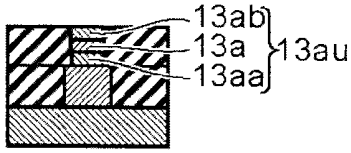


FIG. 22E

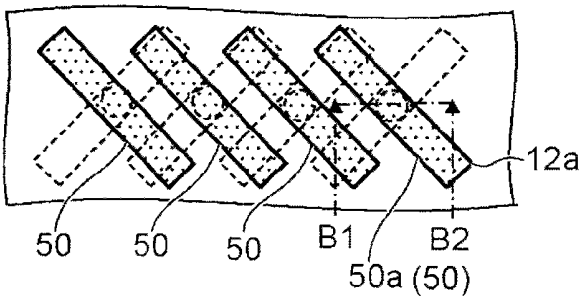


FIG. 22F

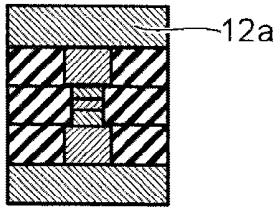


FIG. 23A

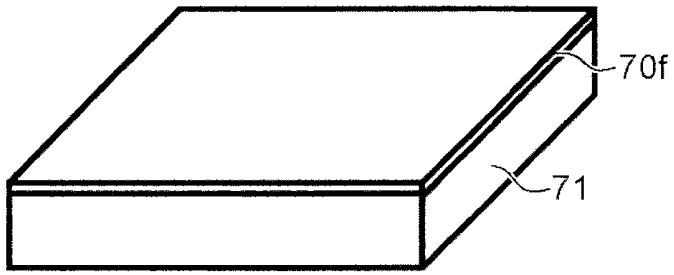


FIG. 23B

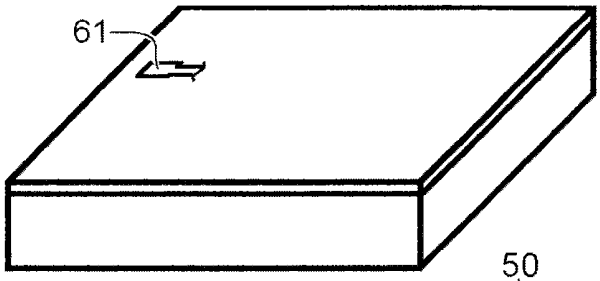


FIG. 23C

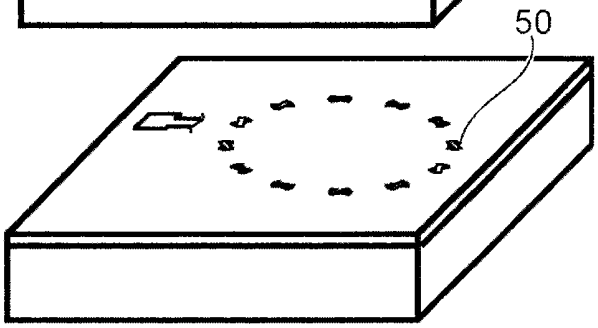


FIG. 23D

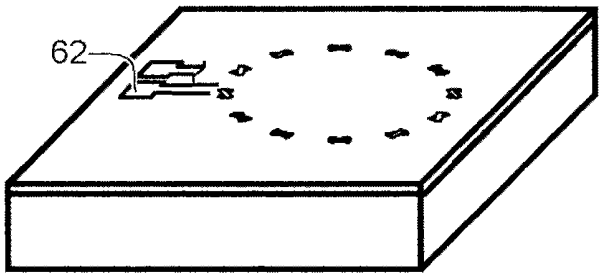


FIG. 23E

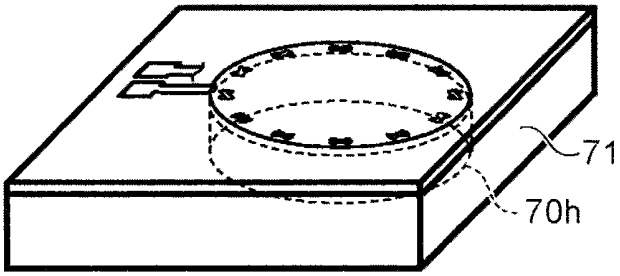


FIG. 24A

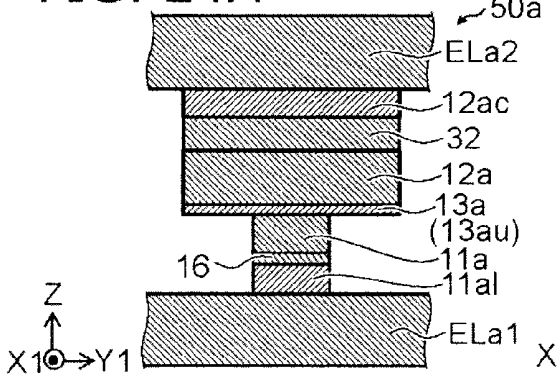


FIG. 24B

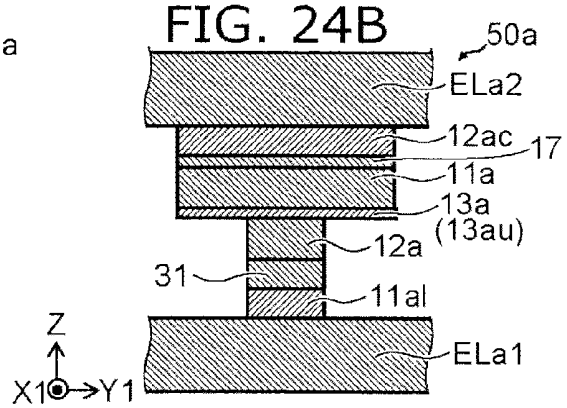
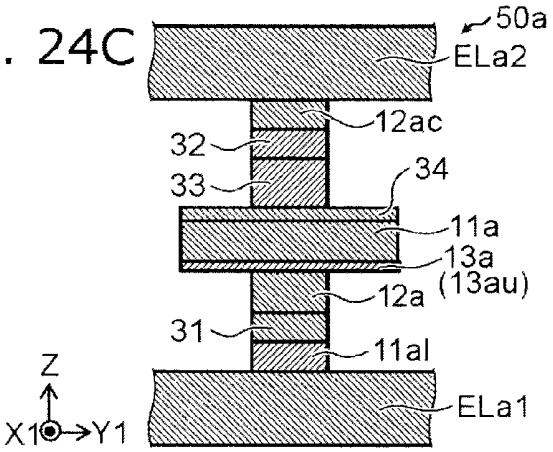


FIG. 24C



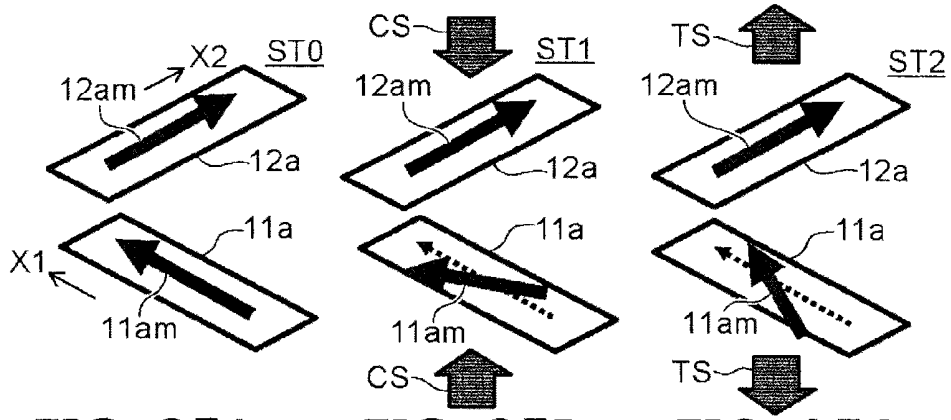


FIG. 25A FIG. 25B FIG. 25C

FIG. 25D

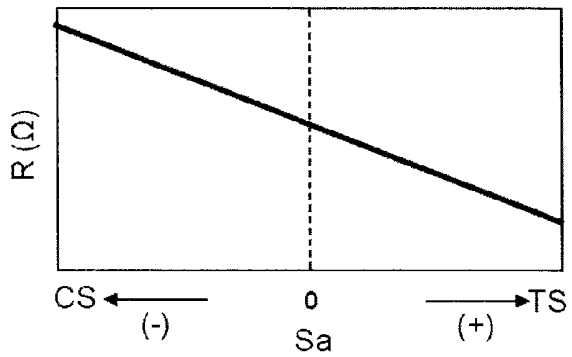


FIG. 26A

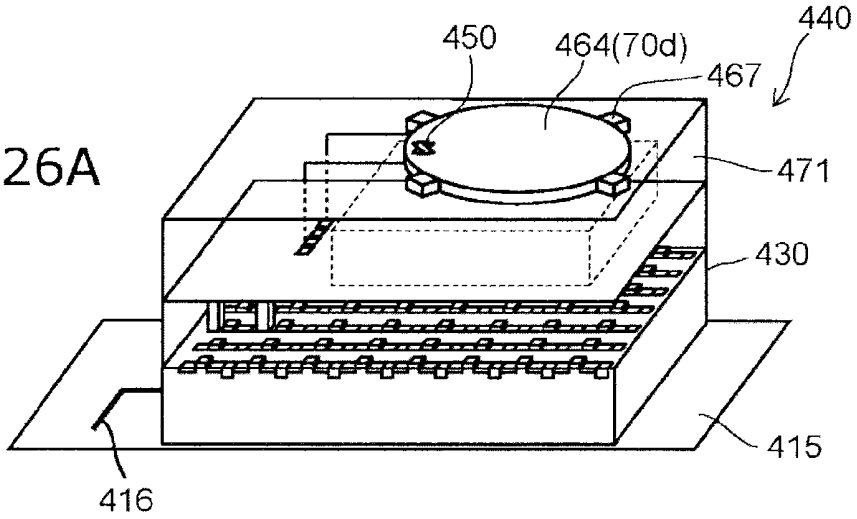


FIG. 26B

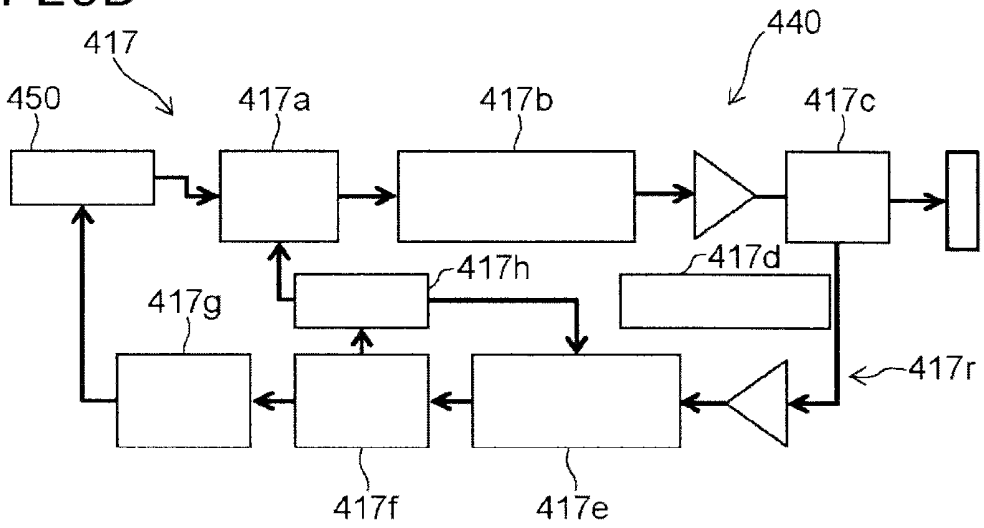


FIG. 26C

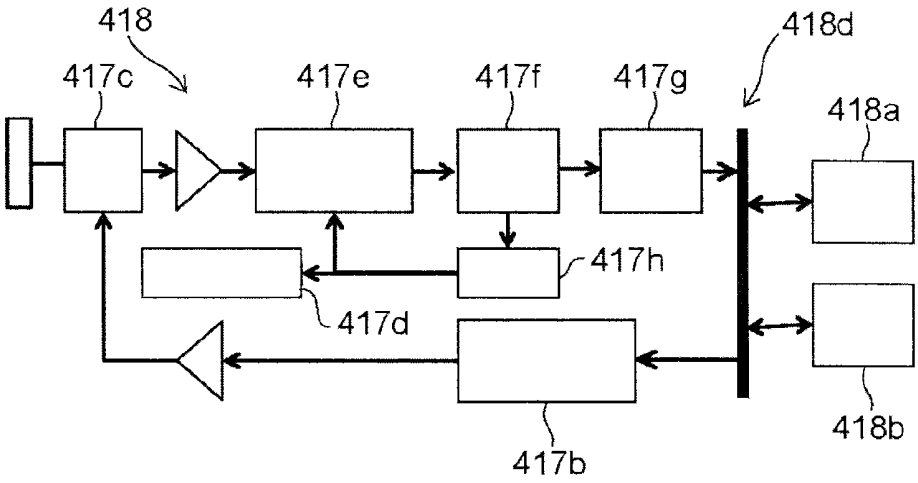


FIG. 27A

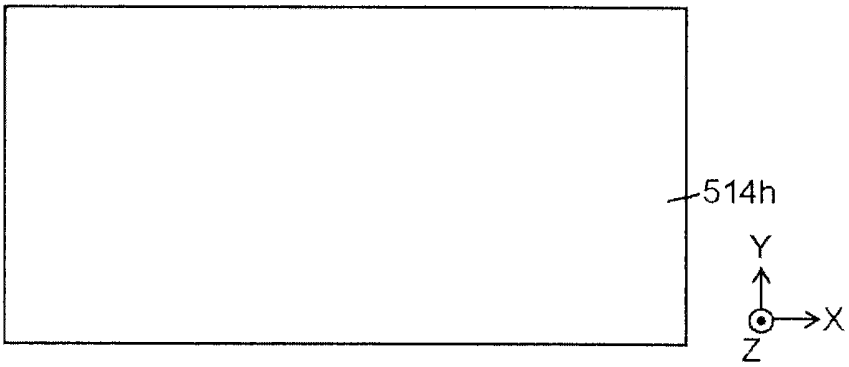


FIG. 27B

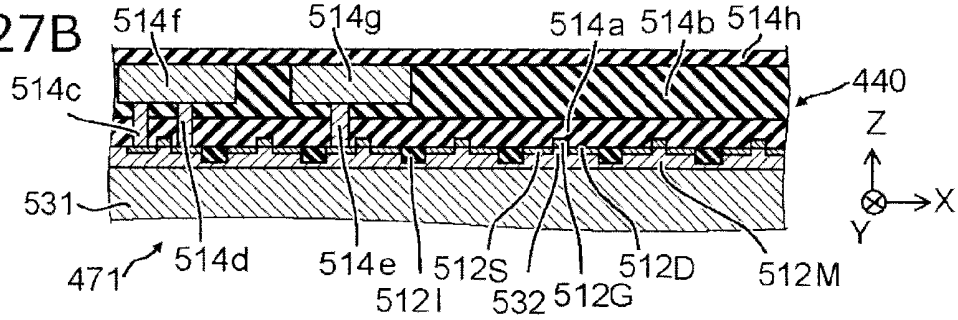


FIG. 28A

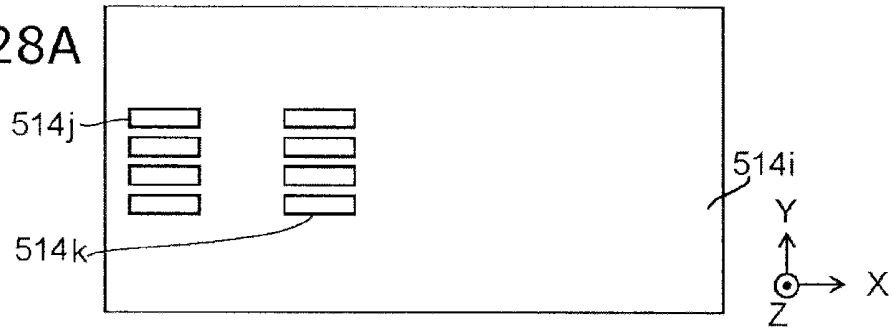


FIG. 28B

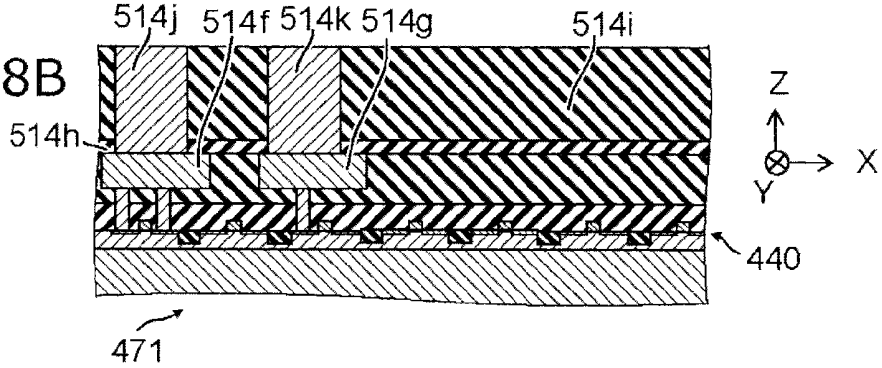


FIG. 29A

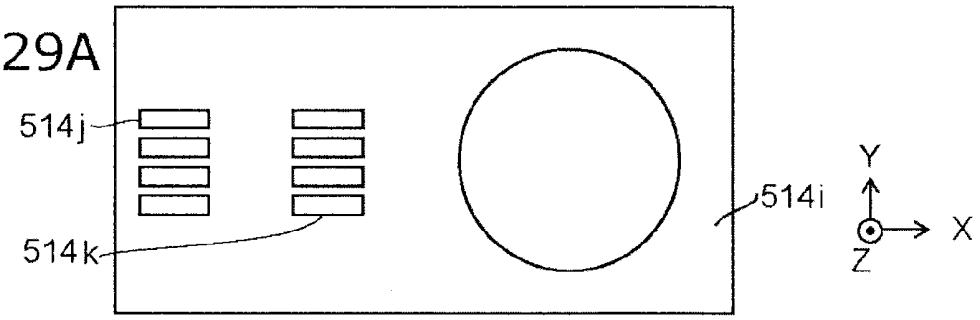


FIG. 29B

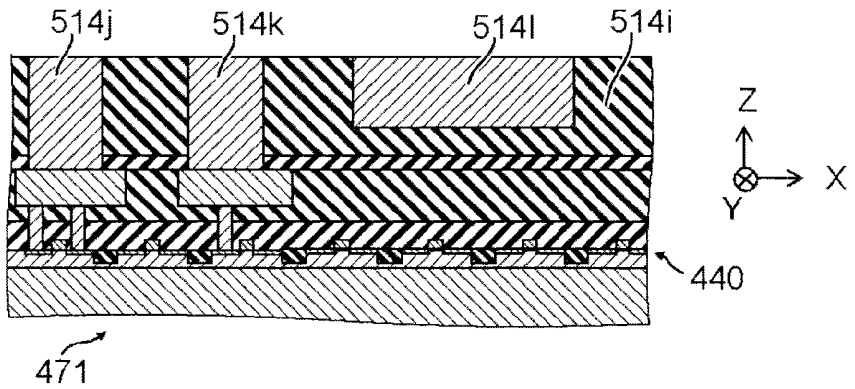


FIG. 30A

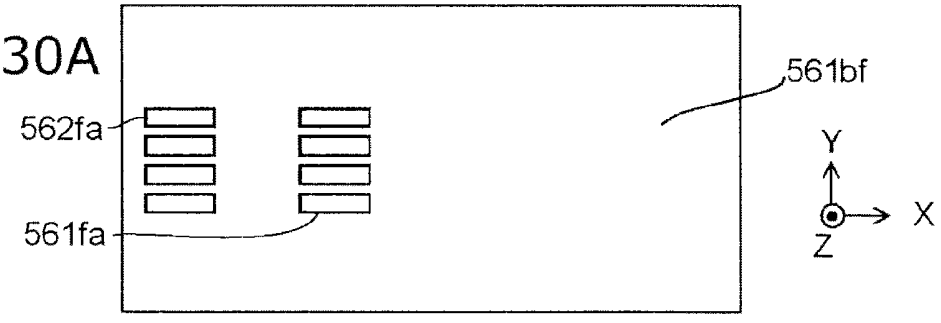


FIG. 30B

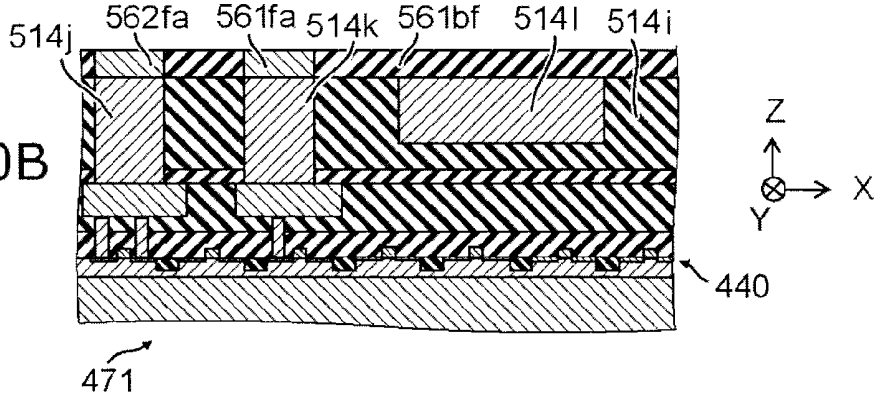


FIG. 31A

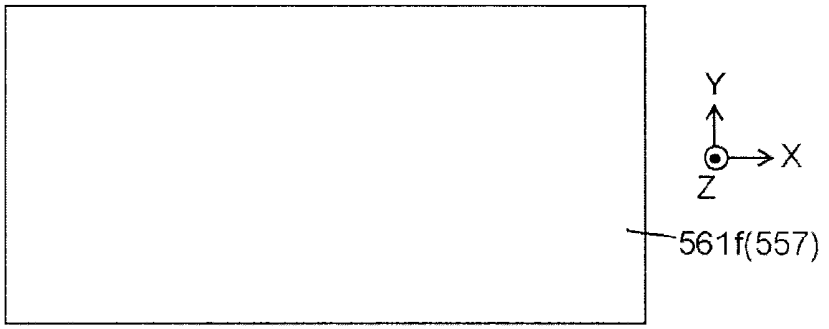


FIG. 31B

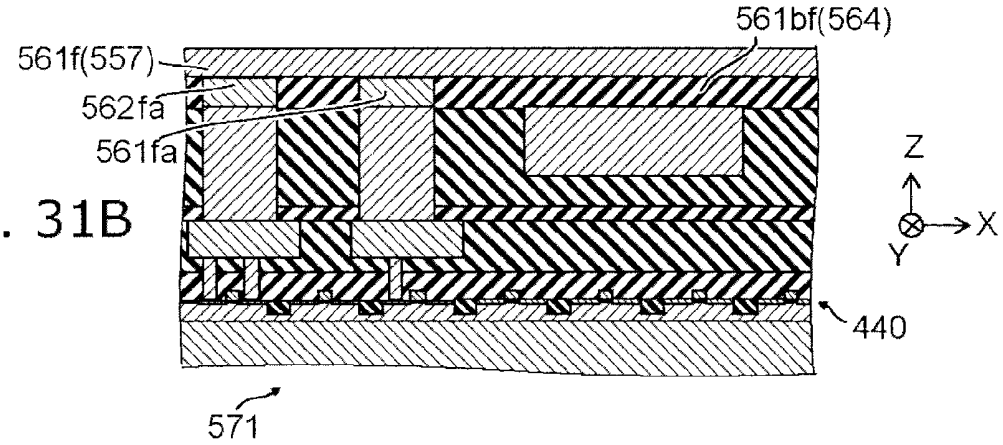


FIG. 32A

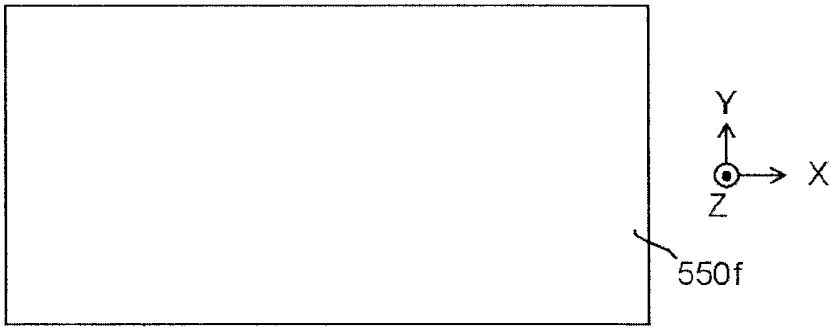


FIG. 32B

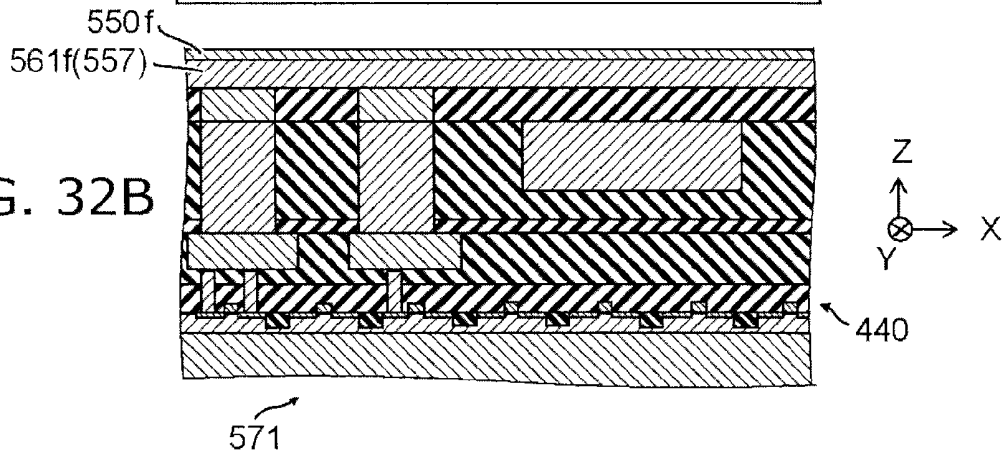


FIG. 33A

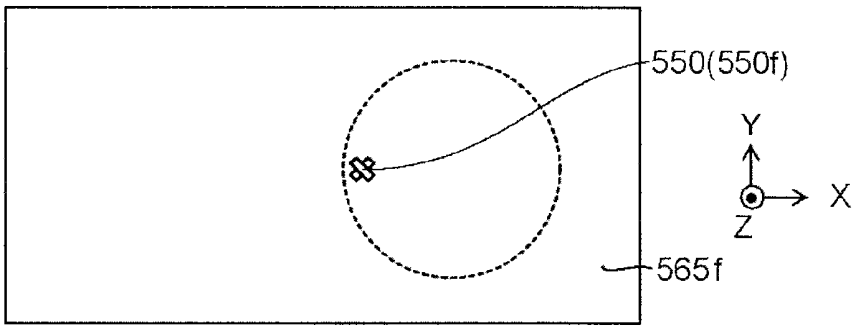


FIG. 33B

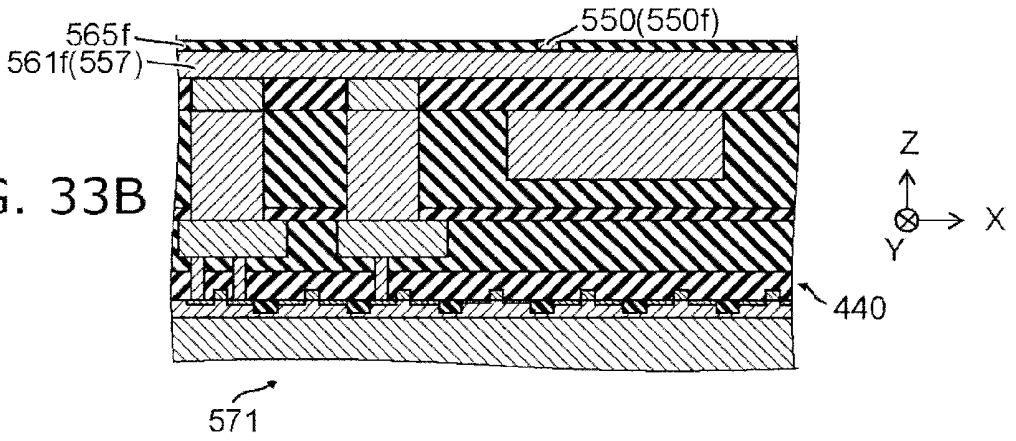


FIG. 34A

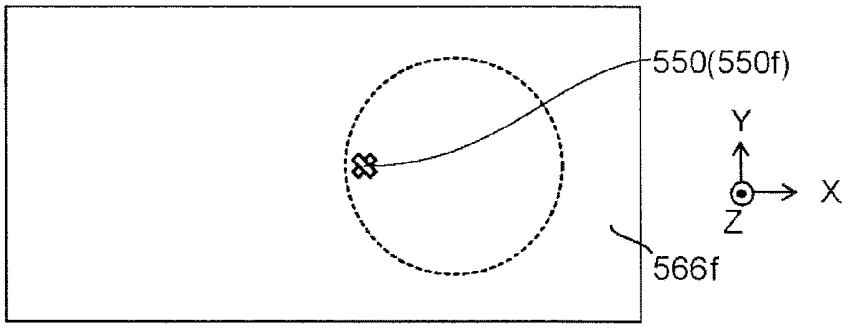


FIG. 34B

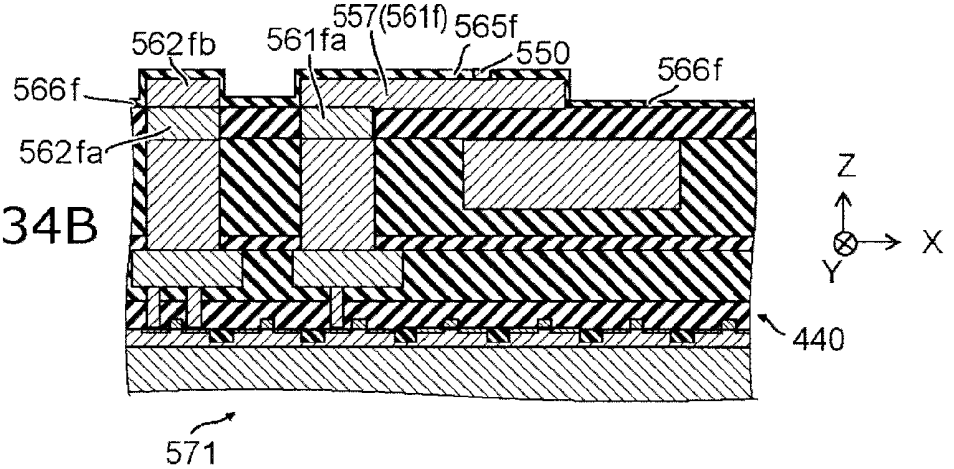


FIG. 35A

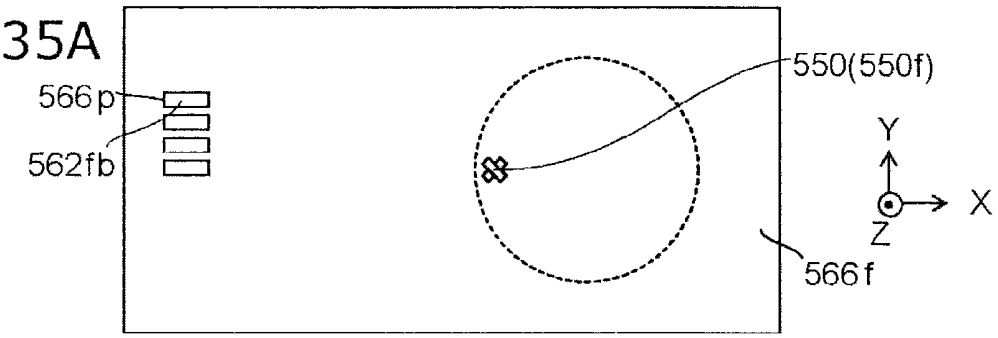


FIG. 35B

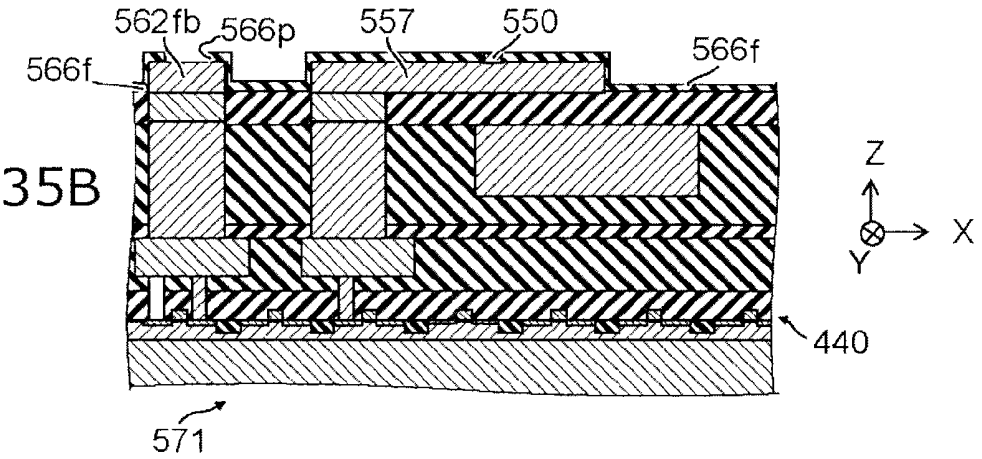


FIG. 36A

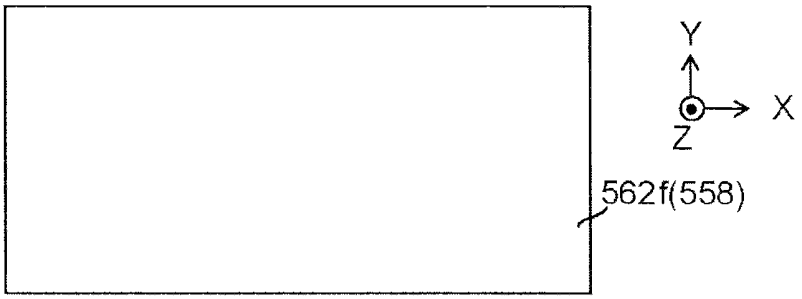


FIG. 36B

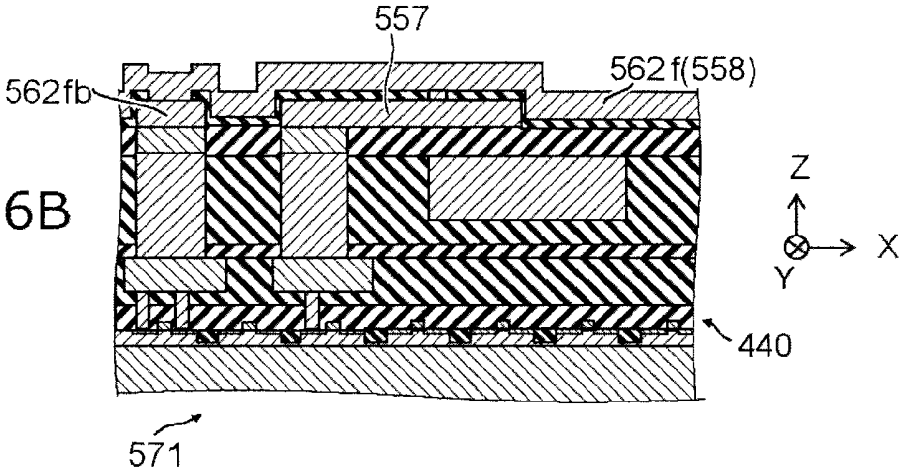


FIG. 37A

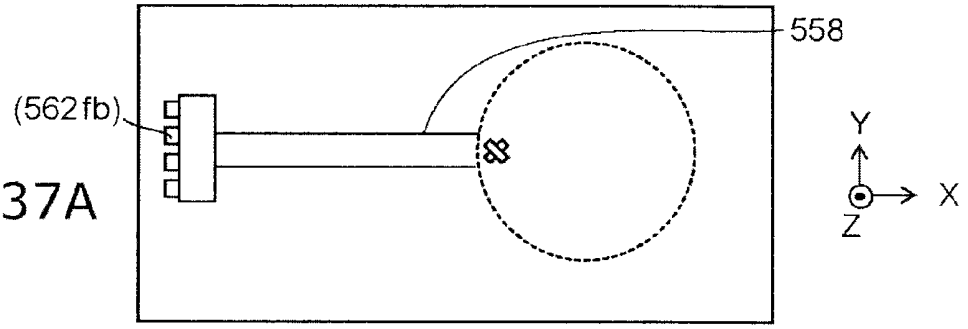


FIG. 37B

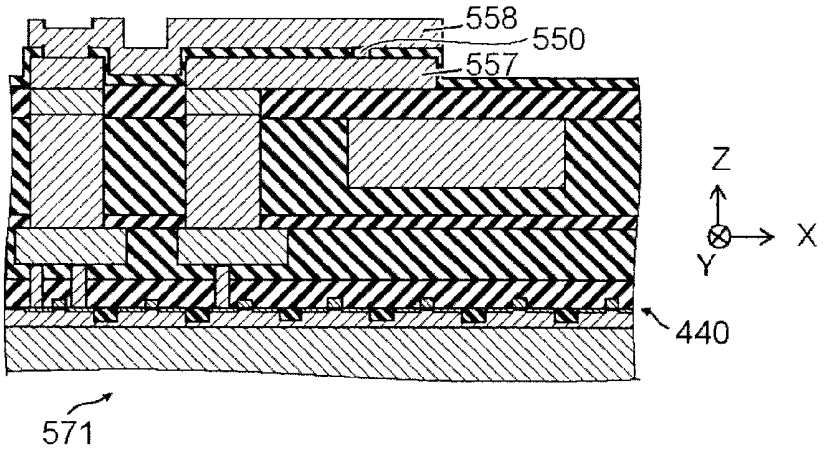


FIG. 38A

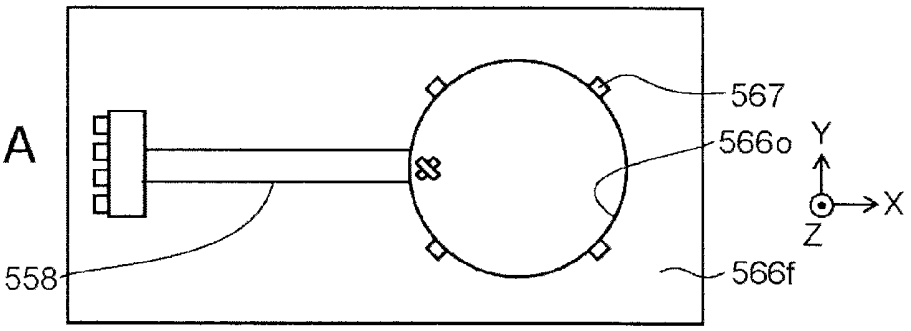
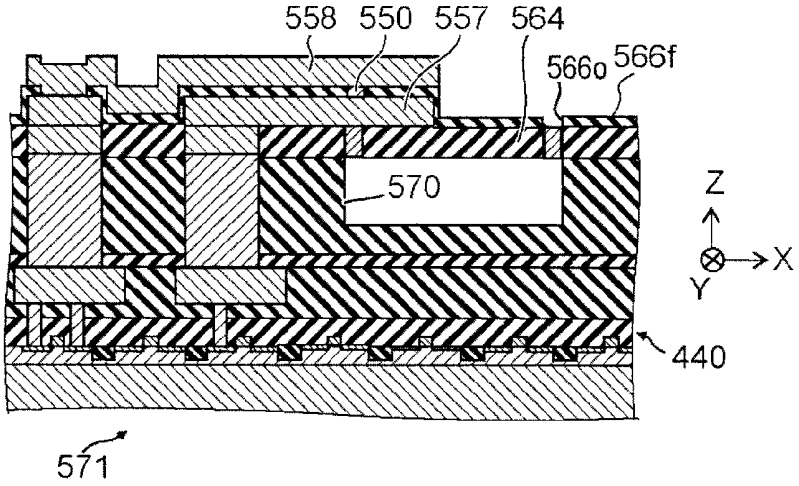


FIG. 38B



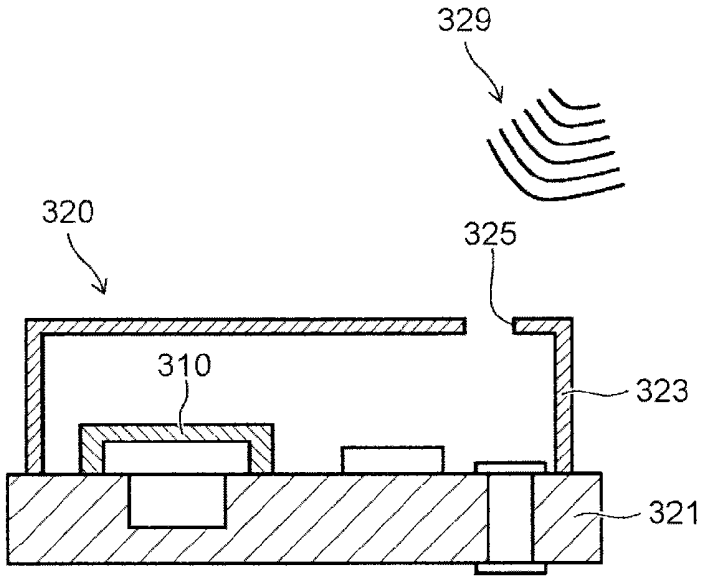


FIG. 39

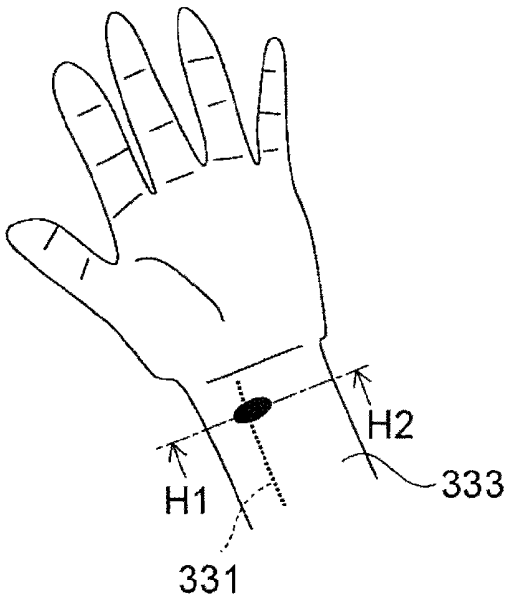


FIG. 40A

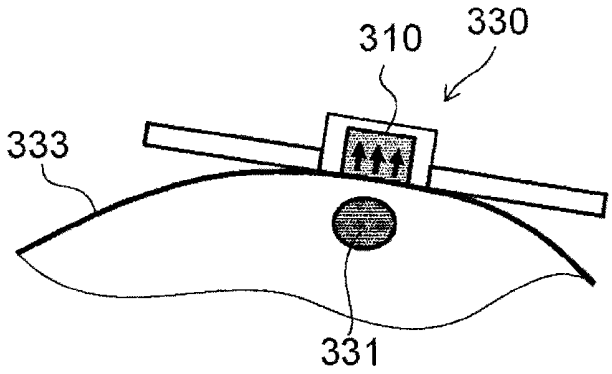


FIG. 40B

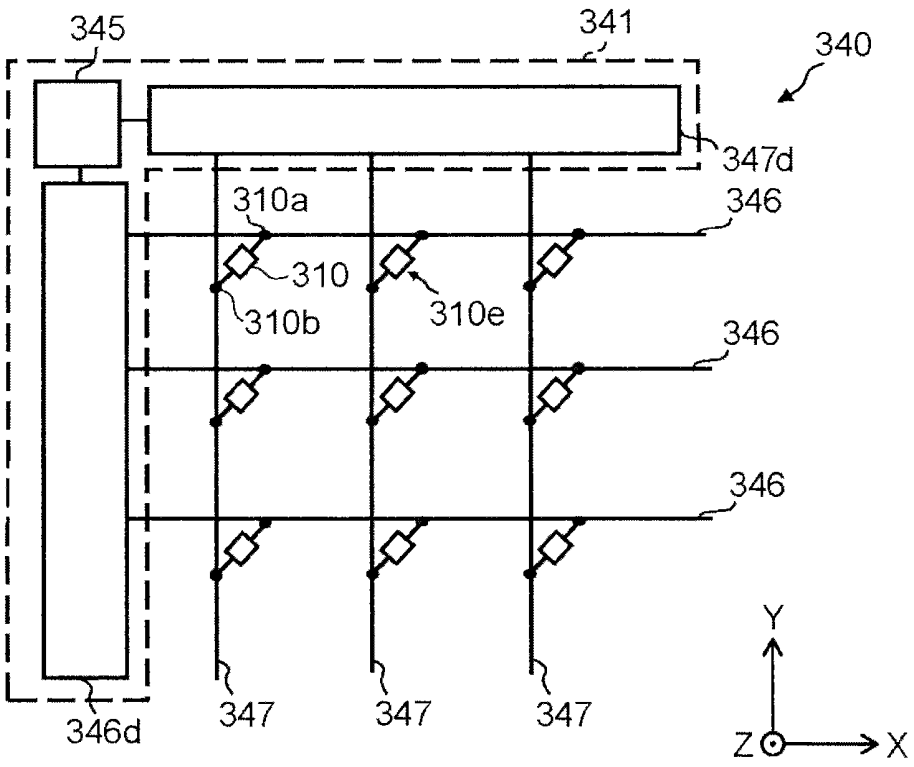

345
341
340
347d
310a
346
310
310b
310e
346
346
346d
347
347
347
Y
Z
X

FIG. 41

PRESSURE SENSOR, MICROPHONE, BLOOD PRESSURE SENSOR, AND TOUCH PANEL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2013-196065, filed on Sep. 20, 2013; the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a pressure sensor, a microphone, a blood pressure sensor, and a touch panel.

BACKGROUND

For pressure sensors using MEMS (micro electro mechanical systems) technology, there are a piezoresistance change type and an electrostatic capacitance type, for example. On the other hand, a pressure sensor using spin technology is proposed. In the pressure sensor using spin-electronics technology, a resistance change in accordance with strain is sensed. A high-sensitivity pressure sensor using spin technology is desired.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** A and FIG. **1**B are schematic views showing a pressure sensor according to a first embodiment;

FIG. **2**A to FIG. **2**D are schematic perspective views showing the pressure sensor according to the first embodiment;

FIG. **3**A to FIG. **3**F are schematic cross-sectional views showing the pressure sensor according to the first embodiment;

FIG. **4**A to FIG. **4**D are schematic diagrams showing the pressure sensor according to the first embodiment;

FIG. **5** is a schematic plan view showing the pressure sensor according to the first embodiment;

FIG. **6**A to FIG. **6**D are schematic plan views showing the pressure sensor according to the first embodiment;

FIG. **7**A to FIG. **7**F are schematic plan views showing the pressure sensor according to the first embodiment;

FIG. **8** is a schematic plan view showing the pressure sensor according to the first embodiment;

FIG. **9**A and FIG. **9**B are schematic plan views showing a pressure sensor according to the first embodiment;

FIG. **10**A to FIG. **10**C are schematic plan views showing pressure sensors according to the first embodiment;

FIG. **11** is a schematic plan view showing a pressure sensor according to the first embodiment;

FIG. **12** is a schematic plan view showing a pressure sensor according to the first embodiment;

FIG. **13**A to FIG. **13**D are schematic plan views showing pressure sensors according to the first embodiment;

FIG. **14**A to FIG. **14**D are schematic plan views showing pressure sensors according to the first embodiment;

FIG. **15**A to FIG. **15**C are schematic diagrams showing pressure sensors according to the first embodiment;

FIG. **16**A to FIG. **16**C are schematic perspective views showing pressure sensors according to the first embodiment;

FIG. **17**A to FIG. **17**E are schematic perspective views showing pressure sensors according to the first embodiment;

FIG. **18**A and FIG. **18**B are schematic plan views showing the pressure sensor according to the first embodiment;

FIG. **19**A to FIG. **19**D are schematic plan views showing the pressure sensor according to the first embodiment;

FIG. **20** is a schematic perspective view showing a pressure sensor according to the first embodiment;

FIG. **21**A to FIG. **21**M are schematic perspective views in order of the steps, showing a method for manufacturing a pressure sensor according to the first embodiment;

FIG. **22**A to FIG. **22**F are schematic views in order of the steps, showing a method for manufacturing a pressure sensor according to the first embodiment;

FIG. **23**A to FIG. **23**E are schematic perspective views in order of the steps, showing a method for manufacturing a pressure sensor according to the embodiment;

FIG. **24**A to FIG. **24**C are schematic cross-sectional views showing pressure sensors according to the first embodiment;

FIG. **25**A to FIG. **25**D are schematic diagrams showing the pressure sensor according to the first embodiment;

FIG. **26**A to FIG. **26**C are schematic diagrams showing a pressure sensor according to the first embodiment;

FIG. **27**A and FIG. **27**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **28**A and FIG. **28**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **29**A and FIG. **29**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **30**A and FIG. **30**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **31**A and FIG. **31**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **32**A and FIG. **32**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **33**A and FIG. **33**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **34**A and FIG. **34**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **35**A and FIG. **35**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **36**A and FIG. **36**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **37**A and FIG. **37**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **38**A and FIG. **38**B are schematic views showing a method for manufacturing a pressure sensor according to a third embodiment;

FIG. **39** is a schematic cross-sectional view showing a microphone according to a second embodiment;

FIG. **40**A and FIG. **40**B are schematic views showing a blood pressure sensor according to a third embodiment; and

FIG. **41** is a schematic diagram showing a touch panel according to a fourth embodiment.

DETAILED DESCRIPTION

According to one embodiment, a pressure sensor includes a support, a film unit and a first sensing element. The film

unit is supported by the support. The film unit has an upper surface. The film unit is deformable. The first sensing element is provided on the upper surface. The first sensing element includes a first magnetic layer in which a magnetization changes in accordance with a deformation of the film unit, a second magnetic layer provided apart from the first magnetic layer in a direction crossing the upper surface, and a first intermediate unit including a first intermediate layer including a portion provided between the first magnetic layer and the second magnetic layer. The first magnetic layer extends in a first direction parallel to the upper surface, and a first major axis length of the first magnetic layer in the first direction is longer than a first minor axis length of the first magnetic layer in a direction parallel to the upper surface and crossing the first direction. The second magnetic layer extends in a second direction parallel to the upper surface and crossing the first direction, and a second major axis length of the second magnetic layer in the second direction is longer than a second minor axis length of the second magnetic layer in a direction parallel to the upper surface and crossing the second direction.

According to one embodiment, a microphone includes a pressure sensor. The pressure sensor includes a support, a film unit and a first sensing element. The film unit is supported by the support. The film unit has an upper surface. The film unit is deformable. The first sensing element is provided on the upper surface. The first sensing element includes a first magnetic layer in which a magnetization changes in accordance with a deformation of the film unit, a second magnetic layer provided apart from the first magnetic layer in a direction crossing the upper surface, and a first intermediate unit including a first intermediate layer including a portion provided between the first magnetic layer and the second magnetic layer. The first magnetic layer extends in a first direction parallel to the upper surface, and a first major axis length of the first magnetic layer in the first direction is longer than a first minor axis length of the first magnetic layer in a direction parallel to the upper surface and crossing the first direction. The second magnetic layer extends in a second direction parallel to the upper surface and crossing the first direction, and a second major axis length of the second magnetic layer in the second direction is longer than a second minor axis length of the second magnetic layer in a direction parallel to the upper surface and crossing the second direction.

According to one embodiment, a blood pressure sensor includes a pressure sensor. The pressure sensor includes a support, a film unit and a first sensing element. The film unit is supported by the support. The film unit has an upper surface. The film unit is deformable. The first sensing element is provided on the upper surface. The first sensing element includes a first magnetic layer in which a magnetization changes in accordance with a deformation of the film unit, a second magnetic layer provided apart from the first magnetic layer in a direction crossing the upper surface, and a first intermediate unit including a first intermediate layer including a portion provided between the first magnetic layer and the second magnetic layer. The first magnetic layer extends in a first direction parallel to the upper surface, and a first major axis length of the first magnetic layer in the first direction is longer than a first minor axis length of the first magnetic layer in a direction parallel to the upper surface and crossing the first direction. The second magnetic layer extends in a second direction parallel to the upper surface and crossing the first direction, and a second major axis length of the second magnetic layer in the second direction is longer than a second minor axis length of the second magnetic layer in a direction parallel to the upper surface and crossing the second direction.

According to one embodiment, a touch panel includes a pressure sensor. The pressure sensor includes a support, a film unit and a first sensing element. The film unit is supported by the support. The film unit has an upper surface. The film unit is deformable. The first sensing element is provided on the upper surface. The first sensing element includes a first magnetic layer in which a magnetization changes in accordance with a deformation of the film unit, a second magnetic layer provided apart from the first magnetic layer in a direction crossing the upper surface, and a first intermediate unit including a first intermediate layer including a portion provided between the first magnetic layer and the second magnetic layer. The first magnetic layer extends in a first direction parallel to the upper surface, and a first major axis length of the first magnetic layer in the first direction is longer than a first minor axis length of the first magnetic layer in a direction parallel to the upper surface and crossing the first direction. The second magnetic layer extends in a second direction parallel to the upper surface and crossing the first direction, and a second major axis length of the second magnetic layer in the second direction is longer than a second minor axis length of the second magnetic layer in a direction parallel to the upper surface and crossing the second direction.

Various embodiments will be described hereinafter with reference to the accompanying drawings.

The drawings are schematic or conceptual; and the relationships between the thickness and width of portions, the proportions of sizes among portions, etc. are not necessarily the same as the actual values thereof. Further, the dimensions and proportions may be illustrated differently among drawings, even for identical portions.

In the specification of this application and the drawings, components similar to those described in regard to a drawing thereinabove are marked with the same reference numerals, and a detailed description is omitted as appropriate.

First Embodiment

FIG. **1**A and FIG. **1**B are schematic views illustrating a pressure sensor according to a first embodiment.

FIG. **1**A is a perspective view. FIG. **1**B is a cross-sectional view taken along line A**1**-A**2** of FIG. **1**A.

As shown in FIG. **1**A and FIG. **1**B, a pressure sensor **110** according to the embodiment includes a film unit **70** and a first sensing element **50***a*.

The film unit **70** has an upper surface **70***u*. The film unit **70** has flexibility. The upper surface **70***u* includes a flexible region. The film unit **70** is deformable. The film unit **70** is supported by a support **70***s*, for example.

The support **70***s* is a substrate, for example. The film unit **70** is a diaphragm, for example. The film unit **70** may be integrated with or separated from the support **70***s*. For the film unit **70**, the same material as the support **70***s* may be used, or a different material from the support **70***s* may be used. Part of a substrate that forms the support **70***s* may be removed, and a portion of the substrate with a smaller thickness may form the film unit **70**.

The thickness of the film unit **70** is smaller than the thickness of the support **70***s*. In the case where the same material is used for the film unit **70** and the support **70***s* and they are integrated together, a portion with a smaller thickness forms the film unit **70**, and a portion with a larger thickness forms the support **70***s*.

The support **70***s* may have a through hole **70***h* penetrating through the support **70***s* in the thickness direction, and the film unit **70** may be provided so as to cover the through hole **70***h*, for example. At this time, the film of the material that forms the film unit **70** may extend also on a portion other than the through hole of the support **70***s*, for example. At this time, of the film of the material that forms the film unit **70**, a portion overlapping the through hole **70***h* forms the film unit **70**.

The film unit **70** has an outer edge **70***r*. In the case where the same material is used for the film unit **70** and the support **70***s* and they are integrated together, the outer edge of the portion with a smaller thickness is the outer edge **70***r* of the film unit **70**. In the case where the support **70***s* has the through hole **70***h* penetrating through the support **70***s* in the thickness direction and the film unit **70** is provided so as to cover the through hole **70***h*, the outer edge of the portion overlapping the through hole **70***h* of the film of the material that forms the film unit **70** is the outer edge **70***r* of the film unit **70**.

The support **70***s* may continuously support the outer edge **70***r* of the film unit **70**, and may support part of the outer edge **70***r* of the film unit **70**.

The first sensing element **50***a* is provided on the upper surface **70***u* of the film unit **70**.

In the specification of this application, the state of being "provided on" includes not only the state of being provided in direct contact but also the state of being provided via another component.

In this example, a plurality of sensing elements **50** are provided on the film unit **70**. The sensing element **50** includes a first to a fourth sensing element **50***a* to **50***d*, for example. The number of sensing elements **50** provided on the film unit **70** may be one. The number of sensing elements **50** may be 5 or more.

In this example, a first interconnection **61** and a second interconnection **62** are provided in the pressure sensor **110**. The first interconnection **61** and the second interconnection **62** are connected to the sensing element **50**. An interlayer insulation film is provided between the first interconnection **61** and the second interconnection **62**, for example, and the first interconnection **61** and the second interconnection **62** are electrically insulated. A voltage is applied between the first interconnection **61** and the second interconnection **62**, and the voltage is applied to the sensing element **50** via the first interconnection **61** and the second interconnection **62**. When a pressure is applied to the pressure sensor **110**, the film unit **70** is deformed. In the sensing element **50**, the electric resistance changes in accordance with the deformation of the film unit **70**. The pressure is sensed by sensing the change in electric change via the first interconnection **61** and the second interconnection **62**.

The direction perpendicular to the upper surface **70***u* of the film unit **70** is defined as the Z-axis direction. One direction perpendicular to the Z-axis direction is defined as the X-axis direction. The direction perpendicular to the Z-axis direction and the X-axis direction is defined as the Y-axis direction.

The film unit **70** has a centroid **70***c*, for example. The centroid **70***c* is the centroid of the shape of the film unit **70** when the film unit **70** is projected onto the X-Y plane. The centroid **70***c* is the centroid in the X-Y plane of the shape of the film unit **70**. The centroid **70***c* corresponds to the centroid of the upper surface **70***u* of the film unit **70**.

In this example, the line connecting the first sensing element **50***a* and the second sensing element **50***b* passes through the centroid **70***c*. That is, the centroid **70***c* of the film unit **70** is disposed between the first sensing element **50***a* and the second sensing element **50***b*. The line connecting the third sensing element **50***c* and the fourth sensing element **50***d* passes through the centroid **70***c*. That is, the centroid **70***c* of the film unit **70** is disposed between the third sensing element **50***c* and the fourth sensing element **50***d*. In this example, the line connecting the third sensing element **50***c* and the fourth sensing element **50***d* crosses the line connecting the first sensing element **50***a* and the second sensing element **50***b*.

Examples of the first to fourth sensing elements **50***a* to **50***d* will now be described.

FIG. **2**A to FIG. **2**D are schematic perspective views illustrating the pressure sensor according to the first embodiment.

FIG. **2**A to FIG. **2**D show examples of the first to fourth sensing elements **50***a* to **50***d*, respectively. In the drawings, the film unit **70** (and the upper surface **70***u* of the film unit **70**) is omitted.

As shown in FIG. **2**A, the first sensing element **50***a* includes a first magnetic layer **11***a*, a second magnetic layer **12***a*, and a first intermediate unit **13***au*. The first sensing element **50***a* is provided on part of the upper surface **70***u* of the film unit **70**.

The magnetization of the first magnetic layer **11***a* (the direction thereof) is variable. The first magnetic layer **11***a* is a magnetization free layer, for example.

The second magnetic layer **12***a* is apart from the first magnetic layer **11***a* in a direction crossing the upper surface **70***u* (for example, the Z-axis direction). As illustrated in FIG. **1**B, the first magnetic layer **11***a* is disposed between the second magnetic layer **12***a* and the film unit **70**, for example. In the embodiment, the second magnetic layer **12***a* may be disposed between the first magnetic layer **11***a* and the film unit **70**.

The first intermediate unit **13***au* includes a first intermediate layer **13***a*. The first intermediate layer **13***a* includes a portion provided between the first magnetic layer **11***a* and the second magnetic layer **12***a*.

The first magnetic layer **11***a* extends in a first direction X1. The first direction X1 is substantially parallel to the upper surface **70***u*, for example. A first major axis length L1 of the first magnetic layer **11***a* in the first direction X1 is longer than a first minor axis length D1 of the first magnetic layer **11***a* in a direction Y2 substantially parallel to the upper surface **70***u* and crossing (for example, orthogonal to) the first direction X1.

The second magnetic layer **12***a* extends in a second direction X2. The second direction X2 is substantially parallel to the upper surface **70***u* and crosses the first direction X1, for example. A second major axis length L2 of the second magnetic layer **12***a* in the second direction X2 is longer than a second minor axis length D2 of the second magnetic layer **12***a* in a direction Y2 substantially parallel to the upper surface **70***u* and crossing (for example, orthogonal to) the second direction X2.

The second sensing element **50***b* is provided on part of the upper surface **70***u* of the film unit **70**.

As shown in FIG. **2**B, the second sensing element **50***b* includes a third magnetic layer **11***b*, a fourth magnetic layer **12***b*, and a second intermediate unit **13***bu*. The magnetization of the third magnetic layer **11***b* (the direction thereof) is variable. The third magnetic layer **11***b* is a magnetization free layer, for example.

The fourth magnetic layer **12***b* is apart from the third magnetic layer **11***b* in a direction crossing the upper surface **70***u* (for example, the Z-axis direction). As illustrated in

FIG. 1B, the third magnetic layer **11***b* is disposed between the fourth magnetic layer **12***b* and the film unit **70**, for example. In the embodiment, the fourth magnetic layer **12***b* may be disposed between the third magnetic layer **11***b* and the film unit **70**.

The second intermediate unit **13***bu* includes a second intermediate layer **13***b*. The second intermediate layer **13***b* includes a portion provided between the third magnetic layer **11***b* and the fourth magnetic layer **12***b*.

The third magnetic layer **11***b* extends in a third direction X3. The third direction X3 is substantially parallel to the upper surface **70***u*, for example. A third major axis length L3 of the third magnetic layer **11***b* in the third direction X3 is longer than a third minor axis length D3 of the third magnetic layer **11***b* in a direction Y3 substantially parallel to the upper surface **70***u* and crossing (for example, orthogonal to) the third direction X3.

The fourth magnetic layer **12***b* extends in a fourth direction X4. The fourth direction X4 is substantially parallel to the upper surface **70***u* and crosses the third direction X3, for example. A fourth major axis length L4 of the fourth magnetic layer **12***b* in the fourth direction X4 is longer than a fourth minor axis length D4 of the fourth magnetic layer **12***b* in a direction Y4 substantially parallel to the upper surface **70***u* and crossing (for example, orthogonal to) the fourth direction X4.

The third direction X3 may run along the first direction X1, for example. The third direction X3 may be parallel to the first direction X1, for example. The absolute value of the angle between the first direction X1 and the third direction X3 may be 5 degrees or less. As described later, the third direction X3 and the first direction X1 may cross each other. Examples of the angle between the first direction X1 and the third direction X3 are described later.

The third sensing element **50***c* is provided on part of the upper surface **70***u*.

As shown in FIG. **2**C, the third sensing element **50***c* includes a fifth magnetic layer **11***c*, a sixth magnetic layer **12***c*, and a third intermediate unit **13***cu*.

The magnetization of the fifth magnetic layer **11***c* (the direction thereof) is variable. The fifth magnetic layer **11***c* is a magnetization free layer, for example.

The sixth magnetic layer **12***c* is apart from the fifth magnetic layer **11***c* in a direction crossing the upper surface **70***u* (for example, the Z-axis direction). The fifth magnetic layer **11***c* is disposed between the sixth magnetic layer **12***c* and the film unit **70**, for example. In the embodiment, the sixth magnetic layer **12***c* may be disposed between the fifth magnetic layer **11***c* and the film unit **70**.

The third intermediate unit **13***cu* includes a third intermediate layer **13***c*. The third intermediate layer **13***c* includes a portion provided between the fifth magnetic layer **11***c* and the sixth magnetic layer **12***c*.

The fifth magnetic layer **11***c* extends in a fifth direction X5. The fifth direction X5 is substantially parallel to the upper surface **70***u*, for example. A fifth major axis length L5 of the fifth magnetic layer **11***c* in the fifth direction X5 is longer than a fifth minor axis length D5 of the fifth magnetic layer **11***c* in a direction Y5 substantially parallel to the upper surface **70***u* and crossing (for example, orthogonal to) the fifth direction X5.

The sixth magnetic layer **12***c* extends in a sixth direction X6. The sixth direction X6 is substantially parallel to the upper surface **70***u* and crosses the fifth direction X5, for example. A sixth major axis length L6 of the sixth magnetic layer **12***c* in the sixth direction X6 is longer than a sixth minor axis length D6 of the sixth magnetic layer **12***c* in a direction Y6 substantially parallel to the upper surface **70***u* and crossing (for example, orthogonal to) the sixth direction X6.

The fourth sensing element **50***d* is provided on part of the upper surface **70***u*.

As shown in FIG. **2**D, the fourth sensing element **50***d* includes a seventh magnetic layer **11***d*, an eighth magnetic layer **12***d*, and a fourth intermediate unit **13***du*.

The magnetization of the seventh magnetic layer **11***d* (the direction thereof) is variable. The seventh magnetic layer **11***d* is a magnetization free layer, for example.

The eighth magnetic layer **12***d* is apart from the seventh magnetic layer **11***d* in a direction crossing the upper surface **70***u* (for example, the Z-axis direction). The seventh magnetic layer **11***d* is disposed between the eighth magnetic layer **12***d* and the film unit **70**, for example. In the embodiment, the eighth magnetic layer **12***d* may be disposed between the seventh magnetic layer **11***d* and the film unit **70**.

The fourth intermediate unit **13***du* includes a fourth intermediate layer **13***d*. The fourth intermediate layer **13***d* includes a portion provided between the seventh magnetic layer **11***d* and the eighth magnetic layer **12***d*.

The seventh magnetic layer **11***d* extends in a seventh direction X7. The seventh direction X7 is substantially parallel to the upper surface **70***u*, for example. A seventh major axis length L7 of the seventh magnetic layer **11***d* in the seventh direction X7 is longer than a seventh minor axis length D7 of the seventh magnetic layer **11***d* in a direction Y7 substantially parallel to the upper surface **70***u* and crossing (for example, orthogonal to) the seventh direction X7.

The eighth magnetic layer **12***d* extends in an eighth direction **8**. The eighth direction X8 is substantially parallel to the upper surface **70***u* and crosses the seventh direction X7, for example. An eighth major axis length L8 of the eighth magnetic layer **12***d* in the eighth direction X8 is longer than an eighth minor axis length D8 of the eighth magnetic layer **11***d* in a direction Y8 substantially parallel to the upper surface **70***u* and crossing (for example, orthogonal to) the eighth direction X8.

A nonmagnetic material may be used for the first intermediate layer **13***a*, the second intermediate layer **13***b*, the third intermediate layer **13***c*, and the fourth intermediate layer **13***d*, for example.

The magnetization of the magnetic layers mentioned above can change in accordance with the deformation of the film unit **70**. In the embodiment, the planar shape of the first magnetic layer **11***a* and the planar shape of the second magnetic layer **12***a* have shape anisotropy. The planar shape of each of the third magnetic layer **11***b*, the fourth magnetic layer **12***b*, the fifth magnetic layer **11***c*, the sixth magnetic layer **12***c*, the seventh magnetic layer **11***d*, and the eighth magnetic layer **12***d* has shape anisotropy. The planar shape of each of these magnetic layers is a substantially rectangular shape, for example. The planar shape of each of these magnetic layers is a rectangle, for example. In the first magnetic layer **11***a*, the extending direction of the long side of the rectangle corresponds to the first direction X1, for example. The short side corresponds to the direction Y1. In the second magnetic layer **12***a*, the extending direction of the long side of the rectangle corresponds to the second direction X2. The short side corresponds to the direction Y1.

In the pressure sensor **110** according to the embodiment, the magnetic layers included in the sensing element **50** have shape anisotropy and the extending directions of the magnetic layers cross each other; thereby, a high-sensitivity pressure sensor can be provided.

Examples of the pressure sensor **110** will now be described.

As the support **70***s*, a plate-like substrate may be used, for example. A hollow portion (for example, the through hole **70***h*) is provided in the substrate, for example.

For the support **70***s*, a semiconductor material such as silicon, a conductive material such as a metal, or an insulating material may be used, for example. The support **70***s* may contain silicon oxide, silicon nitride, or the like, for example. The interior of the hollow portion is in a reduced pressure state (vacuum state), for example. The interior of the hollow portion may be filled with a gas such as air or a liquid. The interior of the hollow portion is designed so that the film unit can bend. The interior of the hollow portion may be connected to the outside air.

The film unit **70** is provided on the hollow portion. As the film unit **70**, a portion thinned by processing of a substrate that forms the support **70***s* is used, for example. The thickness (the length in the Z-axis direction) of the film unit **70** is smaller than the thickness (the length in the Z-axis direction) of the substrate.

When a pressure is applied to the film unit **70**, the film unit **70** bends. The pressure corresponds to the pressure that is to be sensed by the pressure sensor **110**. The applied pressure includes pressure caused by sound waves, ultrasonic waves, or the like. In the case of sensing pressure caused by sound waves, ultrasonic waves, or the like, the pressure sensor **110** functions as a microphone.

For the film unit **70**, an insulating material is used, for example. The film unit **70** contains at least one of silicon oxide, silicon nitride, and silicon oxynitride, for example. A semiconductor material such as silicon may be used for the film unit **70**, for example. A metal material may be used for the film unit **70**, for example.

The thickness of the film unit **70** is not less than 0.1 micrometers (μm) and not more than 3 μm, for example. The thickness is preferably not less than 0.2 μm and not more than 1.5 μm. A stacked film including a silicon oxide film with a thickness of 0.2 μm and a silicon film with a thickness of 0.4 μm may be used as the film unit **70**, for example.

As the first magnetic layer **11***a* and the second magnetic layer **12***a*, a ferromagnetic layer is used, for example. The first magnetic layer **11***a* is a magnetization free layer, for example. The second magnetic layer **12***a* is a reference layer, for example. As the reference layer, a magnetization fixed layer or a magnetization free layer is used. The change in magnetization of the first magnetic layer **11***a* is easier than the change in magnetization of the second magnetization layer **12***a*, for example. Thereby, when a pressure is applied, a change can be made to the relative angle between the magnetization of the first magnetic layer **11***a* and the magnetization of the second magnetic layer **12***a*, as described later.

Similarly, a change can be made to the relative angle between the magnetization of the third magnetic layer **11***b* and the magnetization of the fourth magnetic layer **12***b*. A change can be made to the relative angle between the magnetization of the fifth magnetic layer **11***c* and the magnetization of the sixth magnetic layer **12***c*. A change can be made to the relative angle between the magnetization of the seventh magnetic layer **11***d* and the magnetization of the eighth magnetic layer **12***d*. The following description about the first magnetic layer **11***a* can be applied to the third magnetic layer **11***b*, the fifth magnetic layer **11***c*, and the seventh magnetic layer **11***d*. The following description about the second magnetic layer **12***a* can be applied to the fourth magnetic layer **12***b*, the sixth magnetic layer **12***c*, and the eighth magnetic layer **12***d*. The following description about the first intermediate layer **13***a* can be applied to the second intermediate layer **13***b*, the third intermediate layer **13***c*, and the fourth intermediate layer **13***d*.

Examples of the sensing element **50** (for example, the first sensing element **50***a*) will now be described.

In the following, the description of "material A/material B" refers to the state where a layer of material B is provided on a layer of material A.

FIG. **3**A to FIG. **3**F are schematic cross-sectional views illustrating the pressure sensor according to the first embodiment.

The drawings illustrate the sensing element **50** (the first sensing element **50***a*).

As shown in FIG. **3**A, the first sensing element **50***a* includes a first electrode ELa1 (a lower electrode), an underlayer **11***al*, the first magnetic layer **11***a*, the first intermediate layer **13***a*, the second magnetic layer **12***a*, a cap layer **12***ac*, and a second electrode ELa2 (an upper electrode). The first magnetic layer **11***a* is provided between the first electrode ELa1 and the second electrode ELa2. The second magnetic layer **12***a* is provided between the first magnetic layer **11***a* and the second electrode ELa2. The underlayer **11***a***1** is provided between the first magnetic layer **11***a* and the first electrode ELa1. The cap layer **12***ac* is provided between the second magnetic layer **12***a* and the second electrode ELa2.

Examples of the material used for the layers will now be described using as an example the case where the first magnetic layer **11***a* and the second magnetic layer **12***a* are a magnetization free layer.

As the underlayer **11***al*, Ta/Ru is used, for example. The thickness (the length in the Z-axis direction) of the Ta layer is 3 nm, for example. The thickness of the Ru layer is 2 nm, for example.

As the first magnetic layer **11***a*, a $Co_{40}Fe_{40}B_{20}$ layer with a thickness of 3 nm is used, for example. As the first intermediate layer **13***a*, a MgO layer with a thickness of 1.5 nm is used, for example. As the second magnetic layer **12***a*, a $Co_{40}Fe_{40}B_{20}$ layer with a thickness of 3 nm is used, for example.

As the cap layer **12***ac*, Ta/Ru is used, for example. The thickness of the Ta layer is 1 nm, for example. The thickness of the Ru layer is 5 nm, for example.

For the first electrode ELa1 and the second electrode ELa2, at least one of aluminum (Al), aluminum-copper alloy (Al—Cu), copper (Cu), silver (Ag), and gold (Au) is used, for example. By using such a material with a relatively small electric resistance as the first electrode ELa1 and the second electrode ELa2, a current can be passed through the first sensing element **50***a* efficiently. A nonmagnetic material may be used for the first electrode ELa1 and the second electrode ELa2.

The first electrode ELa1 may have a structure including an underlayer (not shown) for the first electrode ELa1, a cap layer (not shown) for the first electrode ELa1, and a layer provided between them and containing at least one of Al, Al—Cu, Cu, Ag, and Au. Tantalum (Ta)/copper (Cu)/tantalum (Ta) or the like is used as the first electrode ELa1, for example. By using Ta as the underlayer for the first electrode ELa1, the adhesion between the film unit **70** and the first electrode ELa1 can be improved, for example. Also titanium (Ti), titanium nitride (TIN), or the like may be used as the underlayer for the first electrode ELa1.

By using Ta as the cap layer for the first electrode ELa1, the oxidation of copper (Cu) or the like under the cap layer

can be suppressed. Also titanium (Ti), titanium nitride (TIN), or the like may be used as the cap layer for the first electrode ELa1.

As the underlayer **11***al*, a stacked structure of a buffer layer (not shown) and a seed layer (not shown) may be used. The buffer layer eases the roughness of the surface of the first electrode ELa1 or the film unit **70**, and improves the crystallinity of a layer stacked on the buffer layer, for example. As the buffer layer, at least one selected from the group consisting of tantalum (Ta), titanium (Ti), vanadium (V), tungsten (W), zirconium (Zr), hafnium (Hf), and chromium (Cr) is used, for example. An alloy containing at least one selected from these materials may be used as the buffer layer.

The thickness of the buffer layer is preferably not less than 1 nm and not more than 10 nm. The thickness of the buffer layer is more preferably not less than 1 nm and not more than 5 nm. If the thickness of the buffer layer is too small, the buffer effect will be lost. If the thickness of the buffer layer is too large, the thickness of the sensing element **50** will be too large. The seed layer may be formed on the buffer layer, and may have buffer effect. The buffer layer may be omitted. A Ta layer with a thickness of 3 nm is used as the buffer layer, for example.

The seed layer mentioned above controls the crystal orientation of a layer stacked on the seed layer. The seed layer controls the crystal grain size of a layer stacked on the seed layer. A metal of the fcc structure (face-centered cubic structure), the hcp structure (hexagonal close-packed structure), or the bcc structure (body-centered cubic structure) or the like is used as the seed layer.

As the seed layer, ruthenium (Ru) of the hcp structure, NiFe of the fcc structure, or Cu of the fcc structure is used. Thereby, the crystal orientation of a stacked film (a spin valve film) provided on the seed layer can be made the fcc(111) orientation, for example. A Cu layer with a thickness of 2 nm or a Ru layer with a thickness of 2 nm is used as the seed layer, for example. When it is attempted to enhance the crystal orientation properties of a layer formed on the seed layer, the thickness of the seed layer is preferably not less than 1 nm and not more than 5 nm. The thickness of the seed layer is more preferably not less than 1 nm and not more than 3 nm. Thereby, the function as a seed layer of improving the crystal orientation is exhibited sufficiently. On the other hand, when it is not necessary to provide a crystal orientation to a layer provided on the seed layer (for example, when an amorphous magnetization free layer is formed, etc.), the seed layer may be omitted, for example. A Cu layer with a thickness of 2 nm is used as the seed layer, for example.

For the first magnetic layer **11***a*, a ferromagnetic material is used. A ferromagnetic material containing at least one element selected from the group consisting of Fe, Co, and Ni may be used for the first magnetic layer **11***a*, for example. FeCo alloy or NiFe alloy may be used as the material of the first magnetic layer **11***a*, for example. An alloy containing at least one element selected from the group consisting of Fe, Co, and Ni and boron (B) may be used for the first magnetic layer **11***a*. Co—Fe—B alloy, Fe—B alloy, Fe—Co—Si—B alloy, or the like may be used for the first magnetic layer **11***a*, for example. A $Co_{40}Fe_{40}B_{20}$ layer (the thickness being 4 nm, for example) may be used as the first magnetic layer **11***a*, for example.

For the first magnetic layer **11***a*, Fe—Ga alloy, Fe—Co—Ga alloy, a Tb-M-Fe alloy (M being at least one selected from the group consisting of Sm, Eu, Gd, Dy, Ho, and Er), a Tb-M1-Fe-M2 alloy (M1 being at least one selected from the group consisting of Sm, Eu, Gd, Dy, Ho, and Er; M2 being at least one selected from the group consisting of Ti, Cr, Mn, Co, Cu, Nb, Mo, W, and Ta), or an Fe-M3-M4-B alloy (M3 being at least one selected from the group consisting of Ti, Cr, Mn, Co, Cu, Nb, Mo, W, and Ta; M4 being at least one selected from the group consisting of Ce, Pr, Nd, Sm, Tb, Dy, and Er) is used. The λs (magnetostriction constant) of these materials is large.

The first magnetic layer **11***a* may contain at least one of Ni, Fe—Al, and a ferrite (Fe_3O_4, $(FeCo)_3O_4$, or the like), for example.

The thickness of the first magnetic layer **11***a* is 2 nm or more, for example.

The first magnetic layer **11***a* may have a multi-layer structure. The first magnetic layer **11***a* may have a two-layer structure, for example. In the case where a tunnel insulating layer of MgO is used as the first intermediate layer **13***a*, it is preferable that a layer of Co—Fe—B alloy be provided on the interface in contact with the first intermediate layer **13***a*. Thereby, a high magnetoresistance effect is obtained. In this case, it is preferable that a layer of Co—Fe—B alloy be provided on the side in contact with the first intermediate layer **13***a* and a layer of the following material be provided on the opposite side to that. For that layer, Fe—Co—Si—B alloy, Fe—Ga alloy, Fe—Co—Ga alloy, a Tb-M-Fe alloy (M being at least one selected from the group consisting of Sm, Eu, Gd, Dy, Ho, and Er), a Tb-M1-Fe-M2 alloy (M1 being at least one selected from the group consisting of Sm, Eu, Gd, Dy, Ho, and Er; M2 being at least one selected from the group consisting of Ti, Cr, Mn, Co, Cu, Nb, Mo, W, and Ta), an Fe-M3-M4-B alloy (M3 being at least one selected from the group consisting of Ti, Cr, Mn, Co, Cu, Nb, Mo, W, and Ta; M4 being at least one selected from the group consisting of Ce, Pr, Nd, Sm, Tb, Dy, and Er), Ni, Fe—Al, or a ferrite (Fe_3O_4, $(FeCo)_3O_4$, or the like) is used, for example.

As the first magnetic layer **11***a*, a stacked film of $Fe_{80}Ga_{20}/CO_{40}Fe_{40}B_{20}$ is used, for example. The thickness of the $Co_{40}Fe_{40}B_{20}$ is 2 nm, for example. The thickness of the $Fe_{80}Ga_{20}$ is 4 nm, for example.

The first intermediate layer **13***a* cuts the magnetic coupling between the first magnetic layer **11***a* and the second magnetic layer **12***a*, for example. A metal, an insulator, or a semiconductor is used for the first intermediate layer **13***a*, for example. Cu, Au, Ag, or the like is used as the metal, for example.

In the case where a metal is used as the first intermediate layer **13***a*, the thickness of the first intermediate layer **13***a* is approximately not less than 1 nm and not more than 7 nm, for example.

As the insulator or the semiconductor used for the first intermediate layer **13***a*, a magnesium oxide (MgO etc.), an aluminum oxide (Al_2O_3 etc.), a titanium oxide (TiO etc.), a zinc oxide (ZnO etc.), gallium oxide (Ga—O), or the like is used, for example.

In the case where an insulator or a semiconductor is used as the first intermediate layer **13***a*, the thickness of the first intermediate layer **13***a* is approximately not less than 0.6 nm and not more than 2.5 nm, for example. A CCP (current-confined-path) spacer layer may be used as the first intermediate layer **13***a*, for example. In the case where a CCP spacer layer is used as the spacer layer, a structure is used in which a copper (Cu) metal path is formed in an insulating layer of aluminum oxide (Al_2O_3), for example. A MgO layer with a thickness of 1.5 nm is used as the first intermediate layer **13***a*, for example.

For the second magnetic layer **12***a*, a similar ferromagnetic material to the first magnetic layer **11***a* may be used. A

$Co_{40}Fe_{40}B_{20}$ layer (the thickness being 4 nm, for example) may be used as the second magnetic layer **12***a*, for example. When a multi-layer structure is used as the second magnetic layer **12***a*, the second magnetic layer **12***a* may have a two-layer structure, for example. When a tunnel insulating layer of MgO is used as the first intermediate layer **13***a*, it is preferable that a layer of Co—Fe—B alloy be provided on the interface in contact with the first intermediate layer **13***a* of the second magnetic layer **12***a*. A stacked film of $Co_{40}Fe_{40}B_{20}/Fe_{80}Ga_{20}$ is used as the second magnetic layer **12***a*, for example. The thickness of the $Co_{40}Fe_{40}B_{20}$ is 2 nm, for example. The thickness of the $Fe_{80}Ga_{20}$ is 4 nm, for example.

The material used for the second magnetic layer **12***a* may be the same material as the first magnetic layer **11***a*, and each of the first magnetic layer **11***a* and the second magnetic layer **12***a* may be a magnetization free layer. This case is preferable because the operation of the change in magnetization with respect to the strain can be made uniform between the first magnetic layer **11***a* and the second magnetic layer **12***a*, for example.

The cap layer **12***ac* protects a layer provided under the cap layer **12***ac*, for example. A plurality of metal layers are used as the cap layer **12***ac*, for example. A two-layer structure of a Ta layer and a Ru layer (Ta/Ru) is used as the cap layer **12***ac*, for example. The thickness of the Ta layer is 1 nm, for example, and the thickness of the Ru layer is 5 nm, for example. Other metal layers may be provided as the cap layer **12***ac* in place of the Ta layer and the Ru layer. The configuration of the cap layer **12***ac* is arbitrary. A nonmagnetic material may be used as the cap layer **12***ac*, for example. Other materials may be used as the cap layer **12***ac* to the extent that they can protect a layer provided under the cap layer **12***ac*.

As shown in FIG. **3**B, the first sensing element **50***a* may further include an insulating layer **11***i*. The insulating layer **11***i* is provided between the first electrode ELa1 and the second electrode ELa2, for example. The insulating layer **11***i* surrounds the stacked film including the first magnetic layer **11***a*, the first intermediate layer **13***a*, and the second magnetic layer **12***a*, for example.

For the insulating layer **11***i*, an aluminum oxide (for example, Al_2O_3), a silicon oxide (for example, SiO_2), or the like is used, for example. By the insulating layer **11***i*, leakage current around the stacked film can be suppressed.

As shown in FIG. **3**C, a functional layer **16** may be provided between the first magnetic layer **11***a* and the underlayer **11***al*. The first magnetic layer **11***a* is disposed between the functional layer **16** and the first intermediate unit **13***au*. An oxide or a nitride is used for the functional layer **16**, for example. The functional layer **16** contains an oxide of at least one selected from the group consisting of Mg, Al, Si, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Hf, Ta, W, Sn, Cd, and Ga, for example. The functional layer **16** contains a nitride of at least one selected from the group mentioned above, for example. The functional layer **16** contains an oxide of at least one of Mg, Ti, V, Zn, Sn, Cd, and Ga, for example.

On the other hand, the first magnetic layer **11***a* has an amorphous structure, and contains boron, for example. By using the first magnetic layer **11***a* and the functional layer **16** like the above in combination, a high gauge factor is obtained. The gauge factor is the ratio of the amount of magnetoresistance change to the strain, for example. By a high gauge factor, a pressure sensor with a higher sensitivity can be provided.

As shown in FIG. **3**D, the insulating layer **11***i* may be provided in the configuration illustrated in FIG. **3**C.

As shown in FIG. **3**E, a functional layer **17** may be provided between the second magnetic layer **12***a* and the cap layer **12***ac*. The second magnetic layer **12***a* is disposed between the functional layer **17** and the first intermediate unit **13***au*. The material described in regard to the functional layer **16** is used for the functional layer **17**, for example. At this time, the second magnetic layer **12***a* has an amorphous structure, and contains boron, for example, By using the second magnetic layer **12***a* and the functional layer **17** like the above in combination, a high gauge factor is obtained.

As shown in FIG. **3**F, the insulating layer **11***i* may be provided in the configuration illustrated in FIG. **3**E.

In the embodiment, in the first magnetic layer **11***a*, the first major axis length L1 is longer than the first minor axis length D1, as described above. In the second magnetic layer **12***a*, the second major axis length L2 is longer than the second minor axis length D2. These magnetic layers have shape magnetic anisotropy. Thus, the magnetization direction of the first magnetic layer **11***a* is set along the first direction X1 (the direction of the first major axis length L1). The magnetization direction of the second magnetic layer **12***a* is set along the second direction X2 (the direction of the second major axis length L2).

Thus, by utilizing shape anisotropy, the magnetization direction of the magnetization free layer included in the first sensing element **50***a* in a state where the external pressure is small (for example, a state where the external pressure is zero) can be set to an arbitrary direction, without using magnetization direction control by a hard bias of CoPt or the like, an exchange coupling bias using IrMn or the like, or others. Thereby, the pressure can be detected with high sensitivity.

On the other hand, in bias control by a hard bias or an exchange coupling bias, it is difficult to direct the initial magnetization directions of a plurality of magnetization free layers included in a plurality of sensing elements **50** to different directions in the X-Y plane.

In the embodiment, by utilizing shape anisotropy, the initial magnetization direction can be easily set to a desired direction in each of the plurality of sensing elements **50** provided on the upper surface **70***u* of the film unit **70**, for example. Thereby, the operation of each of the plurality of sensing elements **50** can be effectively utilized, for example.

In the pressure sensor **110** of the embodiment, when the film unit **70** is bent by a pressure from the outside, a strain is generated in the sensing element **50** (for example, the first sensing element **50***a*). The sensing element **50** has the function of converting the change in strain to a change in electric resistance.

The operation in which the first sensing element **50***a* functions as a strain sensor is based on application of "inverse magnetostriction effect" and "magnetoresistance effect." The "inverse magnetostriction effect" is obtained in the ferromagnetic layer used as the first magnetic layer **11***a* and the second magnetic layer **12***a*. The "magnetoresistance effect" is exhibited in the stacked film including the first magnetic layer **11***a*, the first intermediate layer **13***a*, and the second magnetic layer **12***a*.

The "inverse magnetostriction effect" is a phenomenon in which the magnetization of a ferromagnetic material is changed by a strain generated in the ferromagnetic material. That is, when a strain is generated in the stacked film of the first sensing element **50***a* due to a pressure from the outside, the magnetization direction of the magnetization free layer is changed. Consequently, the relative angle between the

magnetization of the first magnetic layer **11***a* and the magnetization of the second magnetic layer **12***a* is changed. At this time, a change in electric resistance occurs due to the magnetoresistance effect (MR effect)." The MR effect includes GMR (giant magnetoresistance) effect, TMR (tunneling magnetoresistance) effect, or the like, for example. The MR effect is exhibited by passing a current through the stacked film to read the change in relative angle between the directions of the magnetizations as an electric resistance change.

A strain is generated in the first sensing element **50***a* due to a strain generated in the stacked film, for example. The direction of the magnetization of the magnetization free layer (the first magnetic layer **11***a*) is changed by the strain. The relative angle between the direction of the magnetization of the first magnetic layer **11***a* and the direction of the magnetization of the second magnetic layer **12***a* is changed. The MR effect appears due to the inverse magnetostriction effect.

When the ferromagnetic material used for the magnetization free layer has a positive magnetostriction constant, the direction of the magnetization changes so that the angle between the direction of the magnetization and the direction of a tensile strain becomes smaller and the angle between the direction of the magnetization and the direction of a compressive strain becomes larger. When the ferromagnetic material used for the magnetization free layer has a negative magnetostriction constant, the direction of the magnetization changes so that the angle between the direction of the magnetization and the direction of a tensile strain becomes larger and the angle between the direction of the magnetization and the direction of a compressive strain becomes smaller.

When the combination of the materials of the stacked film of the first magnetic layer **11***a*, the first intermediate layer **13***a*, and the second magnetic layer **12***a* has a positive magnetoresistance effect, the electric resistance decreases as the relative angle between the magnetization of the first magnetic layer **11***a* and the magnetization of the second magnetic layer **12***a* decreases. When the combination of the materials of the stacked film of the first magnetic layer **11***a*, the first intermediate layer **13***a*, and the second magnetic layer **12***a* has a negative magnetoresistance effect, the electric resistance increases as the relative angle between the magnetization of the first magnetic layer **11***a* and the magnetization of the second magnetic layer **12***a* decreases.

Examples of the change in magnetization will now be described. In the following examples, each of the ferromagnetic materials used for the first magnetic layer **11***a* and the second magnetic layer **12***a* has a positive magnetostriction constant, and the stacked film including the first magnetic layer **11***a*, the first intermediate layer **13***a*, and the second magnetic layer **12***a* has a positive magnetoresistance effect. Both the first magnetic layer **11***a* and the second magnetic layer **12***a* are a magnetization free layer.

FIG. **4**A to FIG. **4**D are schematic diagrams illustrating the pressure sensor according to the first embodiment.

The drawings illustrate operations of the sensing element **50** (the first sensing element **50***a*). FIG. **4**A corresponds to a state where no strain is generated in the first sensing element **50***a* (a no-strain state ST0). FIG. **4**B corresponds to a state where a compressive strain is generated in the first sensing element **50***a* (a first state ST1). FIG. **4**C corresponds to a state where a tensile strain is generated in the first sensing element **50***a* (a second state ST2). In these drawings, for easier viewing of the drawings, the first magnetic layer **11***a* and the second magnetic layer **12***a* are depicted, and the first intermediate unit **13***au* is omitted.

FIG. **4**D illustrates the relationship between the strain Sa generated in the first sensing element **50***a* and the electric resistance R (Ω) of the first sensing element **50***a*. The electric resistance R is the electric resistance between the first magnetic layer **11***a* and the second magnetic layer **12***a*.

As shown in FIG. **4**A, in the no-strain state ST0, the magnetization **11***am* of the first magnetic layer **11***a* is set along the first direction X1 in which the first magnetic layer **11***a* extends. In the no-strain state ST0, the magnetization **12***am* of the second magnetic layer **12***a* is set along the second direction X2 in which the second magnetic layer **12***a* extends. These are due to the shape magnetic anisotropy mentioned above.

By changing the angle between the first direction X1 in which the first magnetic layer **11***a* extends and the second direction X2 in which the second magnetic layer **12***a* extends, the relative angle between the direction of the magnetization **11***am* of the first magnetic layer **11***a* and the direction of the magnetization **12***am* of the second magnetic layer **12***a* can be set arbitrarily.

As shown in FIG. **4**B, in the first state ST1 in which a compressive strain CS is generated, the angle between the magnetization **11***am* of the first magnetic layer **11***a* and the magnetization **12***am* of the second magnetic layer **12***a* is larger than the angle in the no-strain state ST0, for example. The electric resistance R changes in conjunction with this.

As shown in FIG. **4**C, in the second state ST2 in which a tensile strain TS is generated, the angle between the magnetization **11***am* of the first magnetic layer **11***a* and the magnetization **12***am* of the second magnetic layer **12***a* is smaller than the angle in the no-strain state ST0, for example. The electric resistance R changes in conjunction with this.

As shown in FIG. **4**D, when a compressive strain CS is generated, the electric resistance R of the first sensing element **50***a* increased as compared to the no-strain state ST0. When a tensile strain TS is generated, the electric resistance R of the first sensing element **50***a* decreased as compared to the no-strain state ST0.

In this way, the first sensing element **50***a* can convert the change in strain Sa generated in the first sensing element **50***a* to a change in electric change R.

As illustrated in FIG. **4**A, in the first sensing element **50***a*, in the no-strain state ST0, the magnetization of the first magnetic layer **11***a* and the magnetization of the second magnetic layer **12***a* can be directed to directions different from each other. Thereby, as illustrated in FIG. **4**D, the electric resistance R changes linearly with respect to the tensile and compressive strain Sa, for example. Thereby, a high-sensitivity pressure sensor can be provided.

FIG. **5** is a schematic plan view illustrating the pressure sensor according to the first embodiment.

As shown in FIG. **5**, in the embodiment, the angle α between the extending direction of the first magnetic layer **11***a* (the first direction X1) and the extending direction of the second magnetic layer **12***a* (the second direction X2) is larger than 0 degrees and smaller than 180 degrees. That is, the first direction X1 crosses the second direction X2. Thereby, the magnetizations of the first magnetic layer **11***a* and the second magnetic layer **12***a* in the no-strain state ST0 are directed to directions different from each other, for example.

The angle βa between the extending direction of the first magnetic layer **11***a* (the first direction X1) and the strain direction Dsa is arbitrary. The angle βb between the extend-

ing direction of the second magnetic layer **12***a* (the second direction X2) and the strain direction Dsa is arbitrary.

In the case where the absolute value of the angle βb is equal to the absolute value of the angle βa, the extending direction of the first magnetic layer **11***a* and the extending direction of the second magnetic layer **12***a* are line-symmetric with respect to the strain direction Dsa. At this time, the magnetization **11***am* of the first magnetic layer **11***a* and the magnetization **12***am* of the second magnetic layer **12***a* can be simultaneously changed with respect to the strain Sa. Thereby, the strain Sa can be detected with higher sensitivity. The difference between the absolute value of the angle βa and the absolute value of the angle βb is 5 degrees or less, for example.

FIG. **6**A to FIG. **6**D are schematic plan views illustrating the pressure sensor according to the first embodiment.

The drawings show examples of the magnetization direction in the no-strain state ST0. The drawings show examples regarding the first magnetic layer **11***a*.

The direction of the initial magnetization **11***am* of the first magnetic layer **11***a* of the first sensing element **50***a* can be set by the direction in which the external magnetic field is applied, for example.

FIG. **6**A illustrates a state where an external magnetic field Hex1 is applied. FIG. **6**B illustrates a state where the external magnetic field Hex1 is removed. As shown in FIG. **6**A, the external magnetic field Hex1 crosses the first direction X1. When the external magnetic field Hex1 is being applied, the direction of the magnetization **11***am* of the first magnetic layer **11***a* is set along the direction of the external magnetic field Hex1.

As shown in FIG. **6**B, when the external magnetic field Hex1 is removed, the direction of the magnetization **11***am* of the first magnetic layer **11***a* is set along the first direction X1 due to the shape anisotropy. The direction of the magnetization **11***am* in FIG. **6**B reflects the direction of the external magnetic field Hex1.

FIG. **6**C illustrates a state where an external magnetic field Hex2 is applied. FIG. **6**D illustrates a state where the external magnetic field Hex2 is removed. As shown in FIG. **6**C, the external magnetic field Hex2 crosses the first direction X1. The direction of the angle from the first direction X1 to the external magnetic field Hex2 is opposite to the direction of the angle from the first direction X1 to the external magnetic field Hex1. When the external magnetic field Hex2 is being applied, the direction of the magnetization **11***am* of the first magnetic layer **11***a* is set along the direction of the external magnetic field Hex2.

As shown in FIG. **6**D, when the external magnetic field Hex2 is removed, the direction of the magnetization **11***am* of the first magnetic layer **11***a* is set along the first direction X1 due to the shape anisotropy. The direction of the magnetization **11***am* in FIG. **6**D reflects the direction of the external magnetic field Hex2. That is, the direction of the magnetization **11***am* in FIG. **6**D is opposite to the direction of the magnetization **11***am* in FIG. **6**B.

Thus, the direction of the magnetization **11***am* when the external magnetic field is removed depends on the direction of the external magnetic field. The direction of the magnetization **11***am* when the external magnetic field is removed is directed to the direction of the magnetization **11***am* projected onto the first direction X1 when the external magnetic field is being applied.

The direction of the magnetization **12***am* of the second magnetic layer **12***a* may be similarly controlled by an external magnetic field, for example.

FIG. **7**A to FIG. **7**F are schematic plan views illustrating the pressure sensor according to the first embodiment.

The drawings show examples of the magnetization direction in the no-strain state ST0.

FIG. **7**A illustrates a state where an external magnetic field Hex3 is applied. FIG. **7**B illustrates a state where the external magnetic field Hex3 is removed. In these examples, the absolute value of the angle between the first direction X1 and the second direction X2 is 45 degrees, for example. As show in FIG. **7**A, the external magnetic field Hex3 crosses the first direction X1 and the second direction X2. The external magnetic field Hex3 is perpendicular to the average direction of the first direction X1 and the second direction X2. As shown in FIG. **7**B, when the external magnetic field Hex3 is removed, the angle between the direction of the magnetization **11***am* of the first magnetic layer **11***a* and the direction of the magnetization **12***am* of the second magnetic layer **12***a* is 135 degrees, for example.

FIG. **7**C illustrates a state where an external magnetic field Hex4 is applied. FIG. **7**D illustrates a state where the external magnetic filed Hex4 is removed. In these examples, the absolute value of the angle between the first direction X1 and the second direction X2 is 45 degrees, for example. As shown in FIG. **7**C, the external magnetic field Hex4 crosses the first direction X1 and the second direction X2. The external magnetic field Hex4 is parallel to the average direction of the first direction X1 and the second direction X2. As shown in FIG. **7**D, when the external magnetic filed Hex4 is removed, the angle between the direction of the magnetization **11***am* of the first magnetic layer **11***a* and the direction of the magnetization **12***am* of the second magnetic layer **12***a* is 45 degrees, for example.

FIG. **7**E illustrates a state where an external magnetic field Hex5 is applied. FIG. **7**F illustrates a state where the external magnetic filed Hex5 is removed. In these examples, the absolute value of the angle between the first direction X1 and the second direction X2 is 45 degrees, for example. As shown in FIG. **7**E, the external magnetic field Hex5 crosses the first direction X1 and the second direction X2. The angle between the external magnetic field Hex5 and the average angle of the first direction X1 and the second direction X2 is less than 90 degrees. As shown in FIG. **7**F, when the external magnetic field Hex5 is removed, the angle between the direction of the magnetization **11***am* of the first magnetic layer **11***a* and the direction of the magnetization **12***am* of the second magnetic layer **12***a* is 45 degrees, for example.

Thus, the relative relationship between the magnetization direction of the first magnetic layer **11***a* and the magnetization direction of the second magnetic layer **12***a* can be variously set by the direction of external magnetic field application.

In the case where the first magnetic layer **11***a* and the second magnetic layer **12***a* have magnetic properties different from each other, the magnetization directions thereof can be arbitrarily set by two magnetization applications, for example.

FIG. **8** is a schematic plan view illustrating the pressure sensor according to the first embodiment.

As shown in FIG. **8**, the magnetization **11***am* of the first magnetic layer **11***a* and the magnetization **12***am* of the second magnetic layer **12***a* are set by the external magnetic field and the direction of shape anisotropy mentioned above.

The angle γ between the magnetization **11***am* of the first magnetic layer **11***a* and the magnetization **12***am* of the second magnetic layer **12***a* may be set based on the use of the pressure sensor **110**.

The angle γ is set to approximately 90 degrees, for example. The angle γ between the magnetization **11***am* of the first magnetic layer **11***a* and the magnetization **12***am* of the second magnetic layer **12***a* is not less than 60 degrees and not more than 120 degrees, for example. The angle α between the first direction X1 and the second direction is not less than 60 degrees and not more than 120 degrees, for example. At this time, the dynamic range of the change in electric resistance R with respect to the tensile and compressive strain is increased, for example.

The angle γ is set larger than 0 degrees and smaller than 90 degrees, for example. The angle α between the first direction X1 and the second direction X2 is larger than 0 degrees and smaller than 90 degrees, for example. At this time, the element resistance can be reduced, for example. At this time, noise such as shot noise and spin torque noise in the pressure sensor **110** can be reduced, for example.

The angle γ is set larger than 90 degrees and smaller than 180 degrees, for example. The angle between the first direction X1 and the second direction X2 is larger than 90 degrees and smaller than 180 degrees, for example. At this time, the change in electric resistance R with respect to the strain can be increased, for example. In the case where a tunneling magnetoresistance effect using an insulator for the first intermediate layer **13***a* is used, the magnetoresistance effect with respect to the change in relative angle of magnetization is large when the angle γ is in a range of larger than 90 degrees and smaller than 180 degrees, for example. By setting in this range, the change in electric resistance R with respect to the change in relative angle of magnetization is increased, for example. Thereby, high sensitivity is obtained.

FIG. **9**A and FIG. **9**B are schematic plan views illustrating a pressure sensor according to the first embodiment.

FIG. **9**B shows an enlarged view of a part PA shown in FIG. **9**A.

The drawings show examples of the arrangement of sensing elements **50** on the upper surface **70***u* of the film unit **70**.

As shown in FIG. **9**A, in a pressure sensor **111** according to the embodiment, the shape of the upper surface **70***u* of the film unit **70** is a circle. The outer edge **70***r* of the film unit **70** is in a circular shape.

A plurality of sensing elements **50** are arranged along the outer edge **70***r* of the film unit **70**. In each of the plurality of sensing elements **50**, the extending direction X11 of the magnetization free layer **11** crosses the extending direction X12 of the reference layer **12**. The magnetization free layer **11** is the first magnetic layer **11***a*, the third magnetic layer **11***b*, the fifth magnetic layer **11***c*, the seventh magnetic layer **11***d*, and the like, for example. The reference layer **12** is the second magnetic layer **12***a*, the fourth magnetic layer **12***b*, the sixth magnetic layer **12***c*, the eighth magnetic layer **12***d*, and the like, for example. Here, magnetization may be variable in the reference layer **12**. The extending direction X11 of the magnetization free layer **11** is the first direction X1, the third direction X3, the fifth direction X5, the seventh direction X7, and the like, for example. The extending direction X12 of the reference layer **12** is the second direction X2, the fourth direction X2, the sixth direction X6, the eighth direction X8, and the like, for example.

A plurality of sensing elements **50** are arranged so as to overlap a plurality of radial lines **75** passing through the centroid **70***c* of the film unit **70**, for example. In this example, the combination of the magnetization free layer **11** and the reference layer **12** is line-symmetric with respect to each of the radial lines **75**.

As shown in FIG. **9**B, the first sensing element **50***a* is disposed between two sensing elements **50** (a sensing element **50***e* and a sensing element **50***f*), for example. The magnetization free layer **11** and the reference layer **12** are provided in each of the sensing element **50***e* and the sensing element **50***f*.

In each of the plurality of sensing elements **50**, a strain Sa is generated along the direction of the radial line **75** passing through the centroid **70***c* of the film unit **70**. In this example, the extending direction X11 of the magnetization free layer **11** and the extending direction X12 of the reference layer **12** are arranged line-symmetrically with respect to the radial line **75**. The angle between the direction of the initial magnetization of the magnetization free layer **11** and the direction of the strain Sa is substantially equal to the angle between the direction of the initial magnetization of the reference layer **12** and the direction of the strain Sa. Thereby, the magnetization of the magnetization free layer **11** and the magnetization of the reference layer **12** when a strain Sa is generated can be simultaneously changed. Thereby, a large change in electric resistance R is obtained.

In this example, the angle between the extending direction X11 of the magnetization free layer **11** and the radial line **75** is equal between sensing elements **50**. The difference between sensing elements **50** in the absolute value of the angle between the extending direction X11 of the magnetization free layer **11** and the radial line **75** is 5 degrees or less, for example. In this example, the angle between the extending direction of the reference layer **12** and the radial line **75** is equal between sensing elements **50**. The difference between sensing elements **50** in the absolute value of the angle between the extending direction of the reference layer **12** and the radial line **75** is 5 degrees or less, for example. By equalizing these angles, the angle between the extending direction X11 of the magnetization free layer **11** and the direction of the strain Sa can be equalized. The angle between the extending direction X12 of the reference layer **12** and the direction of the strain Sa can be equalized. Thus, the change in electric resistance R is substantially equal between sensing elements **50** arranged on the film unit **70**. In the case where a substantially equal change in electric resistance R with respect to the pressure is obtained in a plurality of sensing elements **50**, the plurality of sensing elements **50** may be connected together at least one of in series and in parallel as described later; thereby, the S/N ratio can be increased, for example.

In this example, the distances between the centroid **70***c* of the film unit **70** and the centroids **55** of the plurality of sensing elements **50** are equal to one another. Thereby, the magnitudes of the strains Sa generated in the plurality of sensing elements **50** are substantially equal, for example. The centroid **55** of the sensing element **50** is the centroid of the region where the magnetization free layer **11** (for example, the first magnetic layer **11***a*) and the reference layer **12** (for example, the second magnetic layer **12***a*) overlap when the magnetization free layer **11** and the reference layer **12** are projected onto the X-Y plane. The centroid **55** corresponds to the centroid of the region where the magnetization free layer **11** and the reference layer **12** overlap in the X-Y plane.

FIG. **10**A to FIG. **10**C are schematic plan views illustrating pressure sensors according to the first embodiment.

The drawings show examples of the arrangement of magnetization free layers **11**.

As shown in FIG. **10**A, in a pressure sensor **112***a* according to the embodiment, the extending direction X11 of the magnetization free layer **11** of each of the plurality of

sensing elements **50** is orthogonal to the radial line **75** passing through the centroid **70***c* of the circular film unit **70**.

As shown in FIG. **10**B, in a pressure sensor **112***b* according to the embodiment, the extending direction X11 of the magnetization free layer **11** of each of the plurality of sensing elements **50** is inclined with respect to the radial line **75** passing through the centroid **70***c* of the circular film unit **70**.

As shown in FIG. **10**C, in a pressure sensor **112***c* according to the embodiment, the extending direction X11 of the magnetization free layer **11** of each of the plurality of sensing elements **50** is parallel to the radial line **75** passing through the centroid **70***c* of the circular film unit **70**.

In these examples, the reference layer **12** is omitted. The extending direction X12 of the reference layer **12** is set so as to cross the extending direction X12 of the magnetization free layer **11**.

In the pressure sensors **112***a* and **112***c*, the magnetization direction of the magnetization free layer **11** changes when the direction of the external pressure is a prescribed direction. The magnetization direction of the magnetization free layer **11** changes when the direction of the external pressure is a prescribed polarity.

On the other hand, in the pressure sensor **112***b*, the magnetization direction changes under an external pressure in an arbitrary direction (plus or minus) in accordance with the polarity. Therefore, the external pressure can be sensed independently of the polarity of the external pressure.

The dynamic range in the polarity of a prescribed pressure in the pressure sensors **112***a* and **112***c* is wider than the dynamic range in the polarity of the prescribed pressure in the pressure sensor **112***b*. The arrangement of sensing elements **50** (for example, the extending directions X11 of magnetization free layers **11**) may be set in accordance with the use.

FIG. **11** is a schematic plan view illustrating a pressure sensor according to the first embodiment.

As shown in FIG. **11**, in a pressure sensor **113***a* according to the embodiment, the angle α between the extending direction X11 (for example, the first direction X1 or the like) of the magnetization free layer **11** (for example, the first magnetic layer **11***a* or the like) and the extending direction X12 (for example, the second direction X2 or the like) of the reference layer **12** (for example, the second magnetic layer **12***a* or the like) is 90 degrees in each of the plurality of sensing elements **50**.

The absolute value of a first angle $\beta 1$ between the radial line **75** passing through the centroid **55** of each of the plurality of sensing elements **50** and the centroid **70***c* of the film unit **70** and the extending direction X11 of the magnetization free layer **11** of the sensing element **50** is 45 degrees. The absolute value of the first angle $\beta 1$ may be not less than 30 degrees and not more than 60 degrees. In this example, these angles are 45 degrees.

The absolute value of a second angle $\beta 2$ between the radial line **75** passing through the centroid **55** of each of the plurality of sensing elements **50** and the centroid **70***c* of the film unit **70** and the extending direction X12 of the reference layer **12** of the sensing element **50** is 45 degrees. The absolute value of the second angle $\beta 2$ may be not less than 30 degrees and not more than 60 degrees. In this example, these angles are 45 degrees.

By setting the absolute value of the first angle $\beta 1$ and the absolute value of the second angle $\beta 2$ not less than 30 degrees and not more than 60 degrees, the dynamic range of the electric resistance change with respect to the positive and negative pressure can be widened, for example.

The magnetization direction in each sensing element **50** is set by applying an external magnetic field Hex and removing the external magnetic field Hex, for example.

In the pressure sensor **113***a*, the plurality of sensing elements **50** are separated into a plurality of groups (a first to a fourth group G1 to G4).

In the first group G1, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of a sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **11***m* of the magnetization free layer **11** of the sensing element **50** (for example, the direction of the magnetization **11***am*) is +135 degrees, for example. On the other hand, the angle from the direction from the centroid **55** of the sensing element **50** toward the centroid **70***c* of the film unit **70** (a direction parallel to the radial line **75**) to the magnetization direction **12***m* of the reference layer **12** of the sensing element **50** is −135 degrees.

In the third group G3, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of a sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **11***m* of the magnetization free layer **11** of the sensing element **50** (for example, the direction of the magnetization **11***am*) is +45 degrees, for example. On the other hand, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of the sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **12***m* of the reference layer **12** of the sensing element **50** is +135 degrees.

In the second group G2, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of a sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **11***m* of the magnetization free layer **11** of the sensing element **50** (for example, the direction of the magnetization **11***am*) is +45 degrees, for example. On the other hand, the angle from the direction from the centroid **55** of the sensing element **50** toward the centroid **70***c* of the film unit **70** (a direction parallel to the radial line **75**) to the magnetization direction **12***m* of the reference layer **12** of the sensing element **50** is −45 degrees.

In the fourth group G4, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of a sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **11***m* of the magnetization free layer **11** of the sensing element **50** (for example, the direction of the magnetization **11***am*) is −135 degrees, for example. On the other hand, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of the sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **12***m* of the reference layer **12** of the sensing element **50** is −45 degrees.

Thus, the relationship between the magnetization direction **11***m* of the magnetization free layer **11** and the radial line **75** and the relationship between the magnetization direction **12***m* of the reference layer **12** and the radial line **75** are different between groups.

In the circular film unit **70**, the direction of strain Sa is set along the radial line **75**. The polarity of the properties obtained in the sensing element **50** included in the first group G1 is the same as the polarity of the properties obtained in the sensing element **50** included in the second group G2. The polarity of the properties obtained in the sensing element **50** included in the third group G3 is the same as the polarity of the properties obtained in the sensing element **50** included in the fourth group G4. The polarity of the properties obtained in the sensing element **50** included in the first group G1 is opposite to the polarity of the properties obtained in the sensing element **50** included in the third group G3.

In the case where the angle α between the extending direction X11 of the magnetization free layer **11** and the extending direction X12 of the reference layer **12** is 90 degrees, the electric resistance R when the strain Sa is zero is equal between sensing elements **50**.

The properties obtained in the sensing element **50** of the first group G1 and the second group G2 are strain sensor properties opposite to the properties obtained in the sensing element **50** of the third group G3 and the fourth group G4, with respect to the tensile and compressive strain Sa.

By forming a bridge circuit using a plurality of sensing elements **50** with polarities opposite to one another, the output is increased as described later, for example. The function of temperature compensation is obtained, for example.

In the embodiment, the straight line passing through the centroid of the upper surface **70***u* of the film unit **70** (the centroid **70***c*) and the centroid of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap is defined as a first straight line. The angle between the first straight line and the first direction X1 is defined as a first angle. The straight line passing through the centroid of the upper surface **70***u* (the centroid **70***c*) and the centroid of the region where the third magnetic layer **11***b* and the fourth magnetic layer **12***ba* overlap is defined as a third straight line. The angle between the third straight line and the third direction X3 is defined as a fifth angle. The difference between the absolute value of the first angle and the absolute value of the fifth angle is 5 degrees or less, for example.

In this example, the extending direction of the magnetization free layer **11** of the first sensing element **50***a* is substantially parallel to the extending direction of the magnetization free layer **11** of the second sensing element **50***b*. The absolute value of the angle between the extending direction of the first magnetic layer **11***a* (the first direction X1) and the extending direction of the second magnetic layer **11***b* (the third direction X3) is 5 degrees or less, for example. The absolute value of the angle between the extending direction of the fifth magnetic layer **11***c* (the fifth direction X5) and the extending direction of the seventh magnetic layer **11***d* (the seventh direction X7) is 5 degrees or less, for example.

FIG. **12** is a schematic plan view illustrating a pressure sensor according to the first embodiment.

As shown in FIG. **12**, in a pressure sensor **113***b* according to the embodiment, in each of the plurality of sensing elements **50**, the angle α between the extending direction X11 (for example, the first direction X1 or the like) of the magnetization free layer **11** (for example, the first magnetic layer **11***a* or the like) and the extending direction X12 (for example, the second direction X2 or the like) of the reference layer **12** (for example, the second magnetic layer **12***a* or the like) is 135 degrees. The absolute value of this angle is 45 degrees, for example.

In the first group G1 and the second group G2, the absolute value of the first angle β1 between the radial line **75** passing through the centroid **55** of each of the plurality of sensing elements **50** and the centroid **70***c* of the film unit **70** and the extending direction X11 of the magnetization free layer **11** of the sensing element **50** is 67.5 degrees.

In the first group G1 and the second group G2, the absolute value of the second angle β2 between the radial line **75** passing through the centroid **55** of each of the plurality of sensing elements **50** and the centroid **70***c* of the film unit **70** and the extending direction X12 of the reference layer **12** of the sensing element **50** is 67.5 degrees.

In the third group G3 and the fourth group G4, the absolute value of the first angle β1 between the radial line **75** passing through the centroid **55** of each of the plurality of sensing elements **50** and the centroid **70***e* of the film unit **70** and the extending direction X11 of the magnetization free layer **11** of the sensing element **50** is 22.5 degrees.

In the third group G3 and the fourth group G4, the absolute value of the second angle β2 between the radial line **75** passing through the centroid **55** of each of the plurality of sensing elements **50** and the centroid **70***c* of the film unit **70** and the extending direction X12 of the reference layer **12** of the sensing element **50** is 22.5 degrees.

Thus, the first angle β1 and the second angle β2 may be different between sensing elements **50**.

The magnetization direction in each sensing element **50** is set by applying an external magnetic field Hex and removing the external magnetic field Hex, for example.

In the first group G1, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of a sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **11***m* of the magnetization free layer **11** of the sensing element **50** (for example, the direction of the magnetization **11***am*) is +112.5 degrees, for example. On the other hand, the angle from the direction from the centroid **55** of the sensing element **50** toward the centroid **70***c* of the film unit **70** (a direction parallel to the radial line **75**) to the magnetization direction **12***m* of the reference layer **12** of the sensing element **50** is −112.5 degrees.

In the third group G3, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of a sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **11***m* of the magnetization free layer **11** of the sensing element **50** (for example, the direction of the magnetization **11***am*) is +157.5 degrees, for example. On the other hand, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of the sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **12***m* of the reference layer **12** of the sensing element **50** is +22.5 degrees.

In the second group G2, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of a sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **11***m* of the magnetization free layer **11** of the sensing element **50** (for example, the direction of the magnetization **11***am*) is +67.5 degrees, for example. On the other hand, the angle from the direction from the centroid **55** of the sensing element **50** toward the centroid **70***c* of the film unit **70** (a direction parallel to the radial line **75**) to the magnetization direction **12***m* of the reference layer **12** of the sensing element **50** is −67.5 degrees.

In the fourth group G4, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of a sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction urn of the magnetization free layer **11** of the sensing element **50** (for example, the direction of the magnetization **11***am*) is −22.5 degrees, for example. On the other hand, the angle from the direction from the centroid **70***c* of the film unit **70** toward the centroid **55** of the sensing element **50** (a direction parallel to the radial line **75**) to the magnetization direction **12***m* of the reference layer **12** of the sensing element **50** is −157.5 degrees.

Thus, the relationship between the magnetization direction **11***m* of the magnetization free layer **11** and the radial

line **75** and the relationship between the magnetization direction **12***m* of the reference layer **12** and the radial line **75** are different between groups.

As described above, in the circular film unit **70**, the direction of strain Sa is set along the radial line **75**. The polarity of the properties obtained in the sensing element **50** included in the first group G1 is the same as the polarity of the properties obtained in the sensing element **50** included in the second group G2. The polarity of the properties obtained in the sensing element **50** included in the third group G3 is the same as the polarity of the properties obtained in the sensing element **50** included in the fourth group G4. The polarity of the properties obtained in the sensing element **50** included in the first group G1 is opposite to the polarity of the properties obtained in the sensing element **50** included in the third group G3.

In this example, the angle α between the extending direction X11 of the magnetization free layer **11** and the extending direction X12 of the reference layer **12** is 135 degrees. In this case, the electric resistance R when the strain Sa is zero is equal between sensing elements **50**.

The properties obtained in the sensing element **50** of the first group G1 and the second group G2 are strain sensor properties opposite to the properties obtained in the sensing element **50** of the third group G3 and the fourth group G4, with respect to the tensile and compressive strain Sa.

By forming a bridge circuit using a plurality of sensing elements **50** with polarities opposite to one another, the output is increased as described later, for example. The function of temperature compensation is obtained, for example.

In the example shown in FIG. **12**, in the first sensing element **50***a*, the average direction of the extending direction of the first magnetic layer **11***a* and the extending direction of the second magnetic layer **12***a* is substantially parallel to the radial line **75**. In the first sensing element **50***a*, the straight line passing through the centroid **70***c* of the upper surface **70***u* of the film unit **70** and the centroid **55** of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in a plane parallel to the upper surface **70***u* is defined as a first straight line LN1, for example. The difference between the absolute value of the angle (the first angle β1) between the first straight line LN1 and the first direction X1 and the absolute value of the angle (the second angle β2) between the first straight line LN1 and the second direction X2 is 5 degrees or less. The absolute value of the first angle β1 is not less than 45 degrees and not more than 90 degrees. Also the absolute value of the second angle β2 is not less than 45 degrees and not more than 90 degrees. In this example, these angles are 67.5 degrees.

In the example shown in FIG. **12**, in the third sensing element **50***c*, the average direction of the extending direction of the fifth magnetic layer **11***c* and the extending direction of the sixth magnetic layer **12***c* is substantially perpendicular to the radial line **75**. In the example shown in FIG. **12**, the first sensing element **50***a* may be disposed in the position where the third sensing element **50***c* is provided. At this time, the line passing through the centroid **70***c* of the upper surface **70***u* of the film unit **70** and the centroid **55** of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in a plane parallel to the upper surface **70***u* is defined as a first straight line LN1. At this time, in the first sensing element **50***a* disposed in the position of the third sensing element **50***c*, the difference between the absolute value of the angle (the first angle β1) between the first straight line LN1 and the first direction X1 and the absolute value of the angle (the second angle β2) between the first straight line LN1 and the second direction X2 is 5 degrees or less. The absolute value of the first angle β1 is not less than 0 degrees and not more than 45 degrees. The absolute value of the second angle β2 is not less than 0 degrees and not more than 45 degrees. In this example, these angles are 22.5 degrees.

FIG. **13**A to FIG. **13**D are schematic plan views illustrating pressure sensors according to the first embodiment.

As shown in FIG. **13**A and FIG. **13**B, in pressure sensors **114***a* and **114***b*, the planar shape of the film unit **70** is a flat circle (including an ellipse). As shown in FIG. **13**C, in a pressure sensor **114***c*, the planar shape of the film unit **70** is a square. As shown in FIG. **13**D, in a pressure sensor **114***d*, the planar shape of the film unit **70** is a rectangle. In the embodiment, the planar shape of the film unit **70** may be a polygon (a regular polygon).

In the pressure sensors **114***a* and **114***c*, the distance between the sensing element **50** and the centroid **70***c* of the film unit **70** is equal between sensing elements **50**.

In the pressure sensors **114***b*, **114***c*, and **114***d*, the distance between the outer edge **70***r* of the film unit **70** and the sensing element **50** is equal between sensing elements **50**.

In the pressure sensors **114***a* to **114***d*, a plurality of sensing elements **50** are arranged radially so as to pass through the centroid **70***c* of the film unit **70**, for example.

In the examples shown in FIG. **13**A to FIG. **13**D, the number of sensing elements **50** is four. In the embodiment, the number of sensing elements **50** is arbitrary.

FIG. **14**A to FIG. **14**D are schematic plan views illustrating pressure sensors according to the first embodiment.

As shown in FIG. **14**A, in a pressure sensor **115***a*, the planar shape of the film unit **70** is a circle. The outer edge **70***r* of the film unit **70** is in a circular shape. A plurality of sensing elements **50** are arranged along the outer edge **70***r* in a circular shape.

As shown in FIG. **14**B, in a pressure sensor **115***b*, the planar shape of the film unit **70** is a flat circle (including an ellipse). The outer edge **70***r* of the film unit **70** is in a flat circular shape. A plurality of sensing elements **50** are arranged along the outer edge **70***r* in a flat circular shape.

In the pressure sensors **115***a* and **115***b*, the distances between the plurality of sensing elements **50** and the outer edge **70***r* (the shortest distance Lmin) are equal to one another. In this example, the center of each of the plurality of sensing elements **50** is disposed in a position where the distance from the outer edge **70***r* is the shortest distance Lmin.

As shown in FIG. **14**C, in a pressure sensor **115***b*, the planar shape of the film unit **70** is a square. A plurality of sensing elements **50** are arranged along the sides of the square.

As shown in FIG. **14**D, in a pressure sensor **115***d*, the planar shape of the film unit **70** is a rectangle. A plurality of sensing elements **50** are arranged along the sides of the rectangle.

As illustrated in FIG. **14**B, one straight line (for example, a second straight line) connects the outer edge **70***r* of the upper surface **70***u* of the film unit **70** and the centroid of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap, by the shortest distance. The angle between the second straight line and the first direction X1 is defined as a third angle. The angle between the second straight line and the second direction X2 is defined as a fourth angle. The difference between the absolute value of the third angle and the absolute value of the fourth angle is 5 degrees or less, for example.

The absolute value of the third angle is not less than 30 degrees and not more than 60 degrees. The absolute value of the fourth angle is not less than 30 degrees and not more than 60 degrees. By setting the absolute value of the third angle and the absolute angle of the fourth angle not less than 30 degrees and not more than 60 degrees, the dynamic range of the electric resistance change with respect to the positive and negative pressure can be widened, for example. The absolute value of the third angle may be not less than 45 degrees and not more than 90 degrees. The absolute value of the third angle may be not less than 0 degrees and not more than 45 degrees. The absolute value of the fourth angle may be not less than 45 degrees and not more than 90 degrees. The absolute value of the fourth angle may be not less than 0 degrees and not more than 45 degrees.

In the embodiment, the straight line connecting the outer edge **70***r* of the upper surface **70***u* of the film unit **70** and the centroid of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap by the shortest distance is defined as a second straight line. The straight line connecting the outer edge **70***r* of the upper surface **70***u* and the centroid of the region where the third magnetic layer **11***b* and the fourth magnetic layer **12***b* overlap by the shortest distance is defined as a fourth straight line. The angle between the second straight line and the first direction X1 is defined as a third angle. The angle between the fourth straight line and the third direction X3 is defined as a sixth angle. The difference between the absolute value of the third angle and the absolute value of the sixth angle is 5 degrees or less, for example.

FIG. **15**A to FIG. **15**C are schematic diagrams illustrating pressure sensors according to the first embodiment.

The drawings show examples of the connection state of a plurality of sensing elements.

As shown in FIG. **15**A, in a pressure sensor **116***a* according to the embodiment, a plurality of sensing elements **50** are electrically connected in series. When the number of sensing elements **50** connected in series is denoted by N, the electric signal obtained is N times of that when the number of sensing elements **50** is one. On the other hand, the thermal noise and the Schottky noise are $N^{1/2}$ times. That is, the S/N ratio (signal-noise ratio; SNR) is $N^{1/2}$ times. By increasing the number N of sensing elements **50** connected in series, the S/N ratio can be improved without increasing the size of the film unit **70**.

When a film unit **70** having shape anisotropy is used, the changes in the electric resistance R with respect to the pressure (for example, the polarities) of a plurality of sensing elements **50** that are arranged to gather near the centroid **70***c* of the film unit **70** are similar, for example. Hence, it is possible to sum up the signals of the plurality of sensing elements **50**.

The bias voltage applied to one sensing element **50** is not less than 50 millivolts (mV) and not more than 150 mV, for example. When N sensing elements **50** are connected in series, the bias voltage is not less than 50 mV×N and not more than 150 mV×N. When the number N of sensing elements **50** connected in series is 25, the bias voltage is not less than 1 V and not more than 3.75 V, for example.

When the value of the bias voltage is 1 V or more, the design of an electric circuit that processes the electric signal obtained from the sensing element **50** is easy, and this is preferable in practical terms. A plurality of sensing elements **50** from which electric signals with the same polarity are obtained when pressure is produced are provided, for example. By connecting these sensing elements in series, the S/N ratio can be improved as mentioned above.

Bias voltages (inter-terminal voltages) exceeding 10 V are not preferable in the electric circuit that processes the electric signal obtained from the sensing element **50**. In the embodiment, the number N of sensing elements **50** connected in series and the bias voltage are set so that an appropriate voltage range is obtained.

The voltage when the plurality of sensing elements **50** are electrically connected in series is preferably not less than 1 V and not more than 10 V, for example. The voltage applied between the terminals of sensing elements **50** electrically connected in series (between the terminal of one end and the terminal of the other end) is not less than 1 V and not more than 10 V, for example.

To generate this voltage, when the bias voltage applied to one sensing element **50** is 50 mV, the number N of sensing elements **50** connected in series is preferably not less than 20 and not more than 200. When the bias voltage applied to one sensing element **50** is 150 mV, the number N of sensing elements **50** connected in series is preferably not less than 7 and not more than 66.

As shown in FIG. **15**B, in a pressure sensor **116***b* according to the embodiment, a plurality of sensing elements **50** are electrically connected in parallel. In the embodiment, at least part of a plurality of sensing elements **50** may be electrically connected in parallel.

As shown in FIG. **15**C, in a pressure sensor **116***c* according to the embodiment, a plurality of sensing elements **50** are connected so as to form a Wheatstone bridge circuit. Thereby, the temperature compensation of detected characteristics can be made, for example.

FIG. **16**A to FIG. **16**C are schematic perspective views illustrating pressure sensors according to the first embodiment.

The drawings show examples of the connection in a plurality of sensing elements.

As shown in FIG. **16**A, in a pressure sensor **117***a* according to the embodiment, a plurality of sensing elements **50** are electrically connected in series. The sensing element **50** and a via contract **65** are provided between the first electrode ELa1 (for example, the first interconnection **61**) and the second electrode ELa2 (for example, the second interconnection **62**). Thereby, the current passage direction is one direction in the plurality of sensing elements **50**. The current passed through the plurality of sensing elements **50** is in the downward direction or the upward direction. In this connection, the signal/noise characteristics of the plurality of sensing elements **50** can be made close to one another.

As shown in FIG. **16**B, in a pressure sensor **117***b* according to the embodiment, the via contact **65** is not provided, and the sensing element **50** is disposed between the first electrode ELa1 and the second electrode ELa2. In this example, the directions of the currents passed through adjacent two sensing elements **50** are opposite to each other. In this connection, the density of the arrangement of sensing elements **50** is high.

As shown in FIG. **16**C, in a pressure sensor **117***c* according to the embodiment, a plurality of sensing elements **50** are provided between one first electrode ELa1 and one second electrode ELa2. The plurality of sensing elements **50** are connected in parallel.

FIG. **17**A to FIG. **17**E are schematic perspective views illustrating pressure sensors according to the first embodiment.

As shown in FIG. **17**A, in a pressure sensor **118***a* according to the embodiment, in the first sensing element **50***a*, the planar shape of the first intermediate layer **13***a* (the first intermediate unit **13***au*) is the same as the planar shape of the

first magnetic layer **11***a*. That is, the shape of the first intermediate unit **13***au* in the X-Y plane (a plane parallel to the upper surface **70***u* of the film unit **70**) is the same as the shape of the first magnetic layer **11***a* in the X-Y plane, for example.

As shown in FIG. **17**B, in a pressure sensor **118***b* according to the embodiment, the planar shape of the first intermediate layer **13***a* (the first intermediate unit **13***au*) is different from the planar shape of the first magnetic layer **11***a* and is different also from the planar shape of the second magnetic layer **12***a*. The shape of the first intermediate unit **13***au* in the X-Y plane is the same as the shape of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane, for example.

As shown in FIG. **17**C, in a pressure sensor **118***c* according to the embodiment, the first intermediate unit **13***au* further includes a first intermediate magnetic layer **13***aa* provided between the first intermediate layer **13***a* and the first magnetic layer **11***a* and a second intermediate magnetic layer **13***ab* provided between the first intermediate layer **13***a* and the second magnetic layer **12***a*.

In this example, the shape of the first intermediate unit **13***au* in the X-Y plane is the same as the shape of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane, for example.

The stacked film including the first intermediate magnetic layer **13***aa*, the first intermediate layer **13***a*, and the first intermediate magnetic layer **13***aa*, which stacked film contributes to the magnetoresistance effect due to the existence of the first intermediate magnetic layer **13***aa* and the second intermediate magnetic layer **13***ab*, can be formed by consistent film formation under a reduced pressure. Thereby, a high magnetoresistance effect is obtained, for example.

The first magnetic layer **11***a* and the first intermediate magnetic layer **13***aa* are magnetically coupled, for example. The magnetization direction of the first intermediate magnetic layer **13***aa* is set along the magnetization direction of the first magnetic layer **11***a*. The second magnetic layer **12***a* and the second intermediate magnetic layer **13***ab* are magnetically coupled. The magnetization direction of the second intermediate magnetic layer **13***ab* is set along the magnetization direction of the second magnetic layer **12***a*.

Even when substantially neither the planar shape of the first intermediate magnetic layer **13***aa* nor the planar shape of the second intermediate magnetic layer **13***ab* has shape anisotropy, the initial magnetization of the first intermediate magnetic layer **13***aa* and the initial magnetization of the second intermediate magnetic layer **13***ab* can be controlled because the planar shape of the first magnetic layer **11***a* and the planar shape of the second magnetic layer **12***a* have shape anisotropy.

The material described in regard to the first magnetic layer **11***a* may be used for at least one of the first intermediate magnetic layer **13***aa* and the second intermediate magnetic layer **13***ab*, for example.

As shown in FIG. **17**D, in a pressure sensor **118***d* according to the embodiment, the first intermediate unit **13***au* includes the first intermediate layer **13***a* and the first intermediate magnetic layer **13***aa*. Also in this case, the shape of the first intermediate unit **13***au* in the X-Y plane is the same as the shape of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane, for example.

The stacked film including the first intermediate layer **13***a* and the first intermediate magnetic layer **13***aa*, which stacked film contributes to the magnetoresistance effect due to the existence of the first intermediate magnetic layer **13***aa*, can be formed by consistent film formation under a reduced pressure. Thereby, a high magnetoresistance effect is obtained, for example.

Also at this time, the first magnetic layer **11***a* and the first intermediate magnetic layer **13***aa* are magnetically coupled, for example. The magnetization direction of the first intermediate magnetic layer **13***aa* is set along the magnetization direction of the first magnetic layer **11***a*.

As shown in FIG. **17**E, in a pressure sensor **118***e* according to the embodiment, the first intermediate unit **13***au* includes the first intermediate layer **13***a* and the second intermediate magnetic layer **13***ab*. Also in this case, the shape of the first intermediate unit **13***au* in the X-Y plane is the same as the shape of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane, for example.

The stacked film including the first intermediate layer **13***a* and the second intermediate magnetic layer **13***ab*, which stacked film contributes to the magnetoresistance effect due to the existence of the second intermediate magnetic layer **13***ab*, can be formed by consistent film formation under a reduced pressure. Thereby, a high magnetoresistance effect is obtained, for example.

Also at this time, the second magnetic layer **12***a* and the second intermediate magnetic layer **13***ab* are magnetically coupled, for example. The magnetization direction of the second intermediate magnetic layer **13***ab* is set along the magnetization direction of the second magnetic layer **11***b*.

FIG. **18**A and FIG. **18**B are schematic plan views illustrating the pressure sensor according to the first embodiment.

In the example shown in FIG. **18**A, the planar shape of the first magnetic layer **11***a* is a rectangle, and the planar shape of the second magnetic layer **12***a* is a rectangle. In the example shown in FIG. **18**B, the planar shape of the first magnetic layer **11***a* is an ellipse, and the planar shape of the second magnetic layer **12***a* is an ellipse.

The planar shape of the first magnetic layer **11***a* may be a quadrangle such as a parallelogram or a flat circle (including an ellipse), for example. The planar shape of the second magnetic layer **12***a* may be a quadrangle such as a parallelogram or a flat circle (including an ellipse), for example.

In the first sensing element **50***a*, the first major axis length L1 is not less than twice the first minor axis length D1, for example. The second major axis length L2 is not more than twice the second minor axis length D2.

In the embodiment, pressure can be sensed with a sufficiently high sensitivity even when the size of the magnetization free layer **11** (for example, the first magnetic layer **11***a*) and the size of the reference layer **12** (for example, the second magnetic layer **12***a*) are small.

Thus, the area of the first magnetic layer **11***a* and the area of the second magnetic layer **12***a* can be made sufficiently smaller than the area of the film unit **70**. Each of the area of the first magnetic layer **11***a* and the area of the second magnetic layer **12***a* is not more than ⅕ of the area of the film unit **70**, for example.

When the diameter of the film unit **70** is approximately 60 μm, each of the first minor axis length D1 of the first magnetic layer **11***a* and the second minor axis length D2 of the second magnetic layer **12***a* is 12 μm or less, for example.

When the diameter of the film unit **70** is approximately 600 μm, each of the first minor axis length D1 of the first magnetic layer **11***a* and the second minor axis length D2 of the second magnetic layer **12***a* is 120 μm or less, for example.

In view of the processing accuracy of the sensing element **50** etc., the first magnetic layer **11***a* and the second magnetic layer **12***a* may not be excessively small, for example. Each of the first minor axis length D1 and the second minor axis length D2 may be not less than 0.05 μm and not more than 30 μm, for example.

Each of the first major axis length L1 of the first magnetic layer **11***a* and the second major axis length L2 of the second magnetic layer **12***a* is preferably not less than 0.1 μm and not more than 60 μm, for example.

The above description is applied to any one of the pressure sensors **110**, **111**, **112***a* to **112***c*, **113***a*, **113***b*, **116***a* to **116***c*, **117***a* to **117***c*, and **118***a* to **118***e*, and modifications thereof.

FIG. **19**A to FIG. **19**D are schematic plan views illustrating the pressure sensor according to the first embodiment.

In the example shown in FIG. **19**A, the shape of the first intermediate unit **13***au* in the X-Y plane is the same as the shape of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane.

In the example shown in FIG. **19**B, the first intermediate unit **13***au* in the X-Y plane is located inside the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane.

In the example shown in FIG. **19**C, the outer edge of the first intermediate unit **13***au* in the X-Y plane is located outside the outer edge of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane.

In the example shown in FIG. **19**D, the shape of the first intermediate unit **13***au* in the X-Y plane is a circle, and the shape of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane is a rectangular shape.

In the examples shown in FIG. **19**B and FIG. **19**D, the outer edge **13***aur* of a first intermediate unit region of the first intermediate unit **13***au* in the X-Y plane (a plane parallel to the upper surface **70***u* of the film unit **70**) is on the inside of the outer edge **15***r* of the region where the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap in the X-Y plane.

FIG. **20** is a schematic perspective view illustrating a pressure sensor according to the first embodiment.

As shown in FIG. **20**, also in another pressure sensor **120** according to the embodiment, the first sensing element **50***a* is provided on the upper surface **70***u* of the film unit **70**. The first sensing element **50***a* further includes an upper magnetic layer **12***p*, a middle magnetic layer **11***p*, an upper intermediate unit **13***qu*, and a middle intermediate unit **13***pu*, in addition to the first magnetic layer **11***a*, the first intermediate unit **13***au*, and the second magnetic layer **12***a*.

In this example, at least part of the first magnetic layer **11***a* is disposed between the upper magnetic layer **12***p* and the film unit **70**. At least part of the second magnetic layer **12***a* is disposed between the upper magnetic layer **12***p* and the first magnetic layer **11***a*. At least part of the middle magnetic layer **11***p* is disposed between the upper magnetic layer **12***p* and the second magnetic layer **12***a*. At least part of the upper magnetic layer **12***p* is disposed between the upper magnetic layer **12***p* and the middle magnetic layer **11***p*.

At least part of the upper intermediate unit **13***qu* is disposed between the upper magnetic layer **12***p* and the middle magnetic layer **11***p*. At least part of the middle intermediate unit **13***pu* is disposed between the middle magnetic layer **11***p* and the second magnetic layer **12***a*.

In this example, the upper intermediate unit **13***qu* includes an upper intermediate layer **13***q*, an upper-side magnetic layer **13***qb*, and a lower-side magnetic layer **13***qa*. At least part of the upper-side magnetic layer **13***qb* is provided between the upper intermediate layer **13***q* and the upper magnetic layer **12***p*. At least part of the lower-side magnetic layer **13***qa* is provided between the upper intermediate layer **13***q* and the middle magnetic layer **11***p*.

In this example, the middle intermediate unit **13***pu* includes a middle intermediate layer **13***p*, an upper-side magnetic layer **13***pb*, and a lower-side magnetic layer **13***pa*. At least part of the upper-side magnetic layer **13***pb* is provided between the middle intermediate layer **13***p* and the middle magnetic layer **11***p*. At least part of the lower-side magnetic layer **13***pa* is provided between the middle intermediate layer **13***p* and the second magnetic layer **12***a*.

The configuration and material described in regard to the second magnetic layer **12***a* may be used for the upper magnetic layer **12***p*, for example. The configuration and material described in regard to the first magnetic layer **11***a* may be used for the middle magnetic layer **11***p*, for example.

The configuration and material described in regard to the first intermediate layer **13***a* may be used for at least one of the upper intermediate layer **13***q* and the middle intermediate layer **13***p*. The configuration and material described in regard to the second intermediate magnetic layer **13***ab* may be used for at least one of the upper-side magnetic layer **13***qb* and the upper-side magnetic layer **13***pb*. The configuration and material described in regard to the first intermediate magnetic layer **13***aa* may be used for at least one of the lower-side magnetic layer **13***qa* and the lower-side magnetic layer **13***pa*.

A magnetization free layer may be used as at least one of the middle magnetic layer **11***p* and the upper magnetic layer **12***p*, for example.

The middle magnetic layer **11***p* has shape anisotropy, for example. The upper magnetic layer **12***p* has shape anisotropy. In this example, the extending direction of the middle magnetic layer **11***p* is set along the extending direction of the first magnetic layer **11***a* (the first direction X1). The extending direction of the upper magnetic layer **12***p* is set along the extending direction of the second magnetic layer **12***a* (the second direction X2).

In the embodiment, the extending direction of the middle magnetic layer **11***p* may cross the extending direction of the first magnetic layer **11***a*. The extending direction of the upper magnetic layer **12***p* may cross the extending direction of the second magnetic layer **12***a* (the second direction X2).

The configuration of the pressure sensor **120** may be used for any one of the pressure sensors **110**, **111**, **112***a* to **112***c*, **113***a*, **113***b*, **116***a* to **116***c*, **117***a* to **117***c*, and **118***a* to **118***e*, and modifications thereof.

A method for manufacturing the pressure sensor **118***c* will now be described.

FIG. **21**A to FIG. **21**M are schematic perspective views in order of the steps, illustrating a method for manufacturing a pressure sensor according to the first embodiment.

As shown in FIG. **21**A, a first magnetic film **11***af* that forms the first magnetic layer **11***a* is formed on the first electrode ELa1. It is possible to form the underlayer **11***al* on the first electrode ELa1 and form a second magnetic film **11***af* on the underlayer **11***al*. In FIG. **20**A, the underlayer **11***al* is omitted.

It is possible to process a film that forms the first electrode ELa1 and form the planar shape of the first electrode ELa1 before the formation of the underlayer **11***al* and the first magnetic film **11***af*. Alternatively, after the processing of the stacked film included in the sensing element is finished, the

first electrode ELa1 may be processed to form the planar shape of the first electrode ELa1.

A cap layer (not shown) may be formed into a film on the first magnetic film **11***af*. The cap layer can suppress oxidation etc. when the first magnetic film **11***af* is exposed to the air. The cap layer can be removed by physical etching before the film formation of the intermediate unit, as described later.

Ta (5 nm)/Cu (5 nm)/CoFeSiB (12 nm)/MgO (3 nm) is formed on the first electrode ELa1, for example. The Ta (5 nm)/Cu (5 nm) corresponds to the underlayer. The CoFeSiB (12 nm) corresponds to the first magnetic film **11***af*. The MgO (3 nm) corresponds to the cap layer.

As shown in FIG. **21**B, the film including the underlayer **11***al*/the first magnetic film **11***af*/the cap layer is processed into a shape having shape anisotropy. In this process, a resist is patterned by photolithography, and then the not-shown resist pattern is used as a mask to perform physical etching or chemical etching, for example. Thereby, the first magnetic layer **11***a* is formed.

As shown in FIG. **21**C, an insulating layer **11***if* is embedded and formed into a film around the film including the underlayer **11***al*/the first magnetic layer **11***a*/the cap layer. A lift-off process is performed, for example. While the resist pattern formed in the photolithography of FIG. **21**C is left, the insulating layer **11***if* is formed into a film over the entire surface, and then the resist pattern is removed, for example. As the insulating layer **11***if*, at least one of SiO_x, AlO_x, SiN_x and AlN_x is used, for example.

As shown in FIG. **21**D, part of the cap layer provided on the first magnetic layer **11***a* and part of the surrounding insulating layer **11***if* are removed by physical etching. In the case where the cap layer has not been provided, the oxidized portion of the first magnetic layer **11***a* is removed by physical etching in this process. In the case where a material that is hardly oxidized even when exposed to the air is used as the first magnetic layer **11***a*, the process of FIG. **21**D may not necessarily be performed, for example.

In this process, part of the Ta (5 nm)/Cu (5 nm)/CoFeSiB (12 nm)/MgO (3 nm) formed in the process described in regard to FIG. **21**A is removed, for example. Thereby, a structure of Ta (5 nm)/Cu (5 nm)/CoFeSiB (8 nm) is formed.

The process shown in FIG. **21**E described later and the process shown in FIG. **21**D are performed consistently under a reduced pressure using the same apparatus, for example. Thereby, the film formation of the intermediate unit of FIG. **21**E can be performed while the surface of the first magnetic layer **11***a* after the process of FIG. **21**D is kept clean.

As shown in FIG. **21**E, the first intermediate unit **13***au* including the first intermediate magnetic layer **13***aa*, the first intermediate layer **13***a*, and the second intermediate magnetic layer **13***ab* is formed. A cap layer **13***ac* may be provided on the second intermediate magnetic layer **13***ab*. CoFeB (2 nm)/MgO (2 nm)/CoFeB (6 nm)/MgO (3 nm) is formed, for example. The CoFeB (2 nm) corresponds to the first intermediate magnetic layer **13***aa*. The MgO (2 nm) corresponds to the first intermediate layer **13***a*. The CoFeB (6 nm) corresponds to the second intermediate magnetic layer **13***ab*. The MgO (3 nm) corresponds to the cap layer **13***ac*.

As shown in FIG. **21**F, the first intermediate magnetic layer **13***aa*/the first intermediate layer **13***a*/the second intermediate magnetic layer **13***ab*/the cap layer **13***ac* is processed into a prescribed planar shape. In this process, a resist is patterned by photolithography, and then the not-shown resist pattern is used as a mask to perform physical etching or chemical etching.

As shown in FIG. **21**G, an insulating layer **11***ifa* is embedded and formed into a film around the first intermediate magnetic layer **13***aa*/the first intermediate layer **13***a*/the second intermediate magnetic layer **13***ab*/the cap layer **13***ac*. In this process, a lift-off process is performed, for example. While the resist pattern formed in the photolithography of FIG. **21**F is left, the insulating layer **11***ifa* is formed into a film over the entire surface, and then the resist pattern is removed, for example. At least one of SiO_x, AlO_x, SiN_x, and AlN_x is used as the insulating layer **11***ifa*, for example.

As shown in FIG. **21**H, part of the cap layer **13***ac* provided on the second intermediate magnetic layer **13***ab* and part of the surrounding insulating layer **11***ifa* are removed by physical etching.

In the case where the cap layer **13***ac* has not been provided, the oxidized portion of the second intermediate magnetic layer **13***ab* is removed by physical etching. In the case where a material that is hardly oxidized even when exposed to the air is used as the second intermediate magnetic layer **13***ab*, the process of FIG. **21**H may not necessarily be performed.

In this process, part of the CoFeB (2 nm)/MgO (2 nm)/CoFeB (6 nm)/MgO (3 nm) formed into a film in FIG. **21**E is removed, for example. Thereby, a structure of CoFeB (2 nm)/MgO (2 nm)/CoFeB (2 nm) is formed.

The process of FIG. **21**I described later and the process shown in FIG. **21**H are performed consistently under a reduced pressure using the same apparatus. Thereby, a film that forms the second magnetic layer **12***a* shown in FIG. **21**I can be formed while the surface of the second intermediate magnetic layer **13***ab* after the process of FIG. **21**H is kept clean.

As shown in FIG. **21**I, a second magnetic film **12***af* that forms the second magnetic layer **12***a* and a cap film **12***acf* that forms the cap layer **12***ac* are formed. CoFeSiB (4 nm)/Cu (5 nm)/Ru (10 nm) is formed into a film, for example. The CoFeSiB (4 nm) corresponds to the second magnetic film **12***af* (the second magnetic layer **12***a*). The Cu (5 nm)/Ru (10 nm) corresponds to the cap film **12***acf* (the cap layer **12***ac*).

As shown in FIG. **21**J, the second magnetic film **12***af* and the cap film **12***acf* are processed into a shape having shape anisotropy. Thereby, the second magnetic layer **12***a* and the cap layer **12***ac* are formed. In this process, a resist is patterned by photolithography, and then the not-shown resist pattern is used as a mask to perform physical etching or chemical etching.

As shown in FIG. **21**K, an insulating layer **11***ifb* is embedded and formed into a film around the second magnetic layer **12***a* and the cap layer **12***ac*. In this process, a lift-off process is performed, for example. While the resist pattern formed in the photolithography of FIG. **21**J is left, the insulating layer **11***ifb* is formed into a film over the entire surface, and then the resist pattern is removed, for example. At least one of SiO_x, AlO_x, SiN_x, and AlN_x is used as the insulating layer **11***ifb*, for example.

As shown in FIG. **21**L, part of the cap layer **12***ac* and part of the surrounding insulating layer **11***ifb* are removed by physical etching. In the case where the cap layer **12***ac* has not been provided, the oxidized portion of the second magnetic layer **12***a* is removed by physical etching. In the case where a material that is hardly oxidized even when

exposed to the air is used as the second magnetic layer **12***a*, the process of FIG. **21**L may not necessarily be performed, for example.

In this process, part of the CoFeSiB (4 nm)/Cu (5 nm)/Ru (10 nm) formed into a film in FIG. **21**I is removed, for example. Thereby, a structure of CoFeSiB (4 nm)/Cu (5 nm)/Ru (5 nm) is formed. The process of FIG. **21**M described later and the process shown in FIG. **21**L are performed consistently under a reduced pressure using the same apparatus. Thereby, the second magnetic layer **12***a* of FIG. **21**M can be formed into a film while the surface of the cap layer **12***ac* after the process of FIG. **21**L is kept clean.

As shown in FIG. **21**M, the second electrode ELa2 is formed.

By such a process, the first sensing element **50***a* is formed.

FIG. **22**A to FIG. **22**F are schematic views in order of the steps, illustrating a method for manufacturing a pressure sensor according to the first embodiment.

FIG. **22**A, FIG. **22**C, and FIG. **22**E are schematic plan views. FIG. **22**B is a cross-sectional view taken along line B**1**-B**2** of FIG. **22**A. FIG. **22**D is a cross-sectional view taken along line B**3**-B**4** of FIG. **22**C. FIG. **22**F is a cross-sectional view taken along line B**5**-B**6** of FIG. **22**E. The drawings show also an example of the structure of adjacent sensing elements **50**.

As shown in FIG. **22**A and FIG. **22**B, the first magnetic layer **11***a* is formed on the first electrode ELa1. As shown in FIG. **22**C and FIG. **22**D, the first intermediate unit **13***au* is formed on the first magnetic layer **11***a*. As shown in FIG. **22**E and FIG. **22**F, the second magnetic layer **12***a* is formed on the first intermediate unit **13***au*. Thus, the sensing element **50** (the first sensing element **50***a*) is formed.

In this example, the first intermediate unit **13***au* is formed separately from the first magnetic layer **11***a* and from the second magnetic layer **12***a*.

In this case, as illustrated in FIG. **22**E and FIG. **22**F, in different sensing elements **50**, the first magnetic layer **11***a* and the second magnetic layer **12***a* may be provided so as to overlap each other when projected onto the X-Y plane. When the intermediate units do not overlap in different sensing elements **50**, the different sensing elements **50** can be operated electrically independently. A plurality of sensing elements **50** can be connected together at least one of in series and in parallel by the arrangement of the first electrode ELa1 and the second electrode ELa2 provided in the sensing element **50**, for example. Since the first magnetic layer **11***a* and the second magnetic layer **12***a* overlap each other in different sensing elements **50**, sensing elements **50** can be arranged at high density.

A method for manufacturing the pressure sensor **110** will now be described.

FIG. **23**A to FIG. **23**E are schematic perspective views in order of the steps, illustrating a method for manufacturing a pressure sensor according to the embodiment.

As shown in FIG. **23**A, a thin film **70***f* is formed on a substrate **71** (for example, a Si substrate). The substrate **71** forms the support **70***s*. The thin film **70***f* forms the film unit **70**.

A thin film **70***f* of SiO_x/Si is formed by sputtering on a Si substrate, for example. A SiO_x single layer, a SiN single layer, or a metal layer of Al or the like may be used as the thin film **70***f*. A flexible plastic material such as a polyimide and a paraxylene-based polymer may be used as the thin film **70***f*. An SOI (silicon on insulator) substrate may be used as the substrate **71** and the thin film **70***f*. In the SOI, a stacked film of SiO_2/Si is formed on a Si substrate by attaching the substrates, for example.

As shown in FIG. **23**B, the first interconnection **61** is formed. In this process, a conductive film that forms the first interconnection **61** is formed, and the conductive film is processed by photolithography and etching. In the case where the surroundings of the first interconnection **61** are filled with an insulating film, lift-off process may be used. In the lift-off process, after the etching of the pattern of the first interconnection **61** and before the peeling of the resist, an insulating film is formed into a film over the entire surface and then the resist is removed, for example.

As shown in FIG. **23**C, sensing elements **50** are formed. In this process, a stacked film that forms the sensing element **50** is formed, and the stacked film is processed by photolithography and etching. In the case where the space on the side wall of the stacked body of the sensing element **50** is filled with the insulating layer **11***i*, lift-off process may be used. In the lift-off process, after the processing of the stacked body and before the peeling of the resist, the insulating layer **11***i* is formed into a film over the entire surface and then the resist is removed, for example.

As shown in FIG. **23**D, the second interconnection **62** is formed. In this process, a conductive film that forms the first interconnection **62** is formed, and the conductive film is processed by photolithography and etching. In the case where the surroundings of the second interconnection **62** are filled with an insulating film, lift-off process may be used. In the lift-off process, after the processing of the second interconnection **62** and before the peeling of the resist, an insulating film is formed into a film over the entire surface and then the resist is removed.

As shown in FIG. **23**E, etching is performed from the back surface of the substrate **71** to form a hollow portion **71***h*. Thereby, the film unit **70** and the support **70***s* are formed. In the case where a stacked film of SiO_x/Si is used as the thin film **70***f* that forms the film unit **70**, deep digging processing of the substrate **71** is performed from the back surface (the lower surface) toward the front surface (the upper surface) of the thin film **70***f*, for example. Thereby, the hollow portion **71***h* is formed. In the formation of the hollow portion **71***h*, a both-surface aligner exposure apparatus may be used, for example. Thereby, the hole pattern of the resist can be formed on the back surface in accordance with the position of the sensing element **50** on the front surface.

In the etching of the Si substrate, the Bosch process using RIE may be used, for example. In the Bosch process, an etching process using SF_6 gas and a deposition process using C_4F_8 gas are repeated, for example. Thereby, etching is performed selectively in the depth direction of the substrate **71** (the Z-axis direction) while the etching of the side wall of the substrate **71** is suppressed. A SiO_x layer is used as the end point of the etching, for example. That is, the etching is finished using a SiO_x layer, which is different in etching selectivity from Si. The SiO_x layer functioning as an etching stopper layer may be used as part of the film unit **70**. The SiO_x layer may be removed after the etching by treatment with anhydrous hydrogen fluoride and an alcohol, or the like, etc., for example.

Thus, the pressure sensor **110** according to the embodiment is formed. Other pressure sensors according to the embodiment can be manufactured by similar methods.

FIG. **24**A to FIG. **24**C are schematic cross-sectional views illustrating pressure sensors according to the first embodiment.

In the pressure sensors illustrated in FIG. **24**A and FIG. **24**B, a magnetization fixed layer is used as the reference

layer of the second magnetic layer **12***a*. In the pressure sensor illustrated in FIG. **24**C, two magnetization fixed layers are used.

The drawings illustrate the sensing element **50** (the first sensing element **50***a*).

In the example shown in FIG. **24**A, the first sensing element **50***a* includes the first electrode ELa1 (a lower electrode), the underlayer **11***al*, the first magnetic layer **11***a*, the first intermediate layer **13***a*, the second magnetic layer **12***a*, a pinning layer **32**, the cap layer **12***ac*, and the second electrode ELa2 (an upper electrode). The first magnetic layer **11***a* is provided between the first electrode ELa1 and the second electrode ELa2. The second magnetic layer **12***a* is provided between the first magnetic layer **11***a* and the second electrode ELa2. The first intermediate layer **13***a* is provided between the first magnetic layer **11***a* and the second magnetic layer **12***a*. The underlayer **11***al* is provided between the first magnetic layer **11***a* and the first electrode ELa1. The cap layer **12***ac* is provided between the second magnetic layer **12***a* and the second electrode ELa2. The pinning layer **32** is provided between the second magnetic layer **12***a* and the cap layer **12***ac*.

In the example shown in FIG. **24**B, the first sensing element **50***a* includes the first electrode ELa1 (a lower electrode), the underlayer **11***al*, a pinning layer **31**, the second magnetic layer **12***a*, the first intermediate layer **13***a*, the first magnetic layer **11***a*, the cap layer **12***ac*, and the second electrode ELa2 (an upper electrode). The first magnetic layer **11***a* is provided between the first electrode ELa1 and the second electrode ELa2. The second magnetic layer **12***a* is provided between the first electrode ELa1 and the first magnetic layer **11***a*. The first intermediate layer **13***a* is provided between the first magnetic layer **11***a* and the second magnetic layer **12***a*. The underlayer **11***al* is provided between the second magnetic layer **12***a* and the first electrode ELa1. The cap layer **12***ac* is provided between the first magnetic layer **11***a* and the second electrode ELa2. The pinning layer **31** is provided between the second magnetic layer **12***a* and the underlayer **11***al*.

In the pressure sensor illustrated in FIG. **24**C, an upper intermediate layer **34** is further provided to the pressure sensor illustrated in FIG. **24**B, between the second magnetic layer **12***a* and the cap layer **12***ac*. An upper pinned layer **33** is further provided between the upper intermediate layer **34** and the cap layer **12***a*. A pinning layer **32** is further provided between the upper pinned layer **33** and the cap layer **12***ac*. The configuration described in regard to the first magnetic layer **11***a* may be used for the upper pinned layer **33**. The extending direction of the upper pinned layer **33** crosses the extending direction of the first magnetic layer **11***a*. The extending direction of the upper pinned layer **33** may run along or cross the extending direction of the second magnetic layer **12***a*. In the pressure sensor of this example, the configuration of a magnetization fixed layer/an intermediate layer/a magnetization free layer/an intermediate layer/a magnetization fixed layer is used, for example. The configuration may be called a dual spin valve type, for example.

In the configurations illustrated in FIG. **24**A to FIG. **24**C, the insulating layer **11***i* may be further provided.

The pinning layer **32** provides unidirectional anisotropy to the second magnetic layer **12***a* (a ferromagnetic layer) in contact with the pinning layer **32**, and fixes the magnetization of the second magnetic layer **12***a*, for example. An antiferromagnetic layer is used as the pinning layer **32**, for example. At least one selected from the group consisting of IrMn, PtMn, PdPtMn, and RuRhMn is used for the pinning layer **32**, for example. The thickness of the pinning layer **32** is appropriately adjusted to provide unidirectional anisotropy of a sufficient strength.

When PtMn or PdPtMn is used as the pinning layer **32**, the thickness of the pinning layer **32** is preferably not less than 8 nm and not more than 20 nm. The thickness of the pinning layer **32** is more preferably not less than 10 nm and not more than 15 nm. When IrMn is used as the pinning layer **32**, unidirectional anisotropy can be provided by a smaller thickness than when PtMn is used as the pinning layer **32**. In this case, the thickness of the pinning layer **32** is preferably not less than 4 nm and not more than 18 nm. The thickness of the pinning layer **32** is more preferably not less than 5 nm and not more than 15 nm. An $Ir_{22}Mn_{78}$ layer with a thickness of 7 nm is used as the pinning layer **32**, for example.

A hard magnetic layer may be used as the pinning layer **32**. As the hard magnetic layer, CoPt (the ratio of Co being not less than 50 at. % (atomic percent) and not more than 85 at. %), $(Co_xPt_{100-x})_{100-y}Cr_y$ (x being not less than 50 at. % and not more than 85 at. %, y being not less than 0 at. % and not more than 40 at. %), FePt (the ratio of Pt being not less than 40 at. % and not more than 60 at. %), or the like may be used, for example.

In the case where a magnetization fixed layer is used as the second magnetic layer **12***a*, a ferromagnetic material containing at least one element selected from the group consisting of Fe, Co, and Ni may be used for the second magnetic layer **12***a*. As the material of the first magnetic layer **11***a*, FeCo alloy and NiFe alloy may be used, for example. For the first magnetic layer **11***a*, an alloy containing at least one element selected from the group consisting of Fe, Co, and Ni and boron (B) may be used. For the second magnetic layer **12***a*, Co—Fe—B alloy, Fe—B alloy, Fe—Co—Si—B alloy, or the like may be used, for example. As the second magnetic layer **12***a*, a $Co_{40}Fe_{40}B_{20}$ layer (the thickness being 4 nm, for example) may be used, for example.

In the case where a magnetization fixed layer is used as the second magnetic layer **12***a*, a stacked structure of a pinning layer-side magnetization fixed layer/a magnetic coupling layer/an intermediate layer-side magnetization fixed layer may be used as the second magnetic layer **12***a*. The pinning layer-side magnetization fixed layer is disposed in contact with the pinning layer **32**. The intermediate layer-side magnetization fixed layer is disposed in contact with the intermediate layer (the first intermediate layer **13***a*). Such magnetization fixed layers are called a synthetic pin structure.

As the pinning layer-side magnetization fixed layer, Co_xFe_{100-x} alloy (x being not less than 0 at. % and not more than 100 at. %), Ni_xFe_{100-x} alloy (x being not less than 0 at. % and not more than 100 at. %), or a material in which a nonmagnetic element is added to these is used, for example. As the pinning layer-side magnetization fixed layer, at least one selected from the group consisting of Co, Fe, and Ni is used, for example. As the second magnetization fixed layer, an alloy containing at least one material selected from these materials may be used. As the pinning layer-side magnetization fixed layer, $(Co_xFe_{100-x})_{100-y}B_y$ alloy (x being not less than 0 at. % and not more than 100 at. %, y being not less than 0 at. % and not more than 30 at. %) may be used.

The thickness of the pinning layer-side magnetization fixed layer is preferably not less than 1.5 nm and not more than 5 nm, for example. Thereby, the strength of the unidirectional anisotropic magnetic field caused by the pinning layer **32** can be increased, for example. The strength of the

antiferromagnetic coupling magnetic field between the pinning layer-side magnetization fixed layer and the intermediate layer-side magnetization fixed layer can be increased via a magnetic coupling layer formed in contact with the pinning layer-side magnetization fixed layer, for example. The magnetic thickness (the product of the saturation magnetization Bs and the thickness t (Bs·t)) of the pinning layer-side magnetization fixed layer is preferably substantially equal to the magnetic thickness of the intermediate layer-side magnetization fixed layer, for example.

The saturation magnetization of $Co_{40}Fe_{40}B_{20}$ in a thin film form is approximately 1.9 T (tesla). When a $Co_{40}Fe_{40}B_{20}$ layer with a thickness of 3 nm is used as the intermediate layer-side magnetization fixed layer, the magnetic thickness of the intermediate layer-side magnetization fixed layer is 1.9 T×3 nm, which is 5.7 Tnm, for example. On the other hand, the saturation magnetization of $Co_{75}Fe_{25}$ is approximately 2.1 T. The thickness of the pinning layer-side magnetization fixed layer by which a magnetic thickness equal to the above is obtained is 5.7 Tnm/2.1 T, which is 2.7 nm. In this case, a $Co_{75}Fe_{25}$ layer with a thickness of approximately 2.7 nm is preferably used as the pinning layer-side magnetization fixed layer. A $Co_{75}Fe_{25}$ layer with a thickness of 2.5 nm is used as the pinning layer-side magnetization fixed layer, for example.

The magnetic coupling layer produces an antiferromagnetic coupling between the pinning layer-side magnetization fixed layer and the intermediate layer-side magnetization fixed layer. The magnetic coupling layer forms a synthetic pin structure. Ru is used as the magnetic coupling layer, for example. The thickness of the magnetic coupling layer is preferably not less than 0.8 nm and not more than 1 nm, for example. Other materials than Ru may be used as the magnetic coupling layer to the extent that they produce a sufficient antiferromagnetic coupling between the pinning layer-side magnetization fixed layer and the intermediate layer-side magnetization fixed layer. The thickness of the magnetic coupling layer may be set to a thickness of not less than 0.8 nm and not more than 1 nm corresponding to the second peak (2nd peak) of the RKKY (Ruderman-Kittel-Kasuya-Yosida) coupling. The thickness of the magnetic coupling layer may be set to a thickness of not less than 0.3 nm and not more than 0.6 nm corresponding to the first peak (1st peak) of the RKKY coupling. Ru with a thickness of 0.9 nm is used as the magnetic coupling layer, for example. Thereby, a highly reliable coupling is obtained more stably.

The magnetic layer used as the intermediate layer-side magnetization fixed layer directly contributes to the MR effect. Co—Fe—B alloy is used as the intermediate layer-side magnetization fixed layer, for example. Specifically, $(Co_xFe_{100-x})_{100-y}B_y$ alloy (x being not less than 0 at. % and not more than 100 at. %, y being not less than 0 at. % and not more than 30 at. %) may be used as the intermediate layer-side magnetization fixed layer.

A layer (for example a tunnel insulating layer (not shown)) formed on the intermediate layer-side magnetization fixed layer may be planarized. By the planarization of the tunnel insulating layer, the defect density of the tunnel insulating layer can be reduced. Thereby, a larger MR ratio is obtained with a lower resistance area. When MgO is used as the material of the tunnel insulating layer, an amorphous alloy of $(Co_xFe_{100-x})_{100-y}B_y$ may be used as the intermediate layer-side magnetization fixed layer; thereby, the (100) orientation properties of the MgO layer formed on the tunnel insulating layer can be enhanced, for example. By enhancing the (100) orientation properties of the MgO layer, a larger MR ratio is obtained. The $(Co_xFe_{100-x})_{100-y}B_y$ alloy is crystallized during annealing, with the (100) plane of the MgO layer as a template. Thus, good crystal matching between the MgO and the $(Co_xFe_{100-x})_{100-y}B_y$ alloy is obtained. By obtaining good crystal matching, a larger MR ratio is obtained.

As the intermediate layer-side magnetization fixed layer, Fe—Co alloy may be used as well as Co—Fe—B alloy, for example.

When the intermediate layer-side magnetization fixed layer is thicker, a larger MR ratio is obtained. To obtain a larger fixed magnetic field, the intermediate layer-side magnetization fixed layer is preferably thinner. Between the MR ratio and the fixed magnetic field, there is a trade-off in the thickness of the intermediate layer-side magnetization fixed layer. When Co—Fe—B alloy is used as the intermediate layer-side magnetization fixed layer, the thickness of the intermediate layer-side magnetization fixed layer is preferably not less than 1.5 nm and not more than 5 nm. The thickness of the intermediate layer-side magnetization fixed layer is more preferably not less than 2.0 nm and not more than 4 nm.

For the intermediate layer-side magnetization fixed layer, $Co_{90}Fe_{10}$ alloy of the fcc structure, Co of the hcp structure, or a Co alloy of the hcp structure is used as well as the material described above. As the intermediate layer-side magnetization fixed layer, at least one selected from the group consisting of Co, Fe, and Ni is used, for example. As the intermediate layer-side magnetization fixed layer, an alloy containing at least one material selected from these materials is used. As the intermediate layer-side magnetization fixed layer, an FeCo alloy material of the bcc structure, a Co alloy with a cobalt content of 50 at. % or more, a material with a Ni content of 50 at. % or more (a Ni alloy) may be used; thereby, a larger MR ratio is obtained, for example.

As the intermediate layer-side magnetization fixed layer, a Heusler magnetic alloy layer of Co_2MnGe, Co_2FeGe, Co_2MnSi, Co_2FeSi, Co_2MnAl, Co_2FeAl, $Co_2MnGa_{0.5}Ge_{0.5}$, $Co_2FeGa_{0.5}Ge_{0.5}$, and the like may be used, for example. As the intermediate layer-side magnetization fixed layer, a $Co_{40}Fe_{40}B_{20}$ layer with a thickness of 3 nm is used, for example.

For the pinning layer **31**, the material and configuration described in regard to the pinning layer **32** may be used. For the other layers, materials substantially the same as the material illustrated in regard to FIG. **3**A may be used. For the upper pinned layer **33**, the material and configuration described above when a magnetization fixed layer is used as the second magnetic layer **12***a* may be used. For the upper intermediate layer **34**, the material and configuration described in regard to the first intermediate layer **13***a* may be used, for example.

FIG. **25**A to FIG. **25**D are schematic diagrams illustrating the pressure sensor according to the first embodiment.

The drawings illustrate operations of the sensing element **50** (the first sensing element **50***a*) of the examples shown FIG. **24**A and FIG. **24**B. FIG. **25**A corresponds to a state where no strain is generated in the first sensing element **50***a* (the no-strain state ST0). FIG. **25**B corresponds to a state where a compressive strain is generated in the first sensing element **50***a* (the first state ST1). FIG. **25**C corresponds to a state where a tensile strain is generated in the first sensing element **50***a* (the second state ST2). In these drawings, for easier viewing of the drawings, the first magnetic layer **11***a* and the second magnetic layer **12***a* are depicted, and the first intermediate unit **13***au* is omitted.

FIG. **25**D illustrates the relationship between the strain Sa generated in the first sensing element **50***a* and the electric resistance R (Ω) of the first sensing element **50***a*. The electric resistance R is the electric resistance between the first magnetic layer **11***a* and the second magnetic layer **12***a*.

As shown in FIG. **25**A, in the no-strain state ST0, the magnetization **11***am* of the first magnetic layer **11***a* that is a magnetization free layer is set along the first direction X1 in which the first magnetic layer **11***a* extends. This is due to the shape magnetic anisotropy mentioned above. In the no-strain state ST0, the magnetization **12***am* of the second magnetic layer **12***a* that is a magnetization fixed layer can be fixed to run along the second direction X2 in which the second magnetic layer **12***a* extends. It is assumed that, immediately after the film formation of a stacked body that forms the sensing element, an exchange coupling from the pinning layer **32** is not made on the second magnetic layer **12***a*, for example. Setting the second magnetic layer **12***a* to a state of being a magnetization free layer, the planar shape of the second magnetic layer **12***a* is processed into a shape having shape anisotropy. Thereby, the magnetization **12***am* of the second magnetic layer **12***a* becomes a state of running along the second direction X2. In this state, heat treatment is performed in no magnetic field. Thereby, after cooling after the heat treatment, the magnetization **12***am* of the second magnetic layer **12***a* can be fixed to run along the second direction X2 as it is.

By changing the angle between the first direction X1 in which the first magnetic layer **11***a* extends and the second direction X2 in which the second magnetic layer **12***a* extends, the relative angle between the direction of the magnetization **11***am* of the first magnetic layer **11***a* and the direction of the magnetization **12***am* of the second magnetic layer **12***a* can be set arbitrarily.

As shown in FIG. **25**B, in the first state ST1 where a compressive strain CS is generated, the angle between the magnetization **11***am* of the first magnetic layer **11***a* and the magnetization **12***am* of the second magnetic layer **12***a* is larger than the angle in the no-strain state ST0, for example. The electric resistance R changes in conjunction with this.

As shown in FIG. **25**C, in the second state ST2 where a tensile strain TS is generated, the angle between the magnetization **11***am* of the first magnetic layer **11***a* and the magnetization **12***am* of the second magnetic layer **12***a* is smaller than the angle in the no-strain state ST0, for example. The electric resistance R changes in conjunction with this.

As shown in FIG. **25**D, when a compressive strain CS is generated, the electric resistance R of the first sensing element **50***a* is increased as compared to the no-strain state ST0. When a tensile strain TS is generated, the electric resistance R of the first sensing element **50***a* is decreased as compared to the no-strain state ST0.

In this way, the first sensing element **50***a* can convert the change in strain Sa generated in the first sensing element **50***a* to a change in electric resistance R.

As illustrated in FIG. **25**A, in the first sensing element **50***a*, in the no-strain state ST0, the magnetization of the second magnetic layer that is a magnetization fixed layer and the magnetization of the first magnetic layer that is a magnetization free layer can be directed to directions different from each other. Thereby, as illustrated in FIG. **25**D, the electric resistance R changes linearly with respect to the tensile and compressive strain Sa, for example. Thereby, a high-sensitivity pressure sensor can be provided.

The configuration, the direction of the magnetization **11***a* of the first magnetic layer **11**, and the direction of the magnetization **12***am* of the second magnetic layer **12***a* described in FIG. **5** to FIG. **23**E may be used in the examples described in regard to FIG. **24**A to FIG. **25**D.

FIG. **26**A to FIG. **26**C are schematic diagrams illustrating a pressure sensor according to the first embodiment.

FIG. **26**A is a schematic perspective view, and FIG. **26**B and FIG. **26**C are block diagrams illustrating a pressure sensor **440**.

As shown in FIG. **26**A and FIG. **26**B, in the pressure sensor **440**, a base **471**, a sensing unit **450**, a semiconductor circuit unit **430**, an antenna **415**, an electric interconnection **416**, a transmitting circuit **417**, and a receiving circuit **417***r* are provided.

The antenna **415** is electrically connected to the semiconductor circuit unit **430** via the electric interconnection **416**.

The transmitting circuit **417** transmits data based on an electric signal traveling through the sensing unit **450** wirelessly. At least part of the transmitting circuit **417** may be provided in the semiconductor circuit unit **430**.

The receiving circuit **417***r* receives a control signal from an electronic device **418***d*. At least part of the receiving circuit **417***r* may be provided in the semiconductor circuit unit **430**. By providing the receiving circuit **417***r*, the operation of the pressure sensor **440** can be controlled by operating the electronic device **418***d*, for example.

As shown in FIG. **26**B, in the transmitting circuit **417**, an A/D converter **417***a* connected to the sensing unit **450** and a Manchester encoding unit **417***b* may be provided, for example. A switching unit **417***c* may be provided to switch between transmission and reception. In this case, a timing controller **417***d* may be provided, and switching in the switching unit **417***c* can be controlled by the timing controller **417***d*. A data correction unit **417***e*, a synchronization unit **417***f*, a determination unit **417***g*, and a voltage-controlled oscillator **417***h* (VCO) may be further provided.

As shown in FIG. **26**C, a receiving unit **418** is provided in the electronic device **418***d* used in combination with the pressure sensor **440**. As the electronic device **418***d*, an electronic device such as a mobile terminal may be given, for example.

In this case, the pressure sensor **440** including the transmitting circuit **417** and the electronic device **418***d* including the receiving unit **418** may be used in combination.

In the electronic device **418***d*, a Manchester encoding unit **417***b*, a switching unit **417***c*, a timing controller **417***d*, a data correction unit **417***e*, a synchronization unit **417***f*, a determination unit **417***g*, a voltage-controlled oscillator **417***h*, a memory unit **418***a*, and a central processing unit **418***b* (CPU) may be provided.

In this example, the pressure sensor **440** further includes a fixing unit **467**. The fixing unit **467** fixes a film unit **464** (**70***d*) to the base **471**. The fixing unit **467** may have a larger thickness dimension than the film unit **464** so as to bend less easily even when an external pressure is applied.

Fixing units **467** may be provided at equal intervals at the edge of the film unit **464**, for example.

The fixing unit **467** may be provided so as to continuously surround the entire periphery of the film unit **464** (**70***d*).

The fixing unit **467** may be formed of the same material as the material of the base **471**, for example. In this case, the fixing unit **467** may be formed of silicon or the like, for example.

The fixing unit **467** may be formed of the same material as the material of the film unit **464** (**70***d*), for example.

A method for manufacturing a pressure sensor according to the embodiment will now be described.

FIG. **27**A, FIG. **27**B, FIG. **28**A, FIG. **28**B, FIG. **29**A, FIG. **29**B, FIG. **30**A, FIG. **30**B, FIG. **31**A, FIG. **31**B, FIG. **32**A, FIG. **32**B, FIG. **33**A, FIG. **33**B, FIG. **34**A, FIG. **34**B, FIG. **35**A, FIG. **35**B, FIG. **36**A, FIG. **36**B, FIG. **37**A, FIG. **37**B, FIG. **38**A, and FIG. **38**B are schematic views illustrating a method for manufacturing a pressure sensor according to a third embodiment.

FIG. **27**A to FIG. **38**A are schematic plan views, and FIG. **27**B to FIG. **38**B are schematic cross-sectional views.

As shown in FIG. **27**A and FIG. **27**B, a semiconductor layer **512**M is formed on a surface portion of a semiconductor substrate **531**. Subsequently, an element isolation insulating layer **512**I is formed on the upper surface of the semiconductor layer **512**M. Subsequently, a gate **512**G is formed on the semiconductor layer **512**M via a not-shown insulating layer. Subsequently, a source **512**S and a drain **512**D are formed on both sides of the gate **512**G to form a transistor **532**. Subsequently, an interlayer insulating film **514***a* is formed thereon, and an interlayer insulating film **514***b* is formed.

Subsequently, in the region that forms a non-hollow portion, trenches and holes are formed in parts of the interlayer insulating films **514***a* and **514***b*. Subsequently, a conductive material is buried in the holes to form connection pillars **514***c* to **514***e*. In this case, the connection pillar **514***c* is electrically connected to the source **512**S of a transistor **532**, and the connection pillar **514***d* is electrically connected to the drain **512**D, for example. The connection pillar **514***e* is electrically connected to the source **512**S of another transistor **532**, for example. Subsequently, a conductive material is buried in the trenches to form interconnection units **514***f* and **514***g*. The interconnection unit **514***f* is electrically connected to the connection pillar **514***c* and the connection pillar **514***d*. The interconnection unit **514***g* is electrically connected to the connection pillar **514***e*. Subsequently, an interlayer insulating film **514***h* is formed on the interlayer insulating film **514***b*.

As shown in FIG. **28**A and FIG. **28**B, an interlayer insulating film **514***i* made of silicon oxide (SiO_2) is formed on the interlayer insulating film **514***h* using the CVD (chemical vapor deposition) method, for example. Subsequently, holes are formed in prescribed positions of the interlayer insulating film **514***i*, a conductive material (for example, a metal material) is buried, and the upper surface is planarized using the CMP (chemical mechanical polishing) method. Thereby, a connection pillar **514***j* connected to the interconnection unit **514***f* and a connection pillar **514***k* connected to the interconnection unit **514***g* are formed.

As shown in FIG. **29**A and FIG. **29**B, a recess is formed in a region of the interlayer insulating film **514***i* that forms a hollow portion **570**, and a sacrifice layer **514***l* is buried in the recess. The sacrifice layer **514***l* may be formed using a material that can be formed into a film at low temperature, for example. The material that can be made into a film at low temperature is silicon germanium (SiGe) or the like, for example.

As shown in FIG. **30**A and FIG. **30**B, an insulating film **561***bf* that forms a film unit **564** (**70***d*) is formed on the interlayer insulating film **514***i* and the sacrifice layer **514***l*. The insulating film **561***bf* may be formed using silicon oxide (SiO_2) or the like, for example. A plurality of holes are provided in the insulating film **561***bf*, and a conductive material (for example, a metal material) is buried in the plurality of holes to form a connection pillar **561***fa* and a connection pillar **562***fa*. The connection pillar **561***fa* is electrically connected to the connection pillar **514***k*, and the connection pillar **562***fa* is electrically connected to the connection pillar **514***j*.

As shown in FIG. **31**A and FIG. **31**B, a conductive layer **561***f* that forms an interconnection **557** is formed on the insulating film **561***bf*, the connection pillar **561***fa*, and the connection pillar **562***fa*.

As shown in FIG. **32**A and FIG. **33**B, a stacked film **550***f* is formed on the conductive layer **561***f*.

As shown in FIG. **33**A and FIG. **33**B, the stacked film **550***f* is processed into a prescribed shape, and an insulating film **565***f* that forms an insulating layer **565** is formed thereon. The insulating film **565***f* may be formed using silicon oxide (SiO_2) or the like, for example.

As shown in FIG. **34**A and FIG. **34**B, part of the insulating film **565***f* is removed, and the conductive layer **561***f* is processed into a prescribed shape. Thereby, an interconnection **557** is formed. At this time, part of the conductive layer **561***f* forms a connection pillar **562***fb* electrically connected to the connection pillar **562***fa*. Then, an insulating film **566***f* that forms an insulating layer **566** is formed thereon.

As shown in FIG. **35**A and FIG. **35**B, an opening **566***p* is formed in the insulating film **566***f*. Thereby, the connection pillar **562***fb* is exposed.

As shown in FIG. **36**A and FIG. **36**B, a conductive layer **562***f* that forms an interconnection **558** is formed on the upper surface. Part of the conductive layer **562***f* is electrically connected to the connection pillar **562***fb*. As shown in FIG. **37**A and FIG. **37**B, the conductive layer **562***f* is processed into a prescribed shape. Thereby, an interconnection **558** is formed. The interconnection **558** is electrically connected to the connection pillar **562***fb*.

As shown in FIG. **38**A and FIG. **38**B, an opening **566***o* with a prescribed shape is formed in the insulating film **566***f*. The insulating film **561***bf* is processed via the opening **566***o*, and the sacrifice layer **514***l* is removed via the opening **566***o*. Thereby, a hollow portion **570** is formed. The removal of the sacrifice layer **514***l* can be performed using the wet etching method, for example.

When a fixing unit **567** is shaped like a ring, the space between the edge of the non-hollow portion above the hollow portion **570** and the film unit **564** is filled with an insulating film, for example.

Thus, a pressure sensor is formed.

Second Embodiment

The embodiment relates to a microphone using the pressure sensor according to the first embodiment.

FIG. **39** is a schematic cross-sectional view illustrating a microphone according to a second embodiment.

A microphone **320** according to the embodiment includes a printed circuit board **321**, a cover **323**, and a pressure sensor **310**. The printed circuit board **321** includes a circuit of an amplifier etc., for example. An acoustic hole **325** is provided in the cover **323**. Sound **329** passes through the acoustic hole **325** to enter the inside of the cover **323**.

As the pressure sensor **310**, any one of the pressure sensors described in regard to the first embodiment or modifications thereof are used.

The microphone **320** reacts to sound pressure. By using a high-sensitivity pressure sensor **310**, a high-sensitivity microphone **320** is obtained. The pressure sensor **310** is mounted on the printed circuit board **321**, and an electric signal device is provided, for example. The cover **323** is provided on the printed circuit board **321** so as to cover the pressure sensor **310**.

The embodiment can provide a high-sensitivity microphone.

Third Embodiment

The embodiment relates to a blood pressure sensor using the pressure sensor according to the first embodiment.

FIG. **40**A and FIG. **40**B are schematic views illustrating a blood pressure sensor according to a third embodiment.

FIG. **40**A is a schematic plan view illustrating the skin on an artery of a person. FIG. **40**B is a cross-sectional view taken along line H**1**-H**2** of FIG. **40**A.

In the embodiment, the pressure sensor **310** is used as a blood pressure sensor **330**. Any one of the pressure sensors described in regard to the first embodiment and modifications thereof are used as the pressure sensor **310**.

Thus, high-sensitivity pressure sensing can be made by a small-sized pressure sensor. By pressing the pressure sensor **310** against the skin **333** on an artery **331**, the blood pressure sensor **330** can make blood pressure measurement continuously.

The embodiment can provide a high-sensitivity blood pressure sensor.

Fourth Embodiment

The embodiment relates to a touch panel using the pressure sensor according to the first embodiment.

FIG. **41** is a schematic diagram illustrating a touch panel according to a fourth embodiment.

In the embodiment, the pressure sensor **310** is used as a touch panel **340**. Any one of the pressure sensors described in regard to the first embodiment or modifications thereof are used as the pressure sensor **310**. In the touch panel **340**, the pressure sensor **310** is mounted at least one of in a display and outside a display.

The touch panel **340** includes a plurality of first interconnections **346**, a plurality of second interconnections **347**, a plurality of pressure sensors **310**, and a control unit **341**, for example.

In this example, the plurality of first interconnections **346** are aligned along the Y-axis direction. Each of the plurality of first interconnections **346** extends along the X-axis direction. The plurality of second interconnections **347** are aligned along the X-axis direction. Each of the plurality of second interconnections **347** extends along the Y-axis direction.

Each of the plurality of pressure sensors **310** is provided in the intersection portion of each of the plurality of first interconnections **346** and each of the plurality of second interconnections **347**. One pressure sensor **310** is included in one sensing element **310***e* for detection. The intersection portion includes the position where the first interconnection **346** and the second interconnection **347** cross each other and a region around this.

One end **310***a* of each of the plurality of pressure sensors **310** is connected to each of the plurality of first interconnections **346**. The other end **310***b* of each of the plurality of pressure sensors **310** is connected to each of the plurality of second interconnections **347**.

The control unit **341** is connected to the plurality of first interconnections **346** and the plurality of second interconnections **347**.

The control unit **341** includes a circuit for the first interconnection **346***d* connected to the plurality of first interconnections **346**, a circuit for the second interconnection **347***d* connected to the plurality of second interconnections **347**, and a control circuit **345** connected to the circuit for the first interconnection **346***d* and the circuit for the second interconnection **347***d*, for example.

The pressure sensor **310** can make high-sensitivity pressure sensing with a small size. Thus, a high-definition touch panel can be provided.

The pressure sensor according to the first embodiment can be used for various pressure sensor devices such as atmospheric pressure sensors and air pressure sensors for tires, as well as the uses mentioned above.

The embodiment can provide a pressure sensor, a microphone, a blood pressure sensor, and a touch panel of high sensitivity.

Hereinabove, embodiments of the invention are described with reference to specific examples. However, the invention is not limited to these specific examples. For example, one skilled in the art may appropriately select specific configurations of components of pressure sensors, microphones, blood pressure sensors, and touch panels such as film units, sensing elements, first magnetic layers, second magnetic layers, and intermediate layers from known art and similarly practice the invention. Such practice is included in the scope of the invention to the extent that similar effects thereto are obtained.

Further, any two or more components of the specific examples may be combined within the extent of technical feasibility and are included in the scope of the invention to the extent that the purport of the invention is included.

Moreover, all pressure sensors, microphones, blood pressure sensors, and touch panels practicable by an appropriate design modification by one skilled in the art based on the pressure sensors, the microphones, the blood pressure sensors, and the touch panels described above as embodiments of the invention also are within the scope of the invention to the extent that the spirit of the invention is included.

Various other variations and modifications can be conceived by those skilled in the art within the spirit of the invention, and it is understood that such variations and modifications are also encompassed within the scope of the invention.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the invention.

What is claimed is:

1. A pressure sensor comprising:

a support;

a film unit supported by the support, the film unit having an upper surface, and being deformable; and

a first sensing element provided on the upper surface,

the first sensing element including:

a first magnetic layer, a magnetization of the first magnetic layer being configured to change in accordance with a deformation of the film unit;

a second magnetic layer provided apart from the first magnetic layer in a direction crossing the upper surface; and

a first intermediate unit including a first intermediate layer including a portion provided between the first magnetic layer and the second magnetic layer,

the first magnetic layer extending in a first direction parallel to the upper surface, a first major axis length of the first magnetic layer in the first direction being longer than a first minor axis length of the first magnetic layer in a second direction parallel to the upper surface and crossing the first direction, and

the second magnetic layer extending in the second direction, a second major axis length of the second magnetic layer in the second direction being longer than a second minor axis length of the second magnetic layer in the first direction.

2. The sensor according to claim **1**, wherein

the first intermediate unit has a first intermediate unit region,

the first magnetic layer has an overlapping region where the first magnetic layer overlaps the second magnetic layer, and

an outer edge of the first intermediate unit region in a plane parallel to the upper surface is located inside an outer edge of the overlapping region in the plane.

3. The sensor according to claim **1**, wherein

the first intermediate unit has a first intermediate unit region,

the first magnetic layer has an overlapping region where the first magnetic layer overlaps the second magnetic layer, and

a shape of the first intermediate unit in a plane parallel to the upper surface is same as a shape of the overlapping region in the plane.

4. The sensor according to claim **1**, wherein

a shape of the first intermediate unit in a plane parallel to the upper surface is same as a shape of the first magnetic layer in the plane.

5. The sensor according to claim **1**, wherein

the first intermediate unit further includes a first intermediate magnetic layer provided between the first intermediate layer and the first magnetic layer.

6. The sensor according to claim **1**, wherein

the first intermediate unit further includes a second intermediate magnetic layer provided between the first intermediate layer and the second magnetic layer.

7. The sensor according to claim **1**, wherein

an angle between the first direction and the second direction is not less than 60 degrees and not more than 120 degrees.

8. The sensor according to claim **1**, wherein

an angle between the first direction and the second direction is larger than 0 degrees and smaller than 90 degrees.

9. The sensor according to claim **1**, wherein

an angle between the first direction and the second direction is larger than 90 degrees and smaller than 180 degrees.

10. The sensor according to claim **1**, wherein

an angle between the magnetization of the first magnetic layer and a magnetization of the second magnetic layer is not less than 80 degrees and not more than 100 degrees.

11. The sensor according to claim **1**, wherein

an angle between the magnetization of the first magnetic layer and a magnetization of the second magnetic layer is larger than 0 degrees and smaller than 90 degrees.

12. The sensor according to claim **1**, wherein

an angle between the magnetization of the first magnetic layer and a magnetization of the second magnetic layer is larger than 90 degrees and smaller than 180 degrees.

13. The sensor according to claim **1**, wherein

a difference between an absolute value of a first angle and an absolute value of a second angle is 5 degrees and less,

the first angle is between a first straight line and the first direction, the first straight line passes through a centroid of the upper surface and a centroid of a region where the first magnetic layer overlaps the second magnetic layer, and

the second angle is between the first straight line and the second direction.

14. The sensor according to claim **13**, wherein

the absolute value of the first angle is not less than 30 degrees and not more than 60 degrees.

15. The sensor according to claim **13**, wherein

the absolute value of the first angle is not less than 45 degrees and not more than 90 degrees.

16. The sensor according to claim **13**, wherein

the absolute value of the first angle is not less than 0 degrees and not more than 45 degrees.

17. The sensor according to claim **1**, wherein

a difference between an absolute value of a third angle and an absolute value of a fourth angle is 5 degrees or less,

the third angle is between a second straight line and the first direction, the second straight line connects by a shortest distance an outer edge of the upper surface and a centroid of a region where the first magnetic layer overlaps the second magnetic layer, and

the fourth angle is between the second straight line and the second direction.

18. The sensor according to claim **17**, wherein

the absolute value of the third angle is not less than 30 degrees and not more than 60 degrees.

19. The sensor according to claim **17**, wherein

the absolute value of the third angle is not less than 45 degrees and not more than 90 degrees.

20. The sensor according to claim **17**, wherein

the absolute value of the third angle is not less than 0 degrees and not more than 45 degrees.

21. The sensor according to claim **1**,

further comprising a second sensing element provided on the upper surface,

a centroid of the film unit being disposed between the first sensing element and the second sensing element,

the second sensing element including:

a third magnetic layer, a magnetization of third magnetic layer being configured to change in accordance with the deformation of the film unit;

a fourth magnetic layer provided apart from the third magnetic layer in the direction crossing the upper surface; and

a second intermediate unit including a second intermediate layer including a portion provided between the third magnetic layer and the fourth magnetic layer,

the third magnetic layer extending in a third direction parallel to the upper surface, a third major axis length of the third magnetic layer in the third direction being longer than a third minor axis length of the third magnetic layer in a fourth direction parallel to the upper surface and crossing the third direction, and

the fourth magnetic layer extending in the fourth direction, a fourth major axis length of the fourth magnetic layer in the fourth direction being longer than a fourth minor axis length of the fourth magnetic layer in the third direction.

22. The sensor according to claim 21, wherein

the first magnetic layer has a first overlapping region where the first magnetic layer overlaps the second magnetic layer,

the third magnetic layer has a second overlapping region where the third magnetic layer overlaps the fourth magnetic layer,

a difference between an absolute value of a first angle and an absolute value of a fifth angle is 5 degrees or less,

the first angle is between a first straight line and the first direction, the first straight line passes through a centroid of the upper surface and a centroid of the first overlapping region, and

the fifth angle is between a third straight line and the third direction, the third straight line passes through the centroid of the upper surface and a centroid of the second overlapping region.

23. The sensor according to claim 21, wherein

the first magnetic layer has a first overlapping region where the first magnetic layer overlaps second magnetic layer,

the third magnetic layer has a second overlapping region where the third magnetic layer overlaps the fourth magnetic layer,

a difference between an absolute value of a third angle and an absolute value of a sixth angle is 5 degrees or less,

the third angle is between a second straight line and the first direction, the second straight line connects an outer edge of the upper surface and a centroid of the first overlapping region by a shortest distance, and

the sixth angle is between a fourth straight line and the third direction, the fourth straight line connects an outer edge of the upper surface and a centroid of the second overlapping region by a shortest distance.

24. The sensor according to claim 21, further comprising a third sensing element provided on the upper surface and a fourth sensing element provided on the upper surface,

the centroid of the film unit being disposed between the third sensing element and the fourth sensing element,

a direction from the third sensing element toward the fourth sensing element crossing a direction from the first sensing element toward the second sensing element,

the third sensing element including:

a fifth magnetic layer, a magnetization of the fifth magnetic layer being configured to change in accordance with the deformation of the film unit;

a sixth magnetic layer provided apart from the fifth magnetic layer in the direction crossing the upper surface; and

a third intermediate unit including a third intermediate layer including a portion provided between the fifth magnetic layer and the sixth magnetic layer,

the fifth magnetic layer extending in a fifth direction parallel to the upper surface, a fifth major axis length of the fifth magnetic layer in the fifth direction being longer than a fifth minor axis length of the fifth magnetic layer in a sixth direction parallel to the upper surface and crossing the fifth direction,

the sixth magnetic layer extending in the sixth direction, a sixth major axis length of the sixth magnetic layer in the sixth direction being longer than a sixth minor axis length of the sixth magnetic layer in the fifth direction,

the fourth sensing element including:

a seventh magnetic layer, a magnetization of the seventh magnetic layer being configured to change in accordance with the deformation of the film unit;

an eighth magnetic layer provided apart from the seventh magnetic layer in the direction crossing the upper surface; and

a fourth intermediate unit including a fourth intermediate layer including a portion provided between the seventh magnetic layer and the eighth magnetic layer,

the seventh magnetic layer extending in a seventh direction parallel to the upper surface, a seventh major axis length of the seventh magnetic layer in the seventh direction being longer than a seventh minor axis length of the seventh magnetic layer in an eighth direction parallel to the upper surface and crossing the seventh direction, and

the eighth magnetic layer extending in the eighth direction, an eighth major axis length of the eighth magnetic layer in the eighth direction being longer than an eighth minor axis length of the eighth magnetic layer in the seventh direction.

25. The sensor according to claim 1, wherein the first sensing element is provided in a plurality, and the first sensing elements are provided on the upper surface.

26. The sensor according to claim 25, wherein at least two of the first sensing elements are electrically connected in series.

27. The sensor according to claim 1, wherein

the first major axis length is not less than 0.1 micrometers and not more than 60 micrometers and

the second major axis length is not less than 0.1 micrometers and not more than 60 micrometers.

28. A microphone comprising the pressure sensor according to claim 1.

29. A blood pressure sensor comprising the pressure sensor according to claim 1.

30. A touch panel comprising the pressure sensor according to claim 1.

* * * * *

专利名称(译)	压力传感器，麦克风，血压传感器和触摸屏		
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外部链接	Espacenet USPTO		

摘要(译)

根据一个实施例，压力传感器包括支撑件，由支撑件支撑的薄膜单元，具有上表面并且能够变形的薄膜单元，以及设置在上表面上的第一感测元件。第一传感元件包括第一磁性层，与第一磁性层分开设置的第二磁性层和包括第一中间层的第一中间单元，第一中间层包括设置在第一和第二磁性层之间的部分。第一磁性层在平行于上表面的第一方向上延伸，并且第一磁性层的第一长轴长度长于第一短轴长度。第二磁性层在平行于上表面并与第一方向交叉的第二方向上延伸，并且第二磁性层的第二长轴长度长于第二短轴长度。