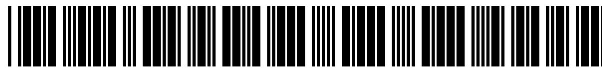
US010234343B2

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

(10) **Patent No.: US 10,234,343 B2**
(45) **Date of Patent: *Mar. 19, 2019**

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

(71) Applicant: **Kabushiki Kaisha Toshiba**, Minato-ku (JP)

(72) Inventors: **Yoshihiko Fuji**, Kanagawa-ken (JP); **Kei Masunishi**, Kanagawa-ken (JP); **Hideaki Fukuzawa**, Kanagawa-ken (JP); **Yoshihiro Higashi**, Ishikawa-ken (JP); **Michiko Hara**, Kanagawa-ken (JP); **Akio Hori**, Kanagawa-ken (JP); **Tomohiko Nagata**, Kanagawa-ken (JP); **Shiori Kaji**, Kanagawa-ken (JP); **Akiko Yuzawa**, Kanagawa-ken (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 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/807,020**

(22) Filed: **Nov. 8, 2017**

(65) **Prior Publication Data**

US 2018/0067005 A1 Mar. 8, 2018

Related U.S. Application Data

(63) Continuation of application No. 15/388,629, filed on Dec. 22, 2016, now Pat. No. 9,921,114, which is a (Continued)

(30) **Foreign Application Priority Data**

Jun. 12, 2013 (JP) 2013-124111

(51) **Int. Cl.**
G01L 9/00 (2006.01)
G01L 1/22 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01L 1/2287*** (2013.01); ***A61B 5/02141*** (2013.01); ***A61B 5/02438*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G01L 1/2287; G01L 1/12; G01L 1/205; G01L 1/2262; G01L 1/2293; G01L 5/161;
(Continued)

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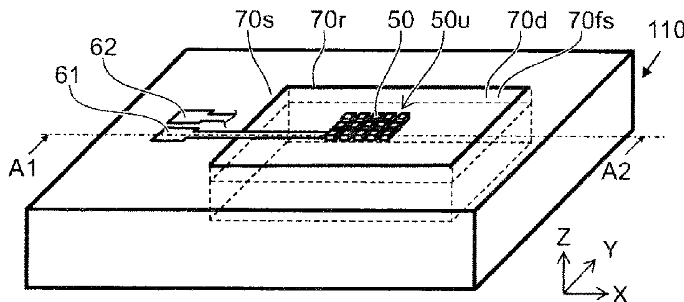
Primary Examiner — Max H Noori
(74) *Attorney, Agent, or Firm* — Oblon, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

According to one embodiment, a pressure sensor includes a film part, and a sensing unit. A circumscribing rectangle circumscribing a configuration of a film surface of the film part has a first side, a second side, a third side connected to one end of the first side and one end of the second side, a fourth side connected to one other end of the first side and
(Continued)



one other end of the second side, and a centroid of the circumscribing rectangle. The circumscribing rectangle includes a first region enclosed by the first side, line segments connecting the centroid to the one end of the first side, and to the one other end of the first side. The sensing unit includes sensing elements provided on a portion of the film surface overlapping the first region. Each sensing element includes a first, second magnetic layers, and a spacer layer.

7 Claims, 38 Drawing Sheets

Related U.S. Application Data

continuation of application No. 14/197,448, filed on Mar. 5, 2014, now Pat. No. 9,596,995.

(51) **Int. Cl.**

A61B 5/021	(2006.01)
G01L 1/12	(2006.01)
A61B 5/024	(2006.01)
H04R 1/02	(2006.01)
H04R 19/00	(2006.01)
G01L 1/20	(2006.01)
G01L 5/16	(2006.01)
G06F 3/041	(2006.01)
A61B 5/00	(2006.01)
H04R 1/04	(2006.01)
H04R 7/00	(2006.01)
H04R 19/04	(2006.01)

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

CPC ***A61B 5/7475*** (2013.01); ***G01L 1/12*** (2013.01); ***G01L 1/205*** (2013.01); ***G01L 1/2262*** (2013.01); ***G01L 1/2293*** (2013.01); ***G01L 5/161*** (2013.01); ***G01L 9/0051*** (2013.01); ***G06F 3/041*** (2013.01); ***G06F 3/0414*** (2013.01); ***H04R 1/028*** (2013.01); ***H04R 1/04*** (2013.01); ***H04R 7/00*** (2013.01); ***H04R 19/005*** (2013.01); *G06F 2203/04105* (2013.01); *H04R 19/04* (2013.01); *H04R 2499/11* (2013.01)

(58) **Field of Classification Search**

CPC G01L 9/0051; A61B 5/02141; A61B 5/02438; A61B 5/7475; H04R 1/028; H04R 1/04; H04R 7/00; H04R 19/005; H04R 19/04; H04R 2499/11; G06F 3/041; G06F 3/0414; G06F 2203/04105

USPC 73/862.628

See application file for complete search history.

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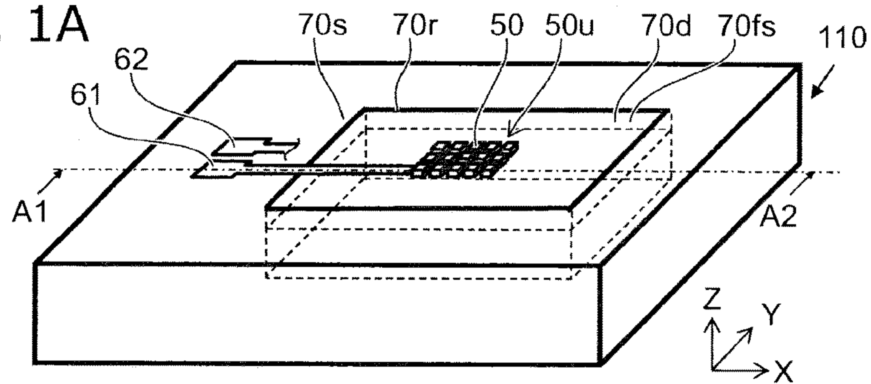
FIG. 1A



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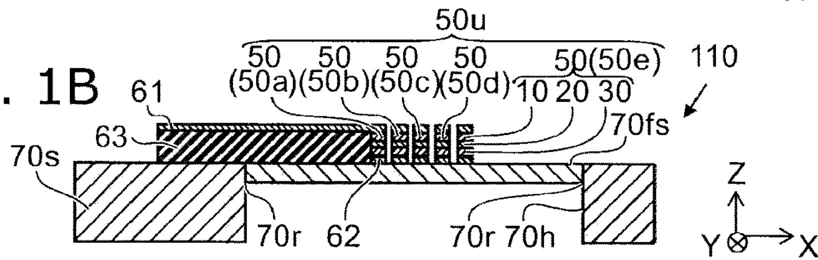


FIG. 1C

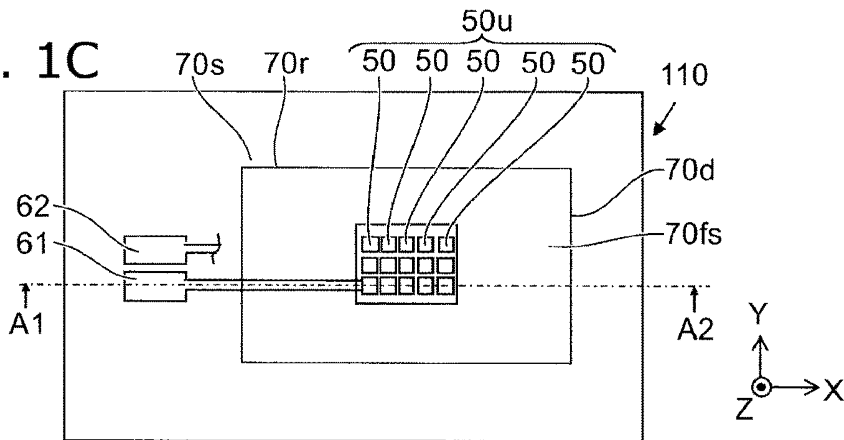
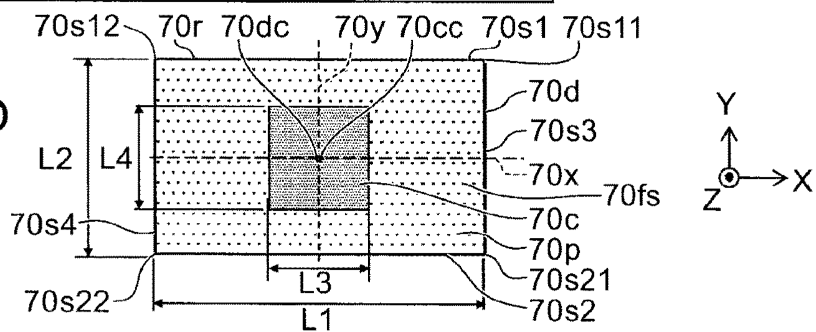


FIG. 1D



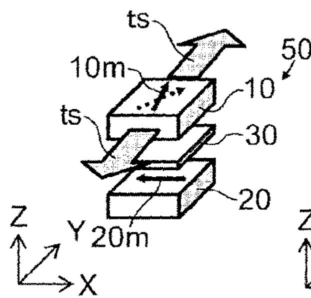


FIG. 2A

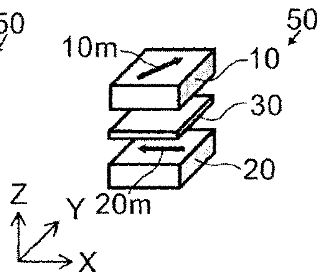


FIG. 2B

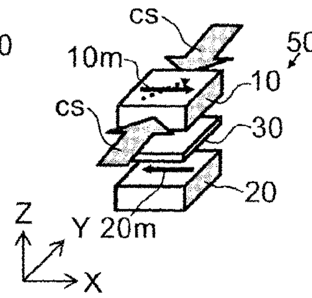
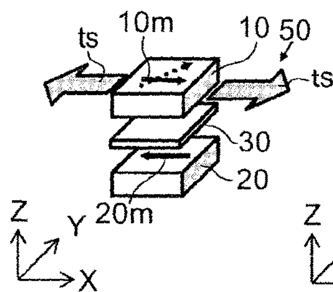


FIG. 2C



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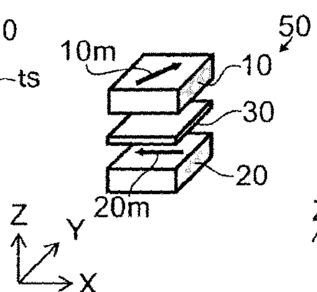


FIG. 2E

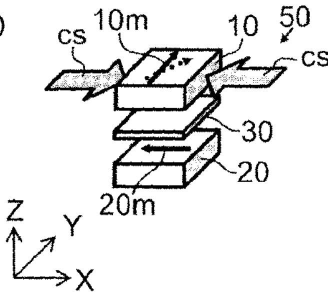


FIG. 2F

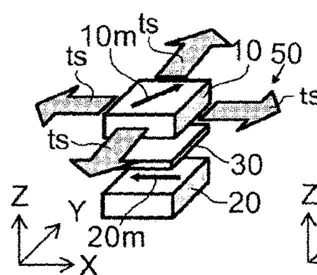


FIG. 2G

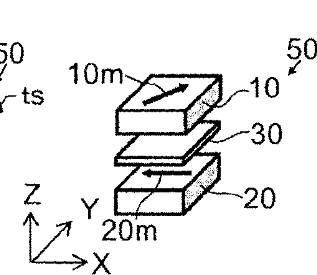


FIG. 2H

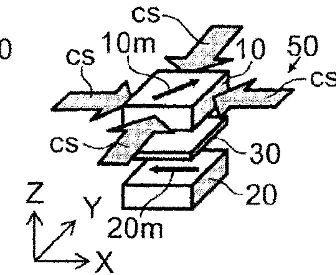


FIG. 2I

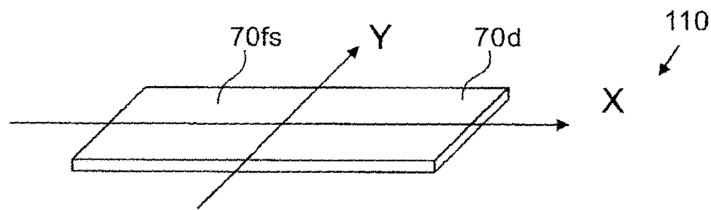


FIG. 3A

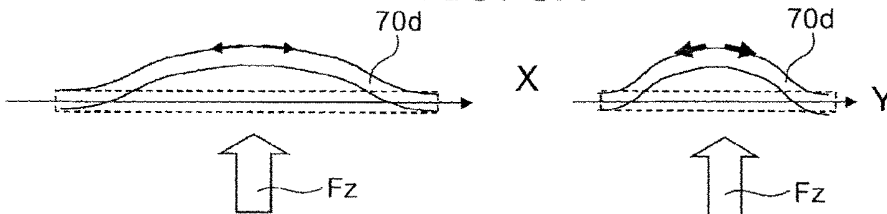
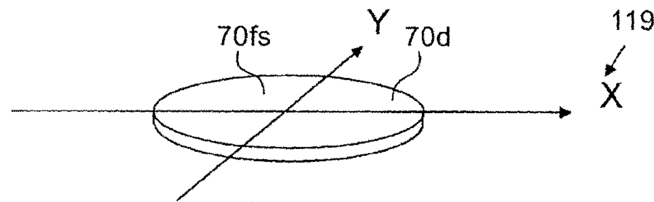


FIG. 3B

FIG. 3C



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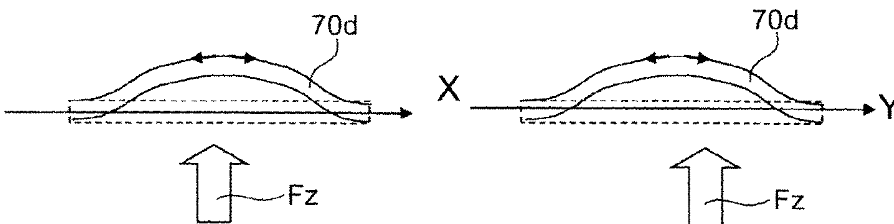


FIG. 4B

FIG. 4C

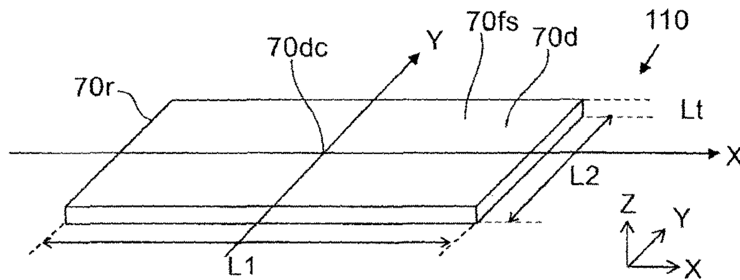


FIG. 5A

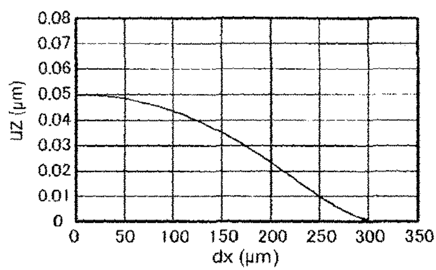


FIG. 5B

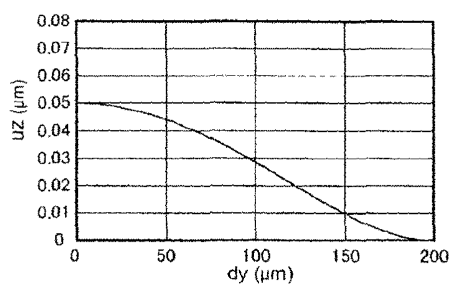


FIG. 5C

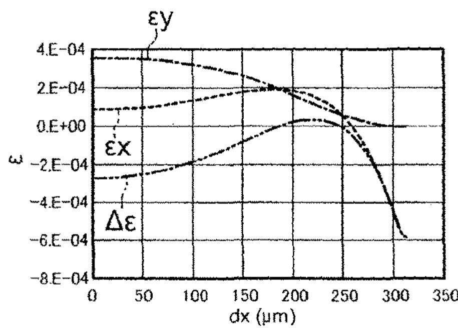


FIG. 5D

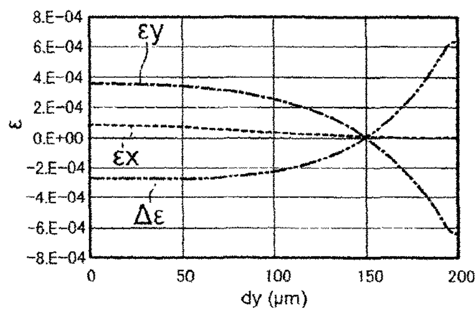


FIG. 5E

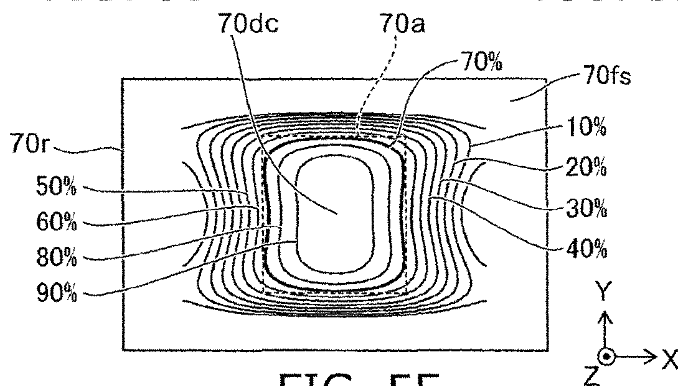


FIG. 5F

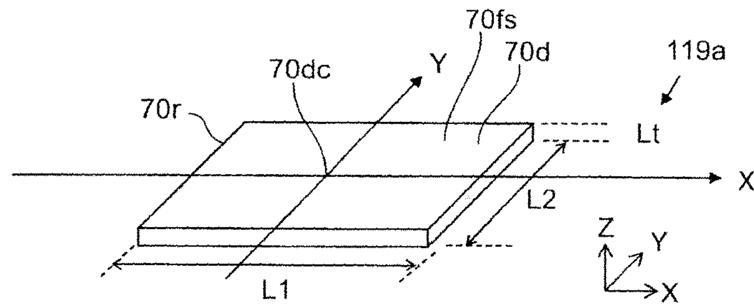


FIG. 6A

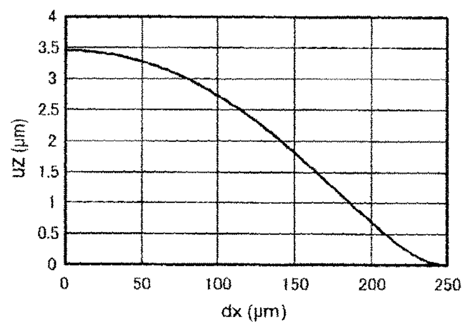


FIG. 6B

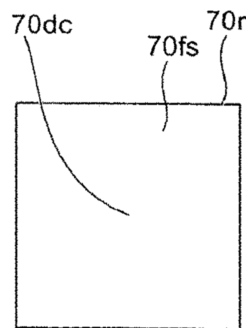


FIG. 6D

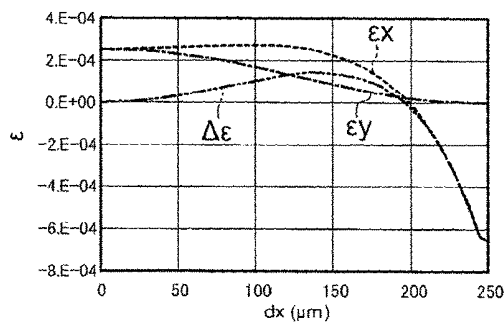


FIG. 6C

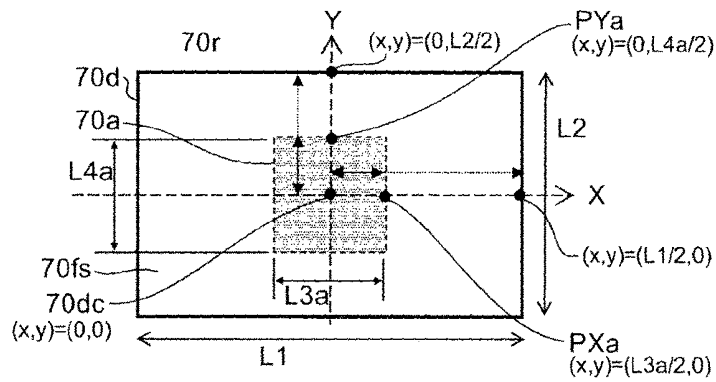


FIG. 7

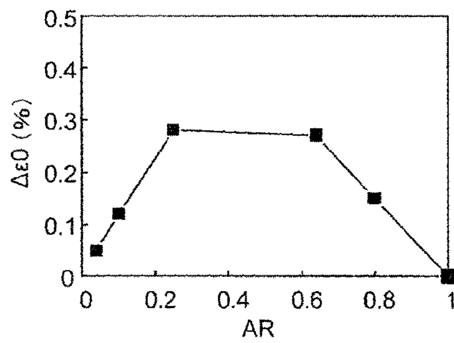


FIG. 8A

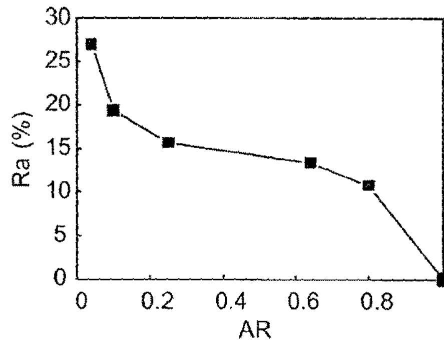


FIG. 8B

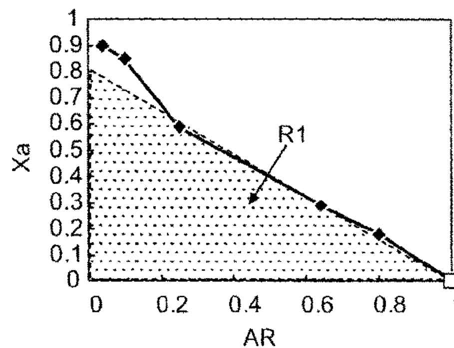


FIG. 8C

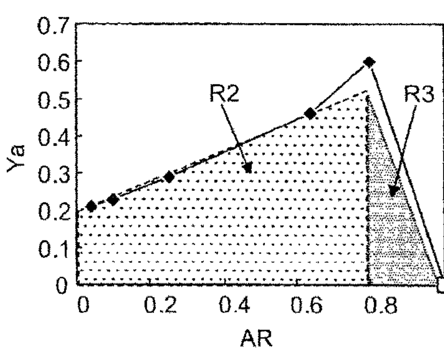


FIG. 8D

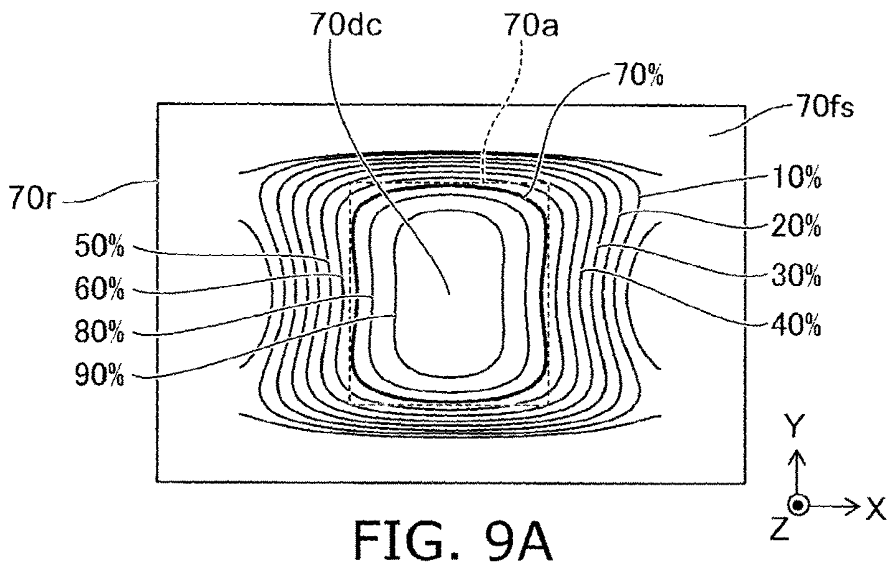


FIG. 9A

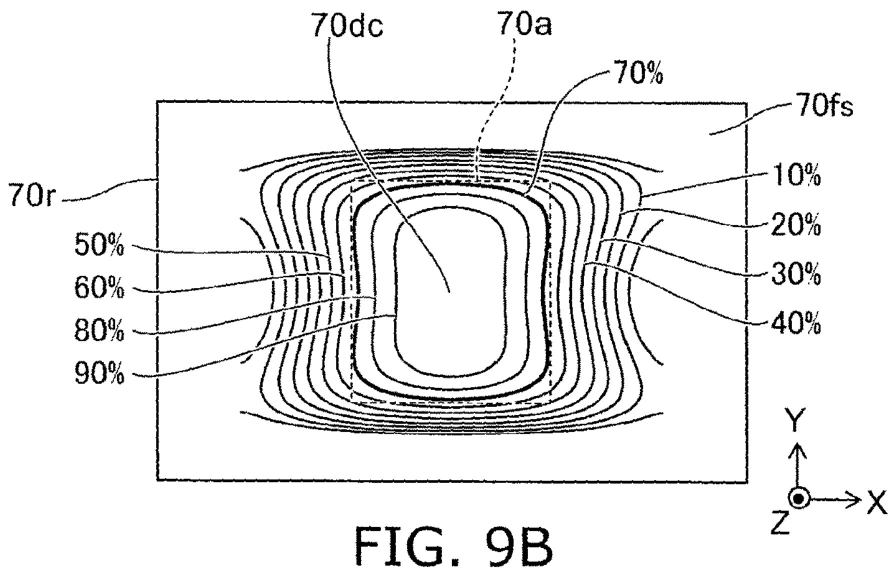


FIG. 9B

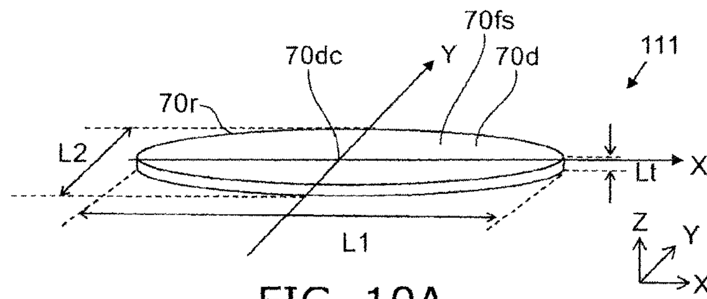


FIG. 10A

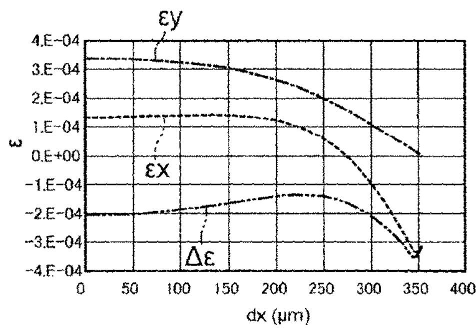


FIG. 10B

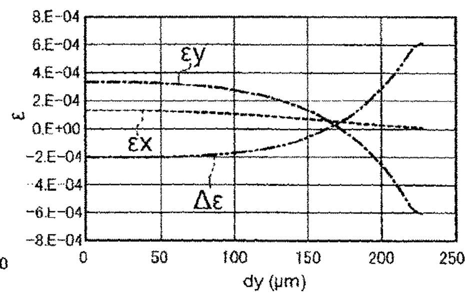


FIG. 10C

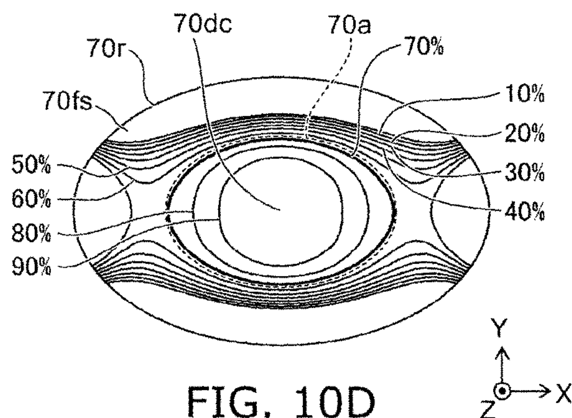


FIG. 10D

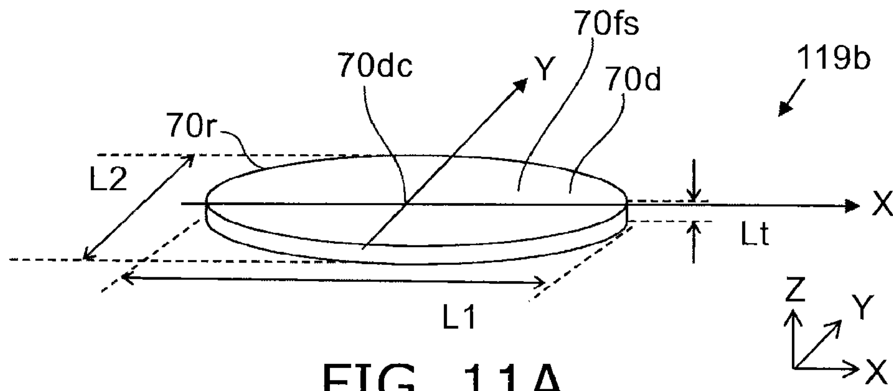


FIG. 11A

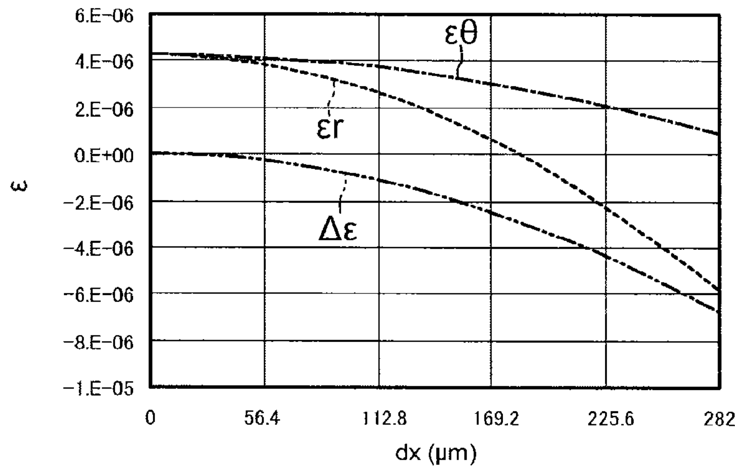


FIG. 11B

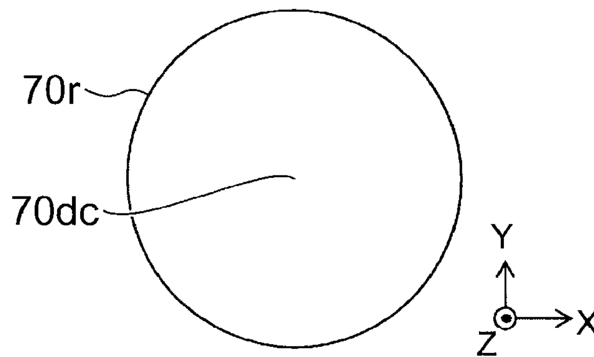


FIG. 11C

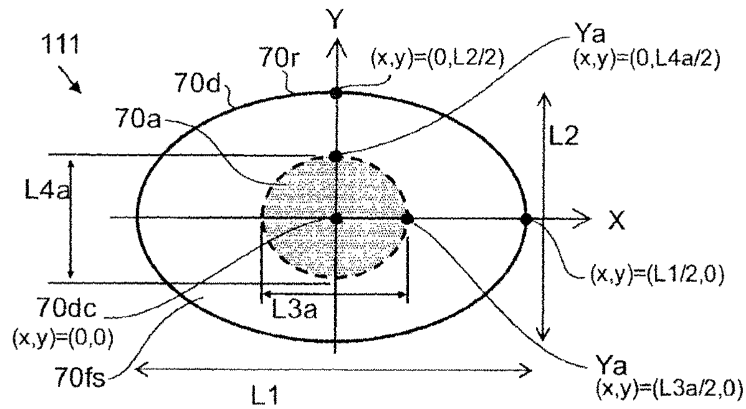


FIG. 12

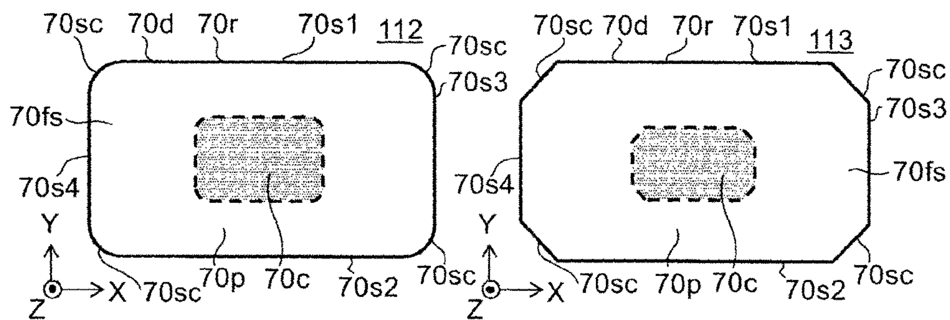


FIG. 13A

FIG. 13B

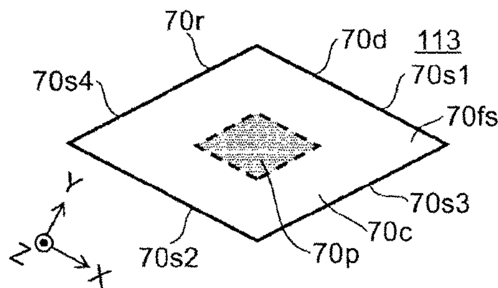


FIG. 13C

FIG. 14A

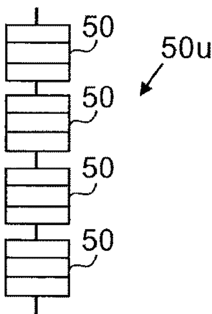


FIG. 14B

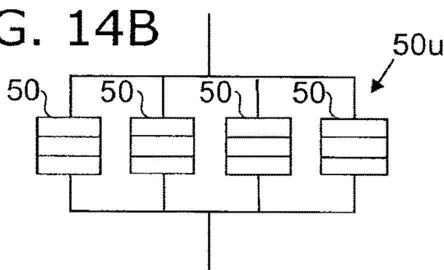
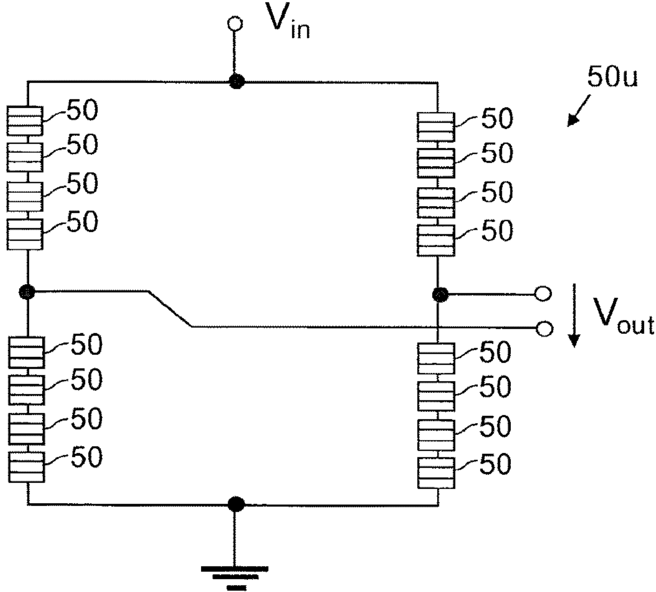


FIG. 14C



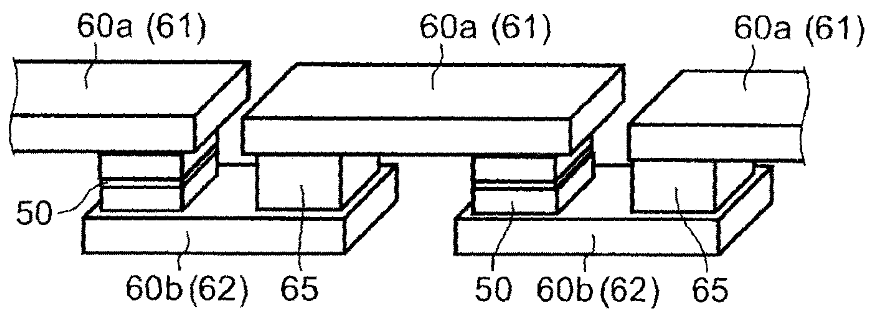


FIG. 15A

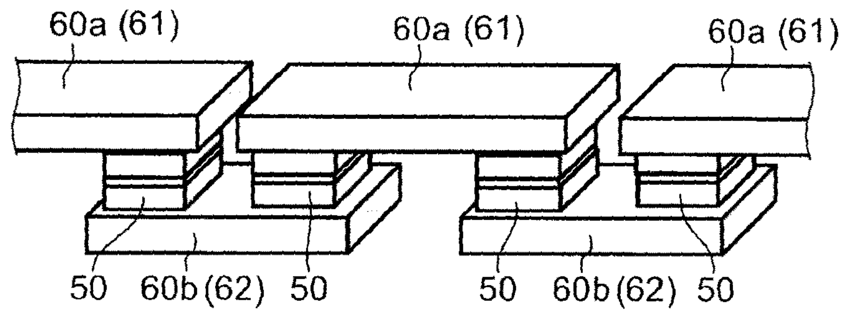


FIG. 15B

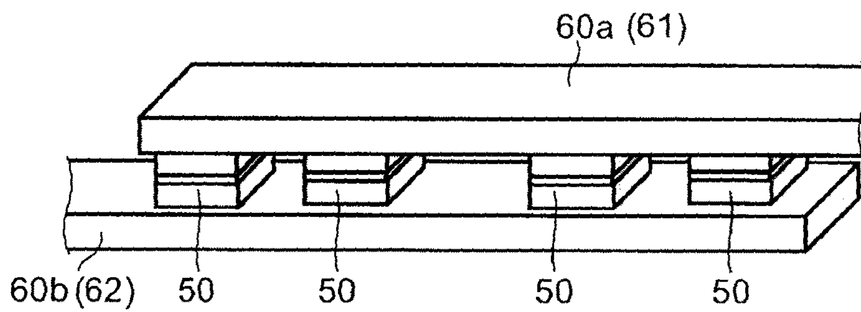


FIG. 15C

FIG. 16A

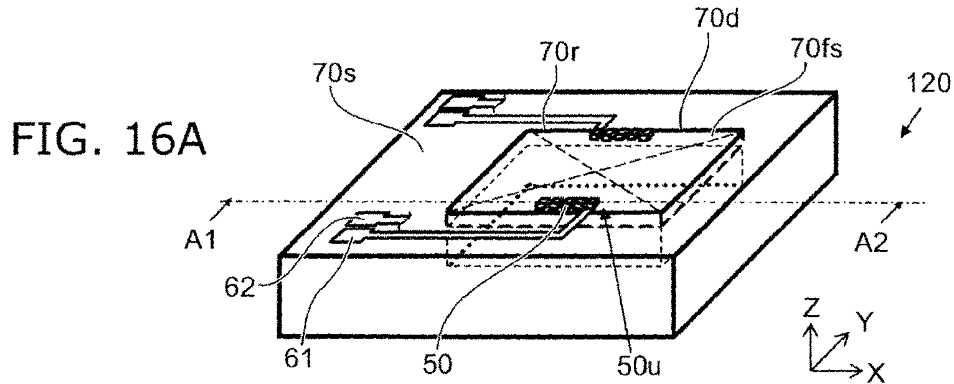


FIG. 16B

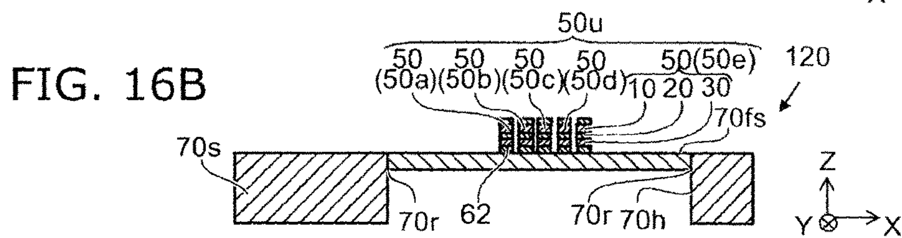


FIG. 16C

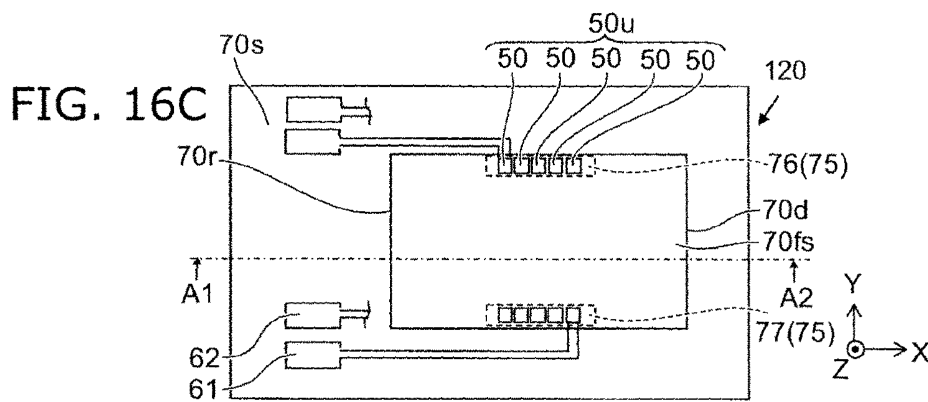
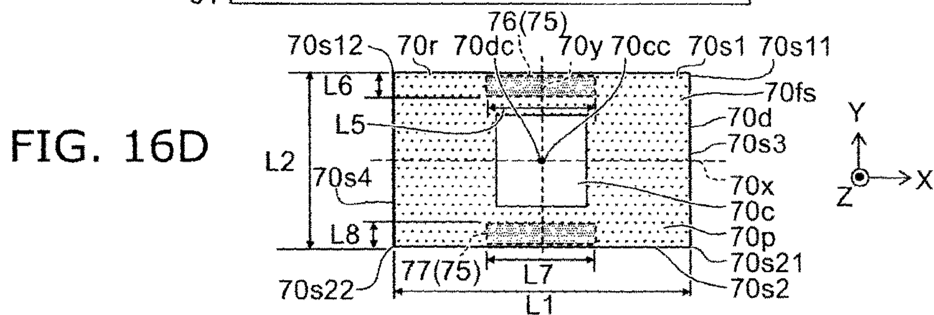


FIG. 16D



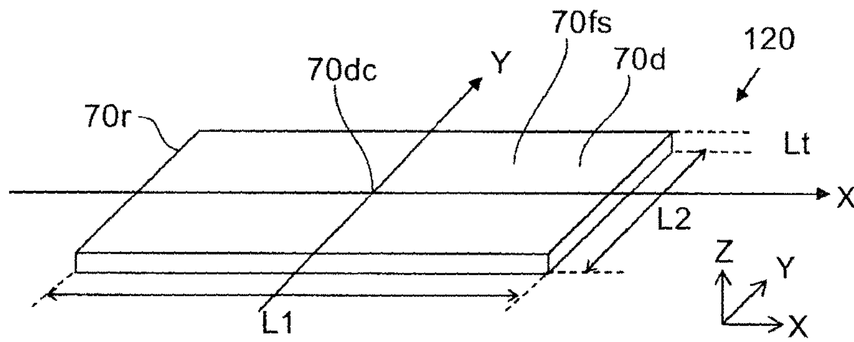


FIG. 17A

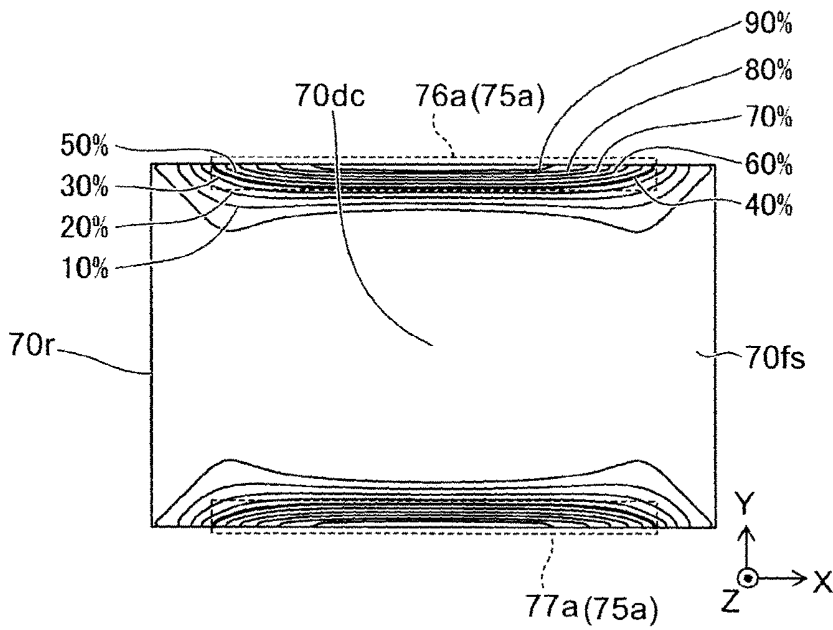


FIG. 17B

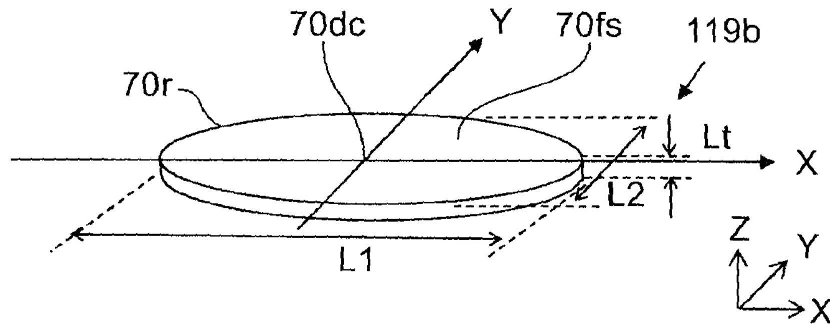


FIG. 18A

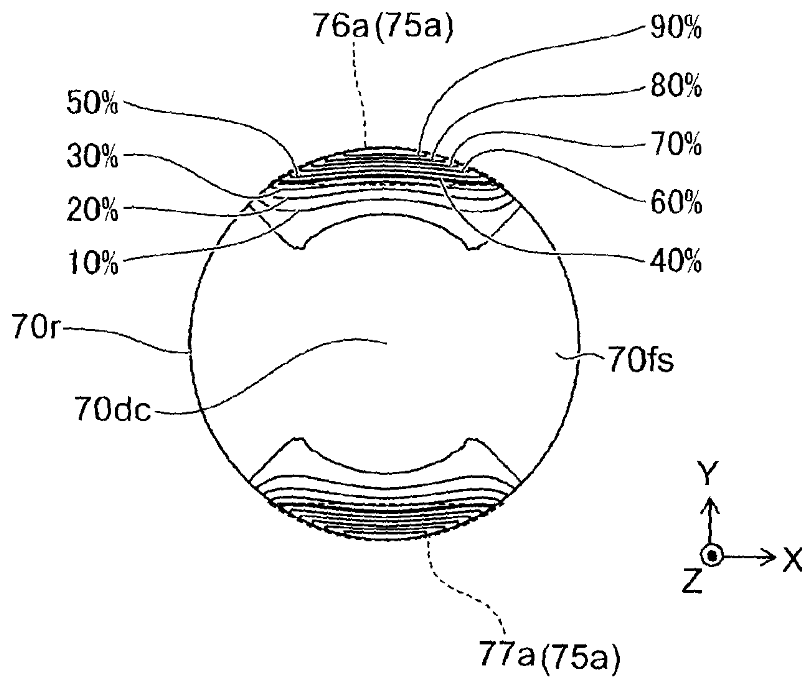


FIG. 18B

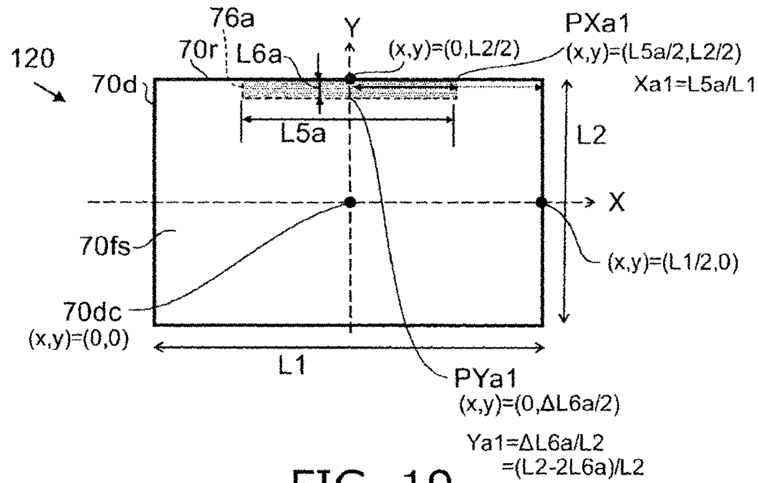


FIG. 19

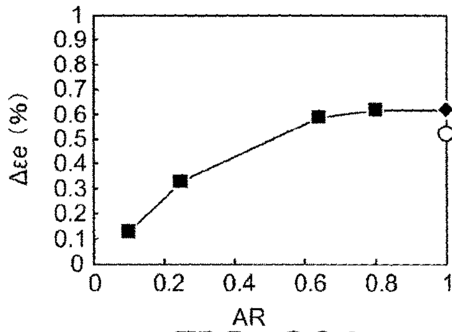


FIG. 20A

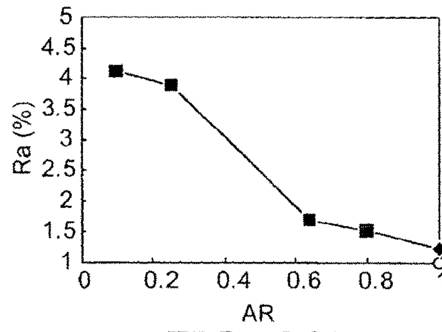


FIG. 20B

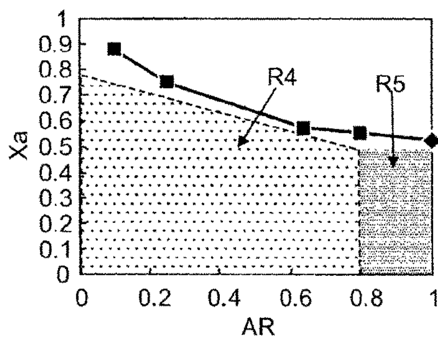


FIG. 20C

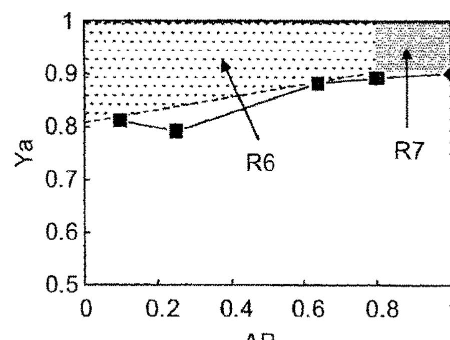


FIG. 20D

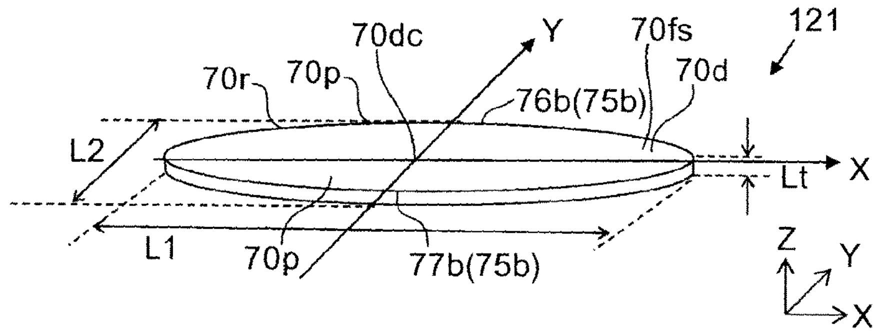


FIG. 21A

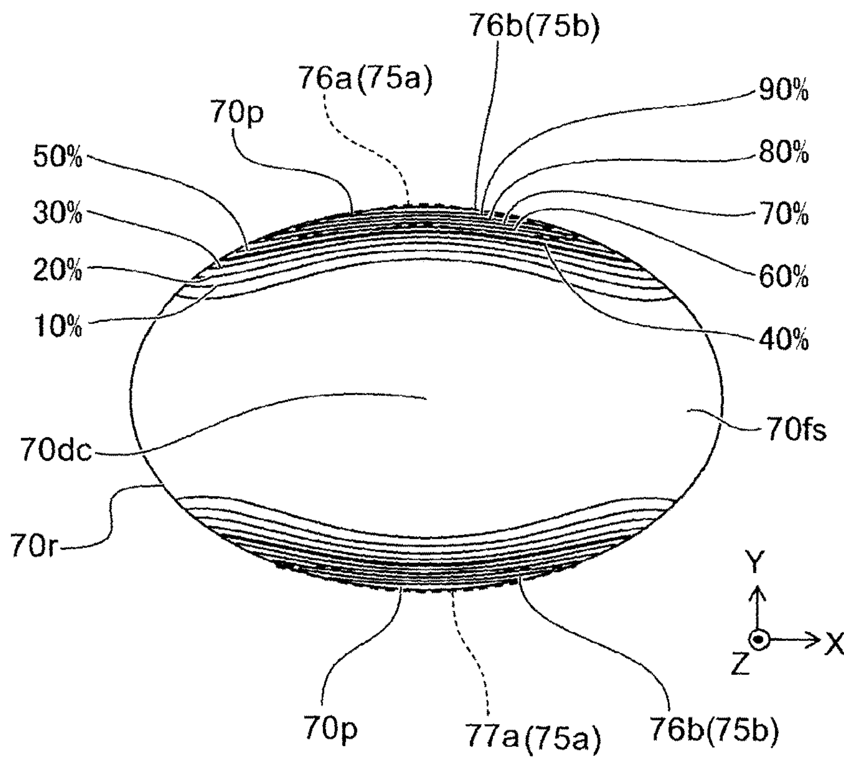


FIG. 21B

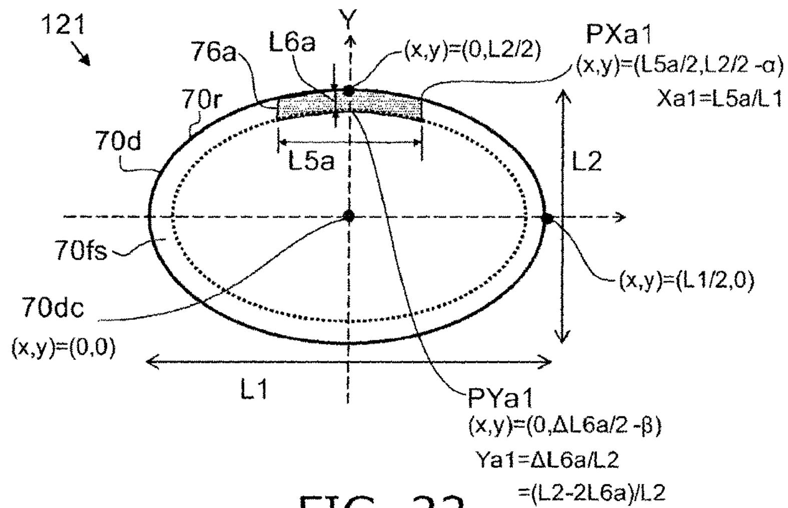


FIG. 22

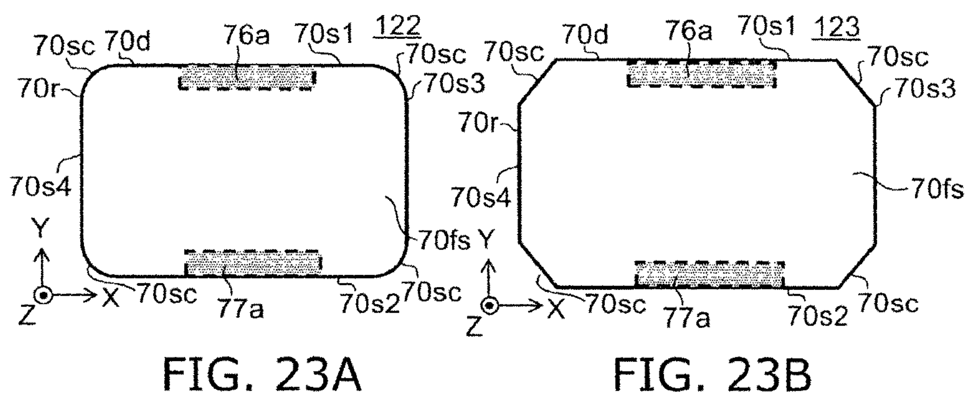


FIG. 23A

FIG. 23B

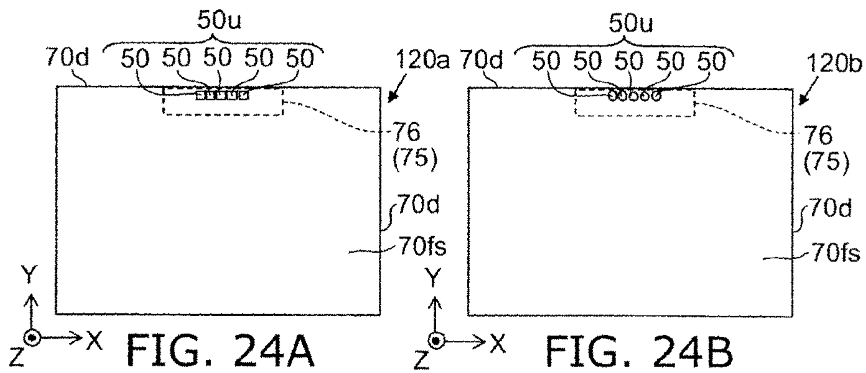


FIG. 24A FIG. 24B

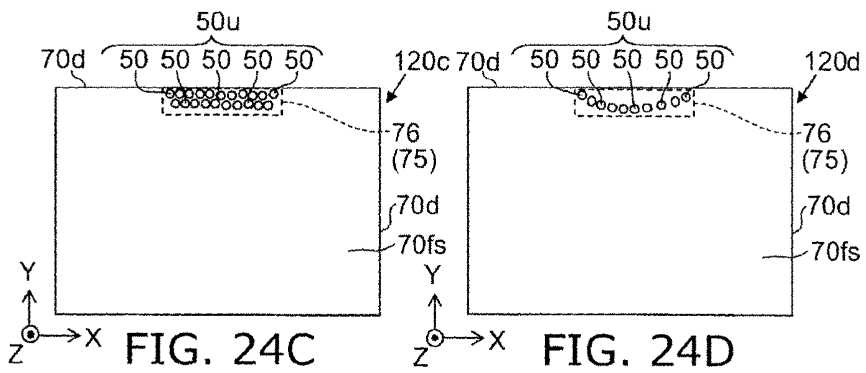


FIG. 24C FIG. 24D

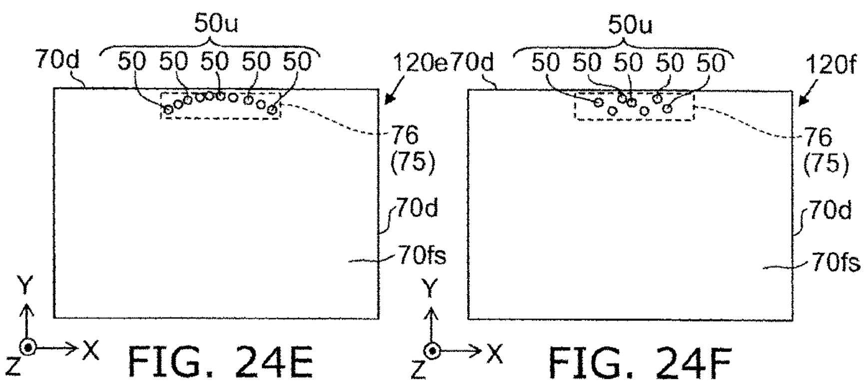


FIG. 24E FIG. 24F

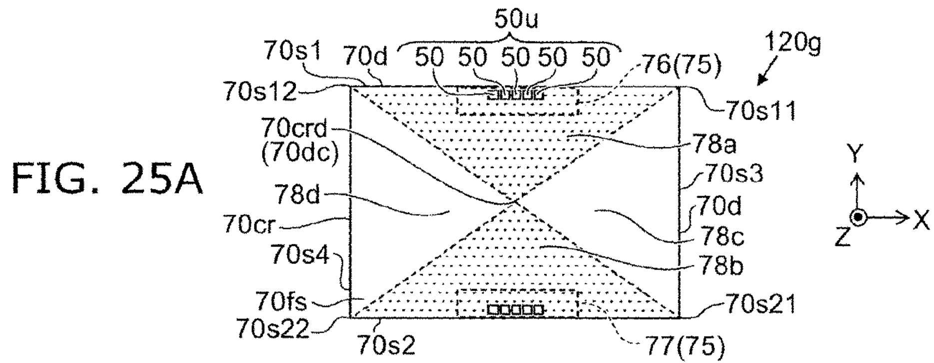


FIG. 25A

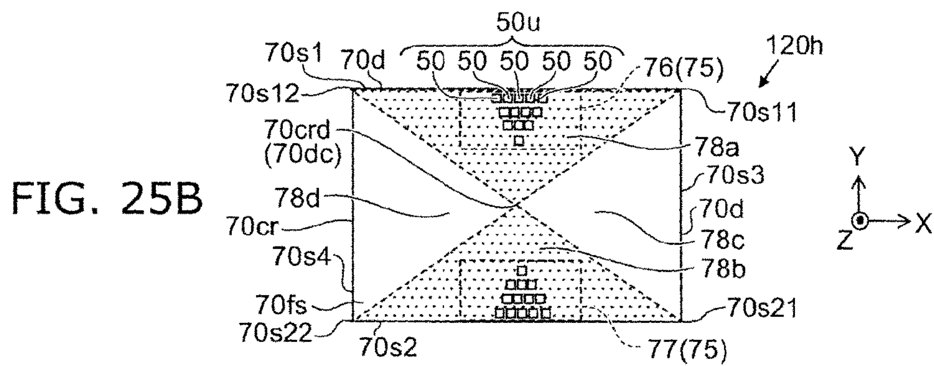


FIG. 25B

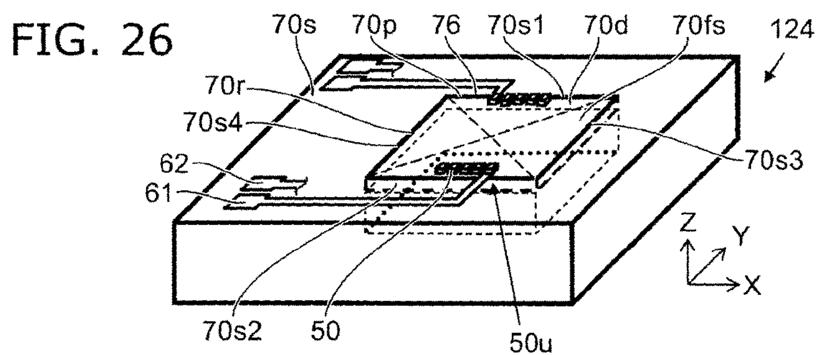


FIG. 26

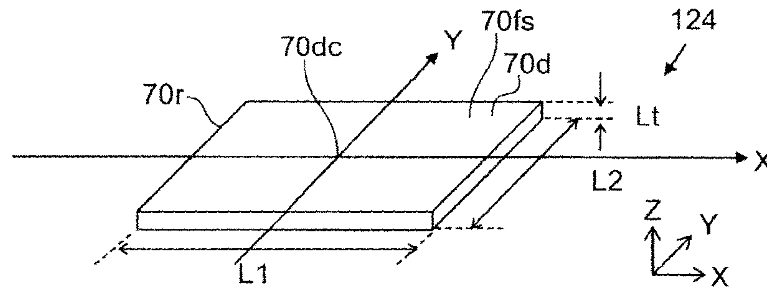


FIG. 27A

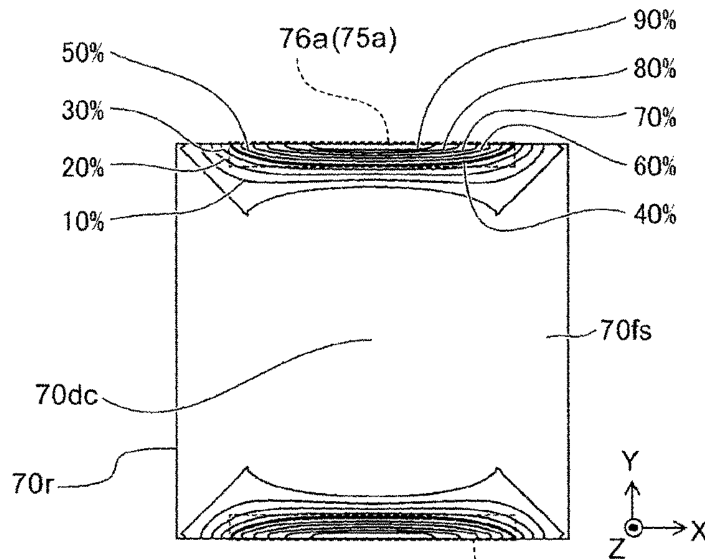
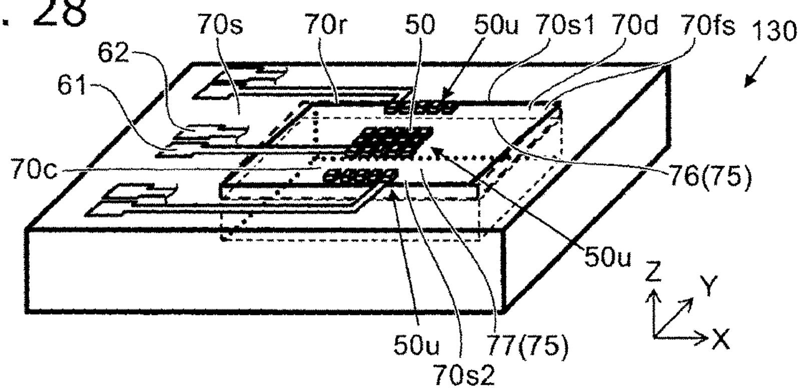


FIG. 27B

FIG. 28



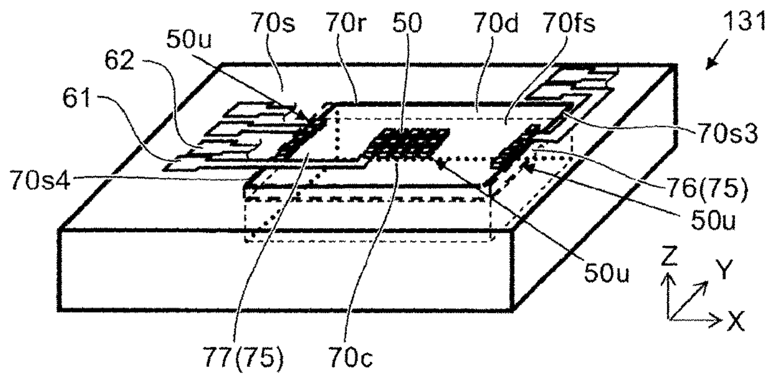


FIG. 29

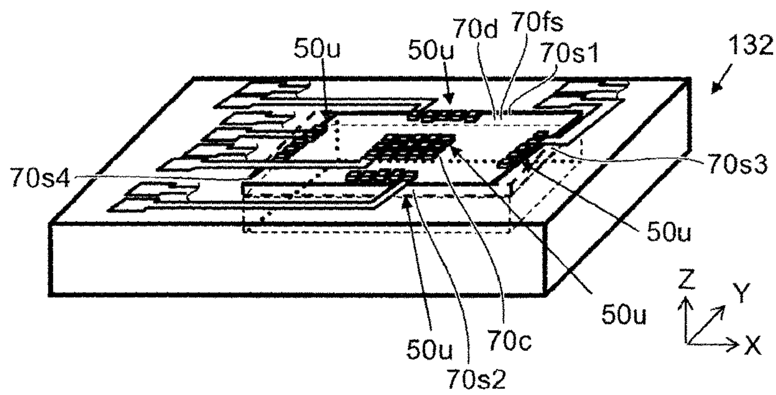


FIG. 30

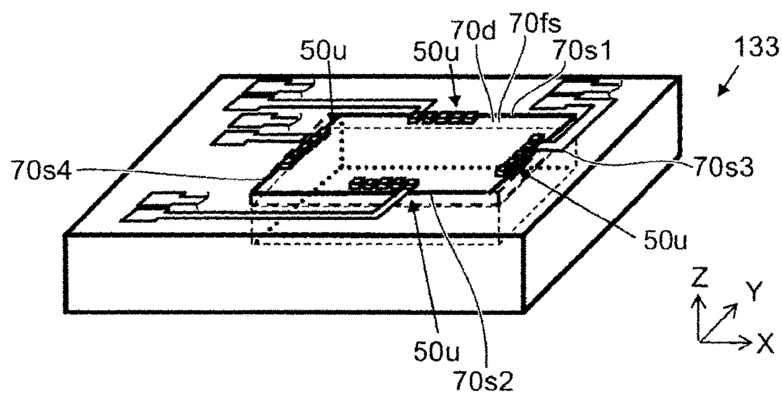


FIG. 31

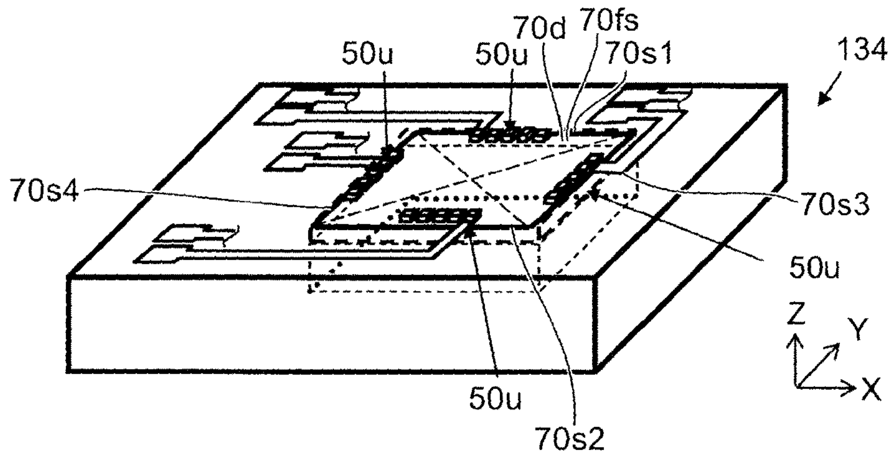


FIG. 32

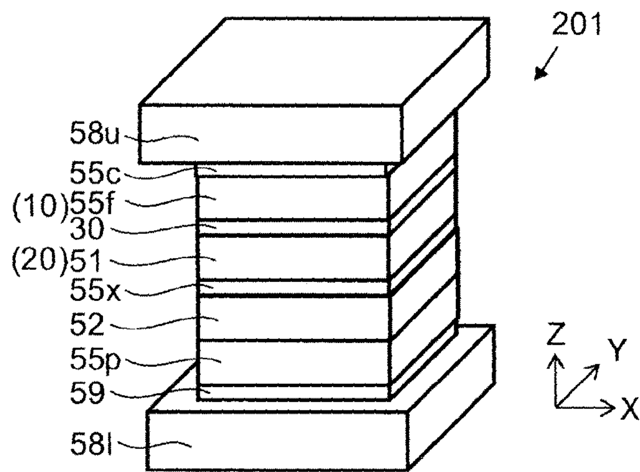


FIG. 33

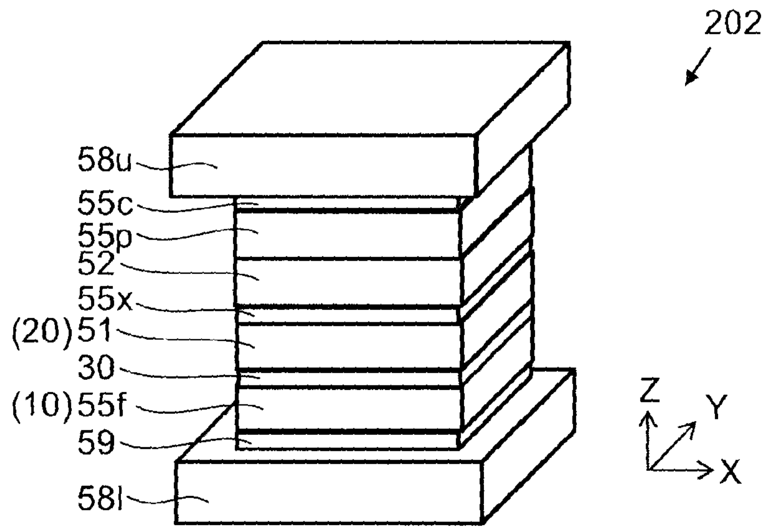


FIG. 34

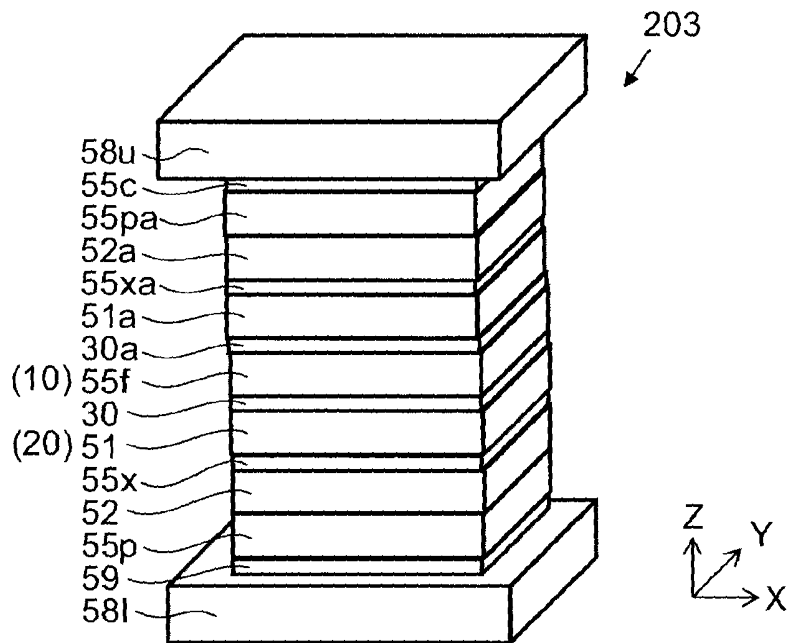


FIG. 35

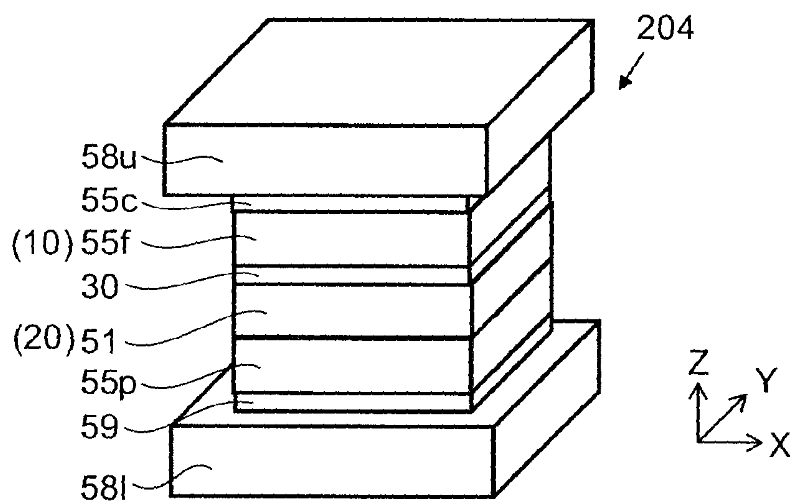


FIG. 36

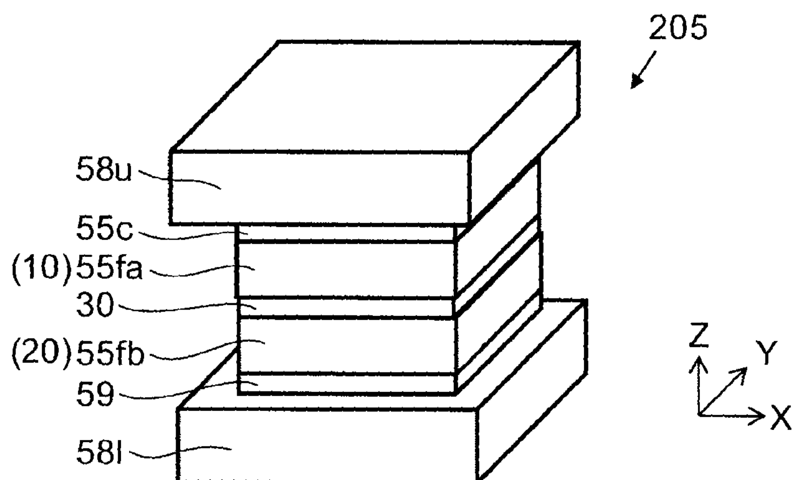


FIG. 37

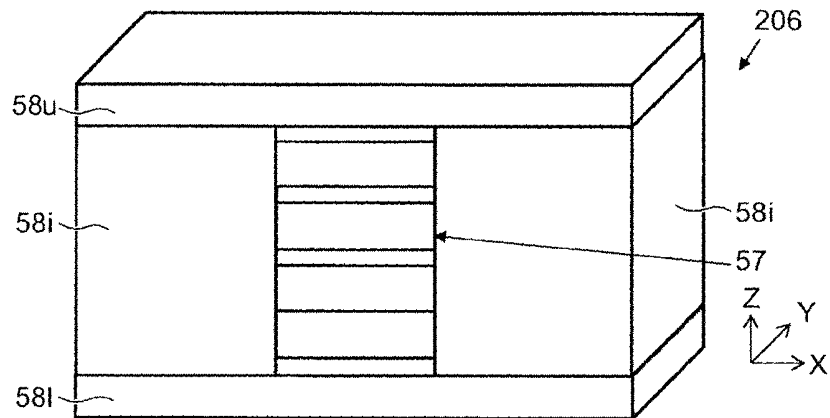


FIG. 38

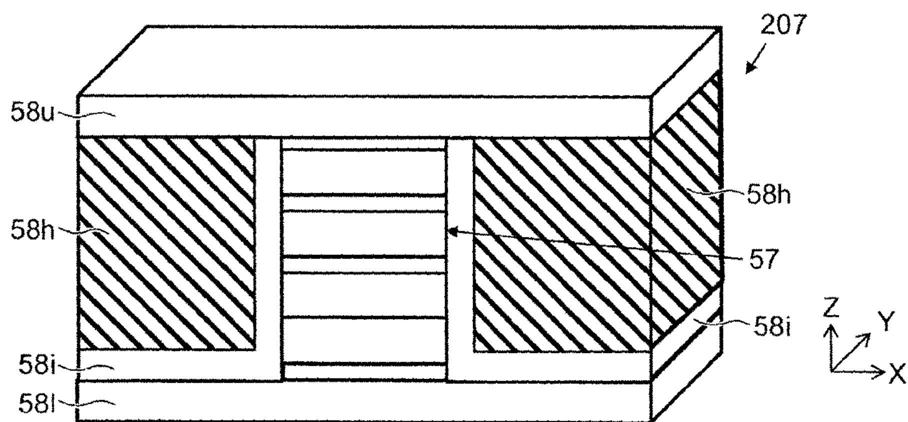


FIG. 39

FIG. 40A

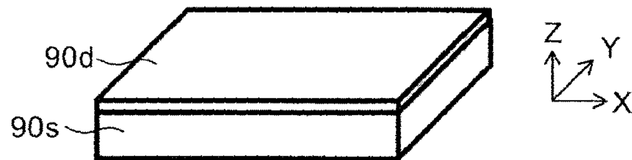


FIG. 40B

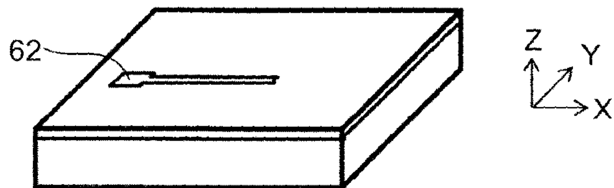


FIG. 40C

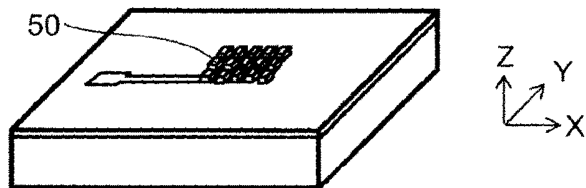


FIG. 40D

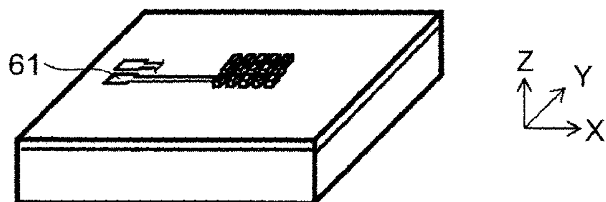


FIG. 40E

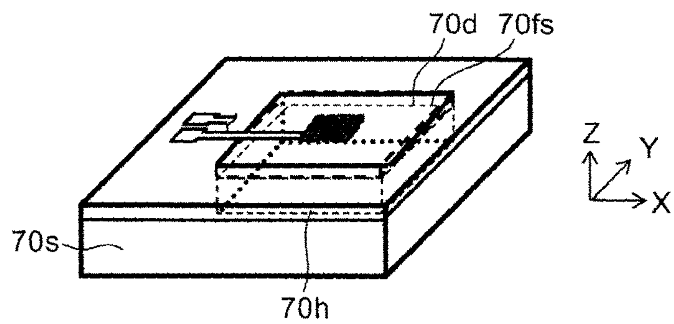


FIG. 41A

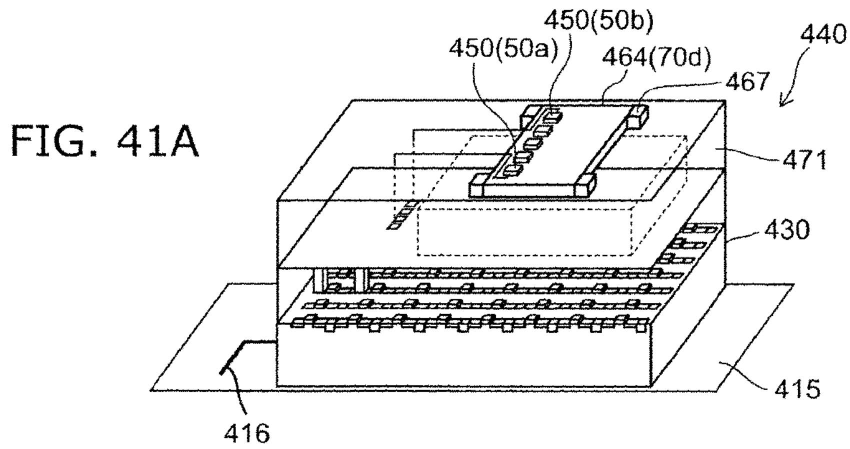


FIG. 41B

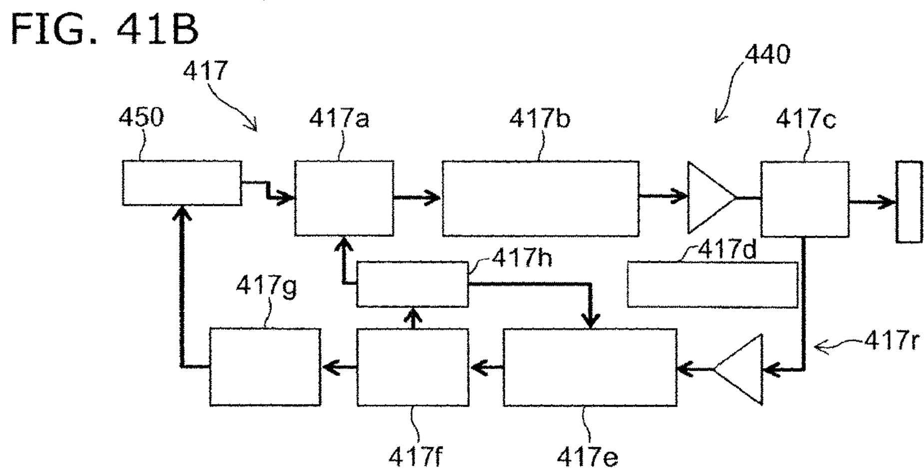


FIG. 41C

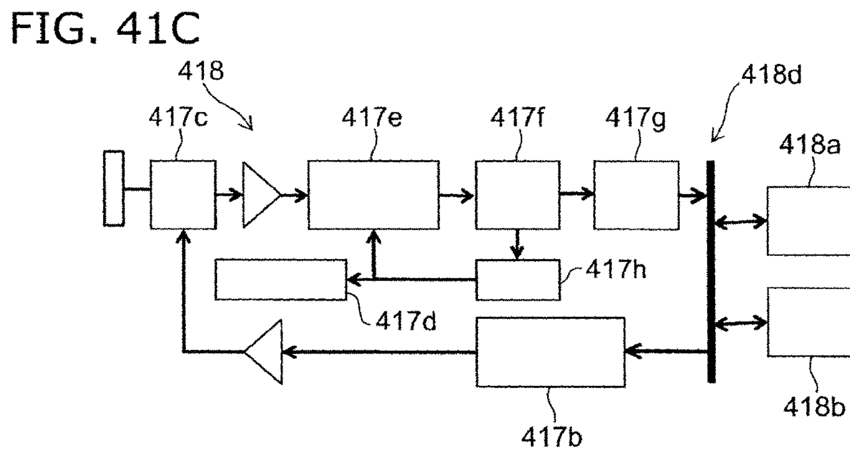


FIG. 42A

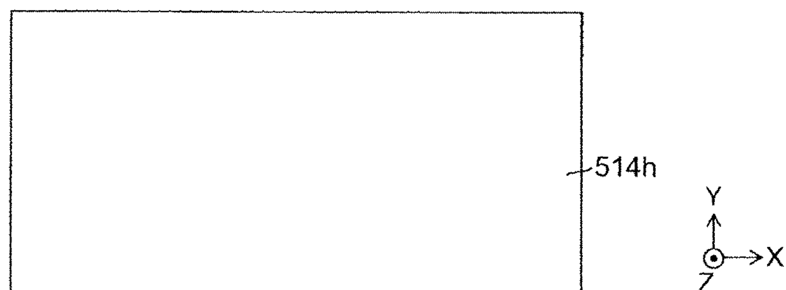


FIG. 42B

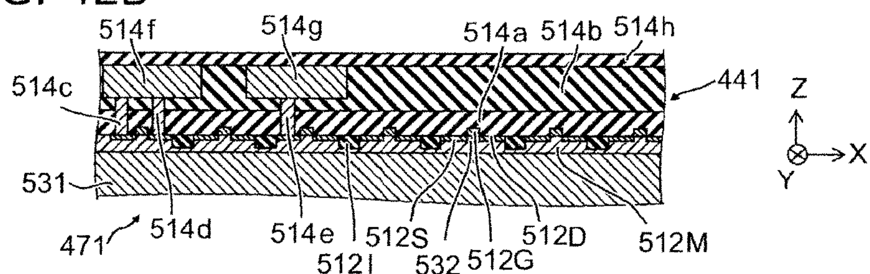


FIG. 43A

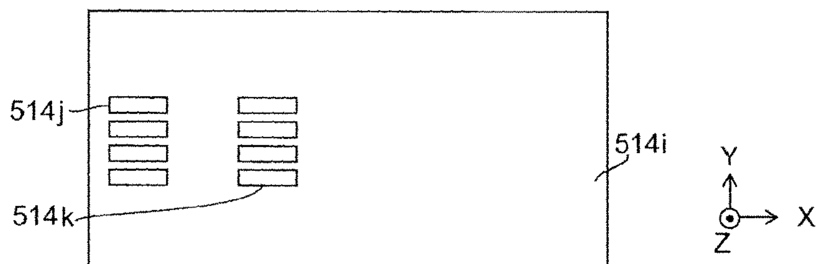


FIG. 43B

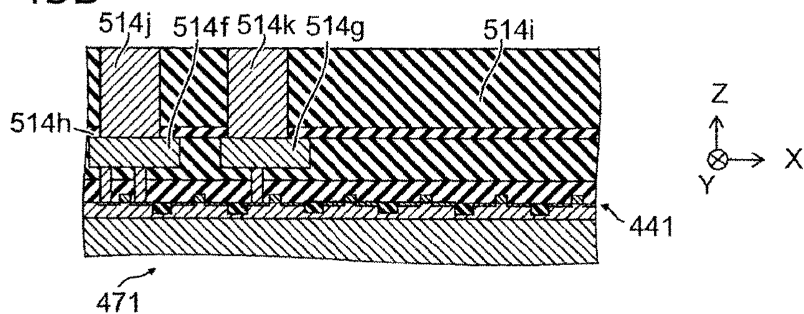


FIG. 44A

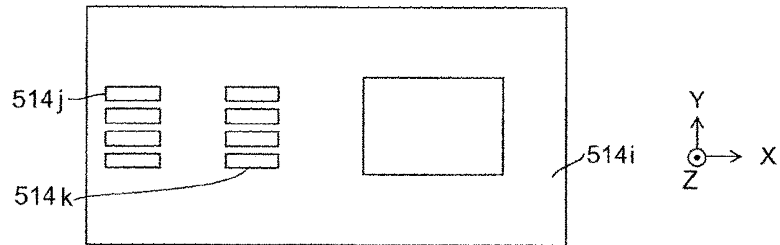


FIG. 44B

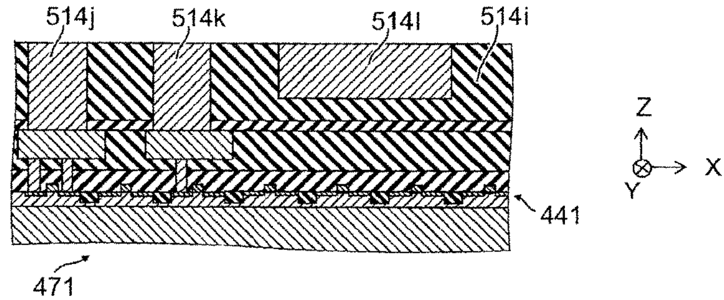


FIG. 45A

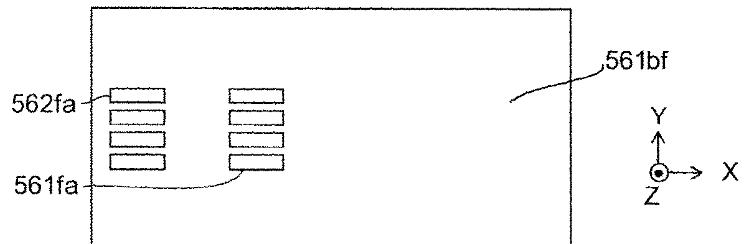


FIG. 45B

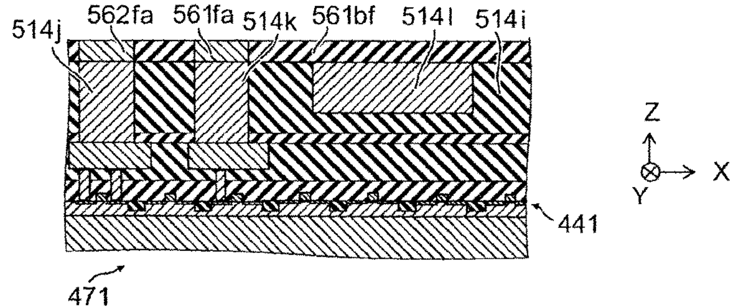


FIG. 46A

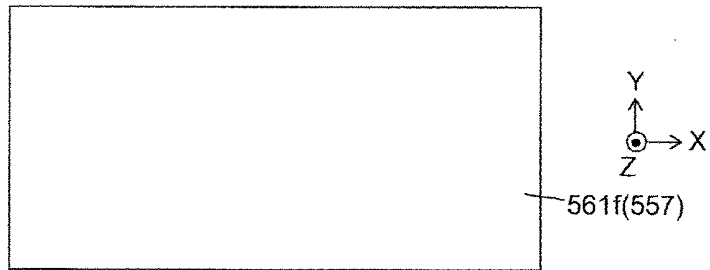


FIG. 46B

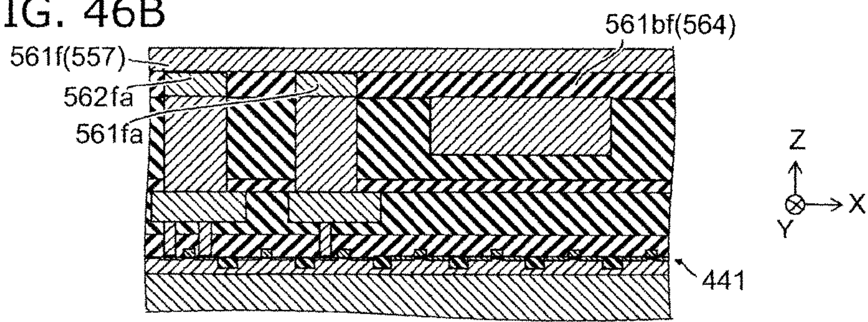


FIG. 47A

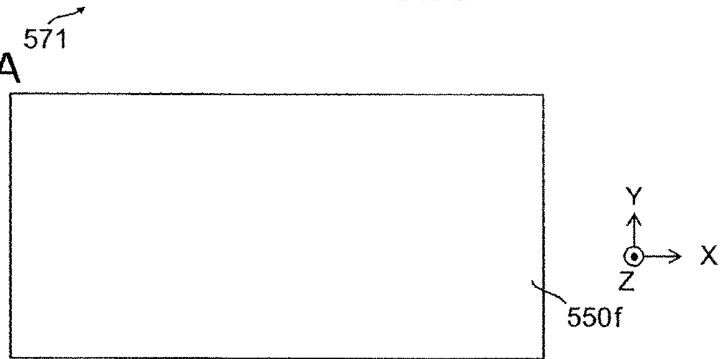


FIG. 47B

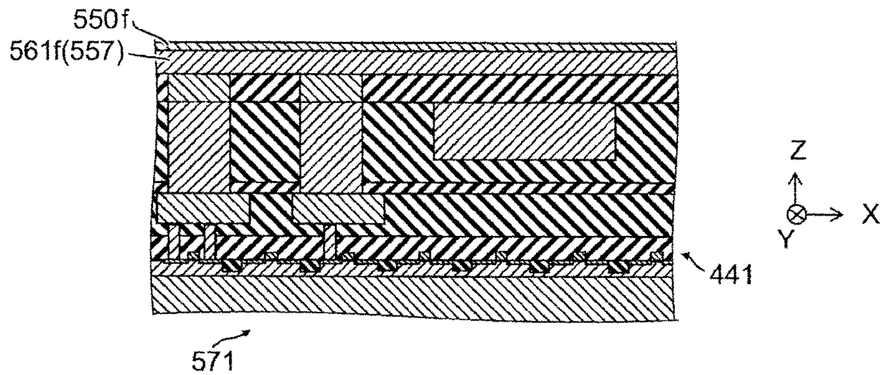


FIG. 48A

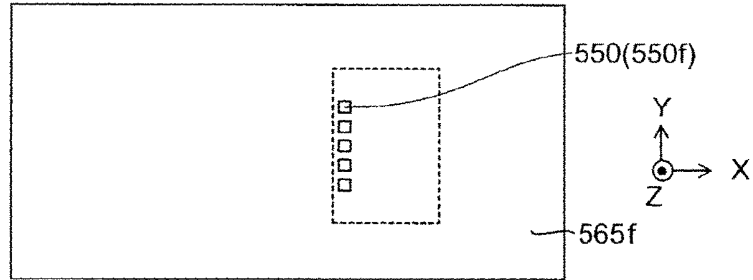


FIG. 48B

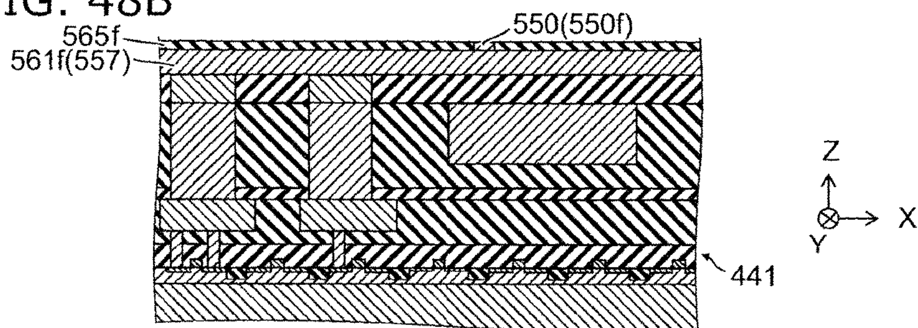


FIG. 49A

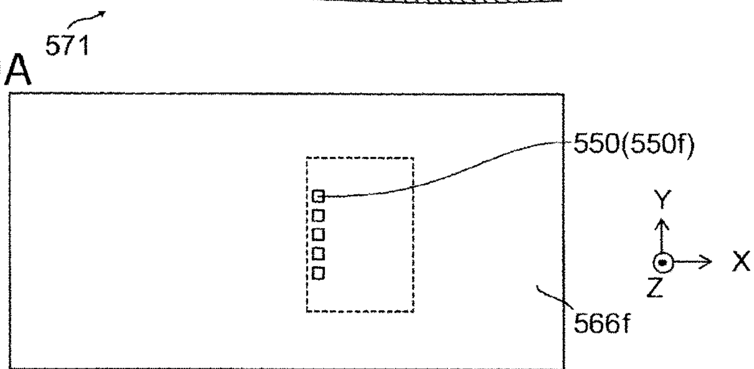


FIG. 49B

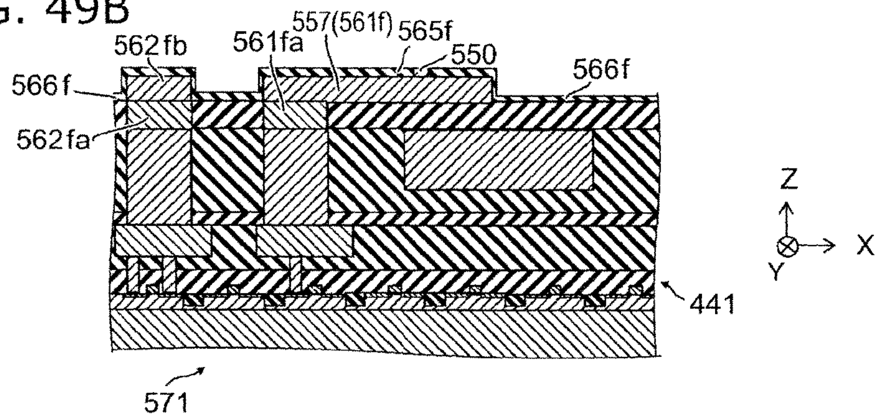


FIG. 50A

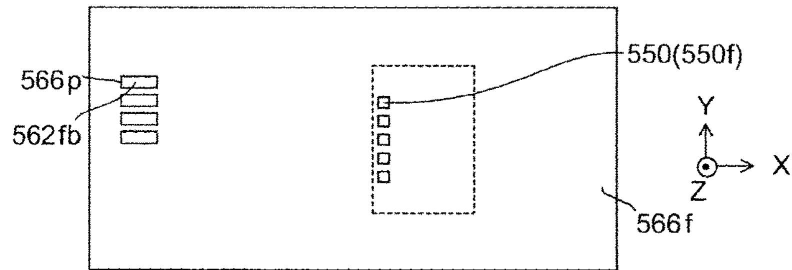


FIG. 50B

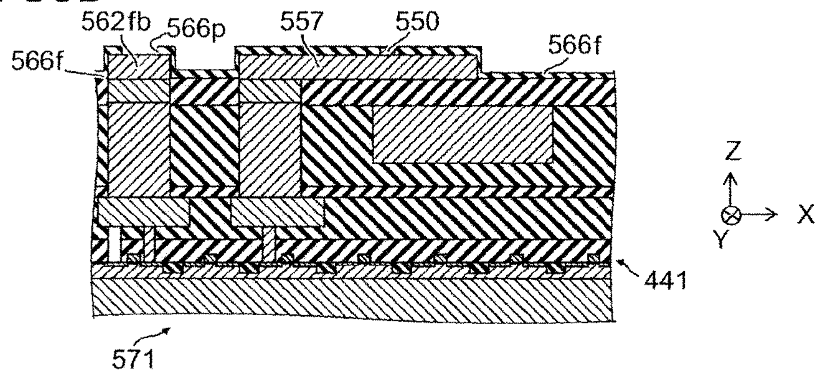


FIG. 51A

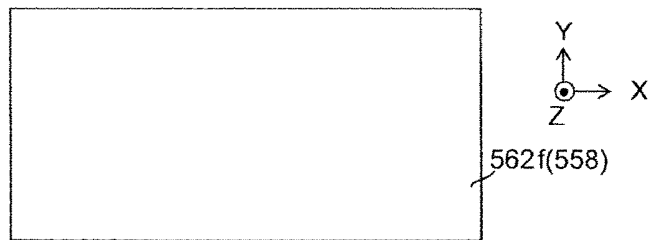


FIG. 51B

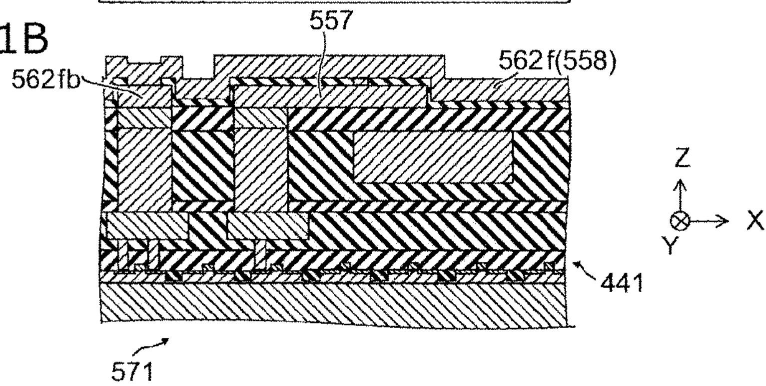


FIG. 52A

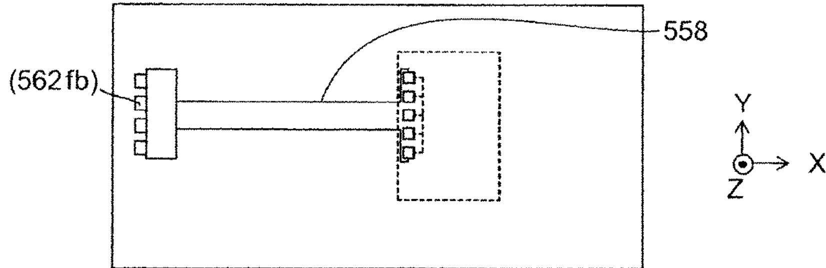


FIG. 52B

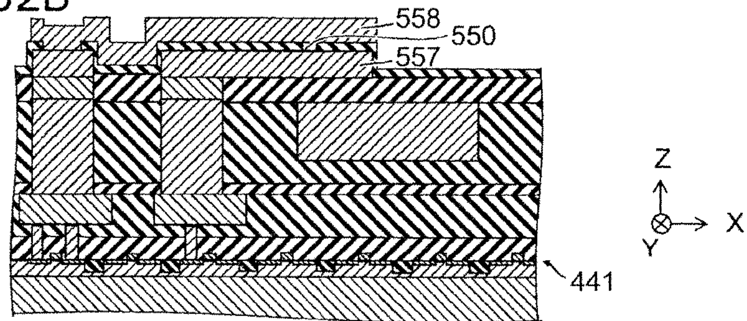


FIG. 53A

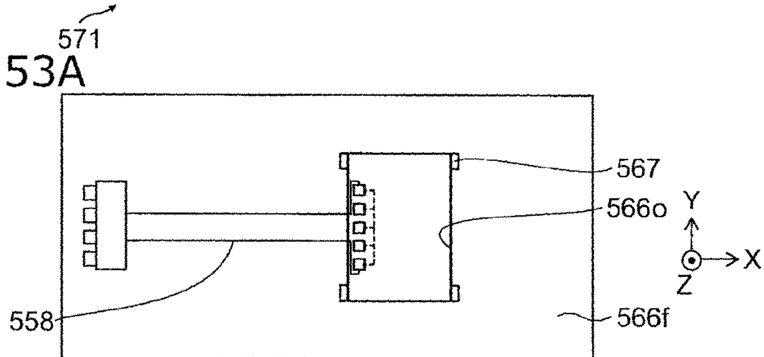
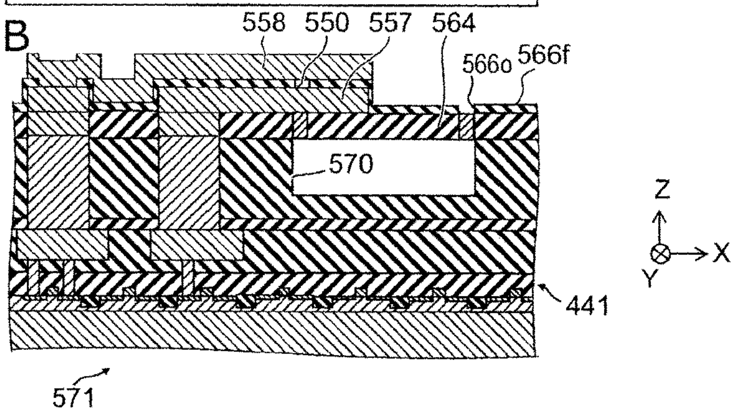


FIG. 53B



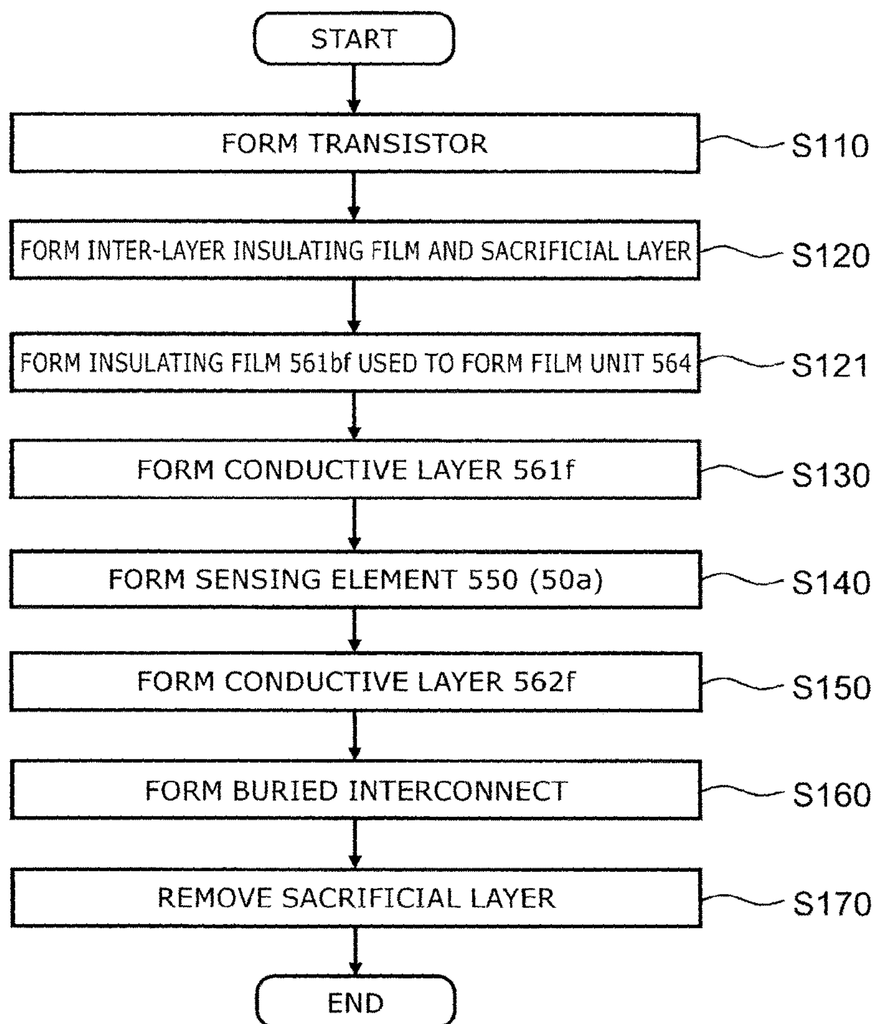


FIG. 54

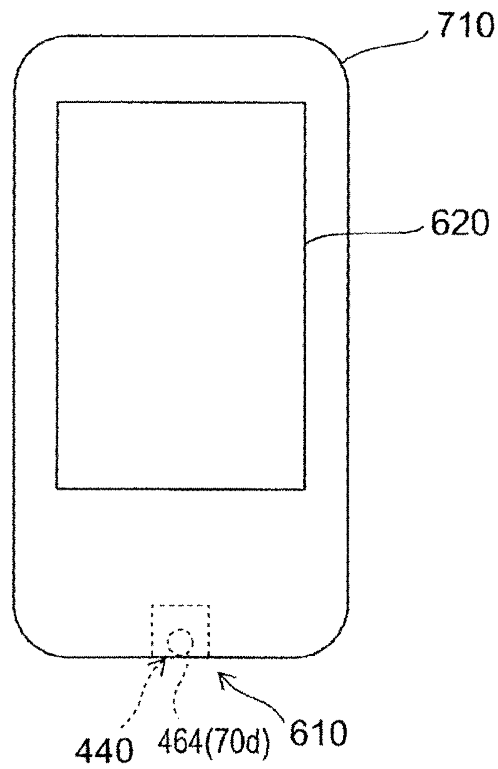


FIG. 55

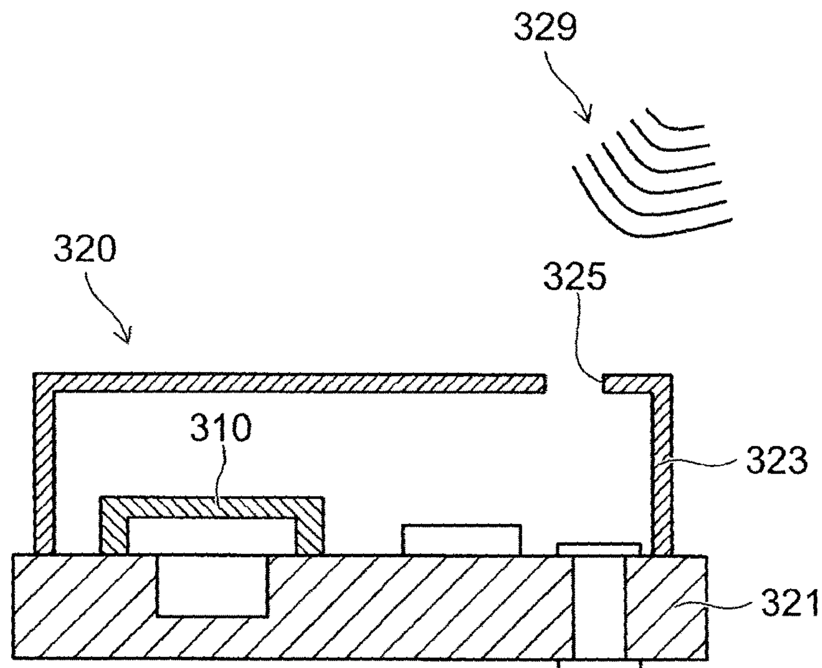


FIG. 56

FIG. 57A

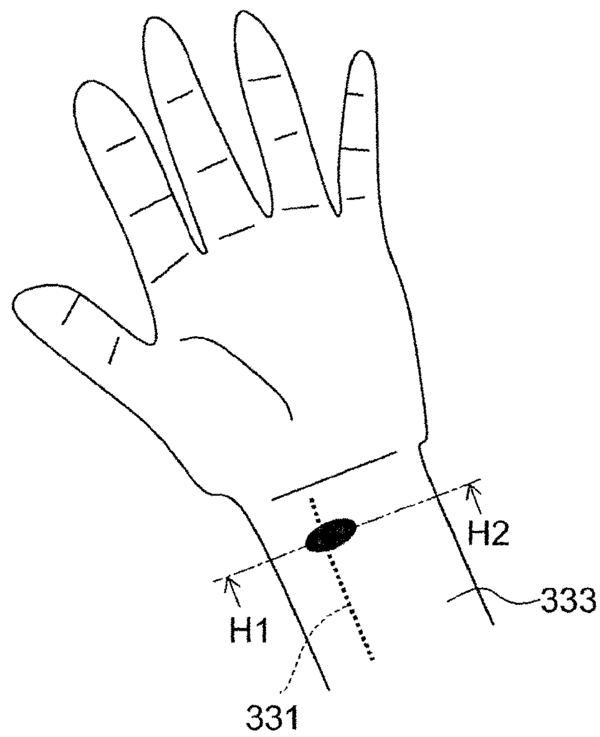
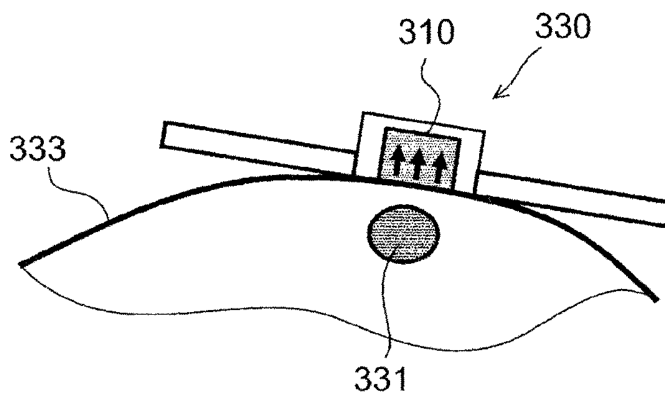


FIG. 57B



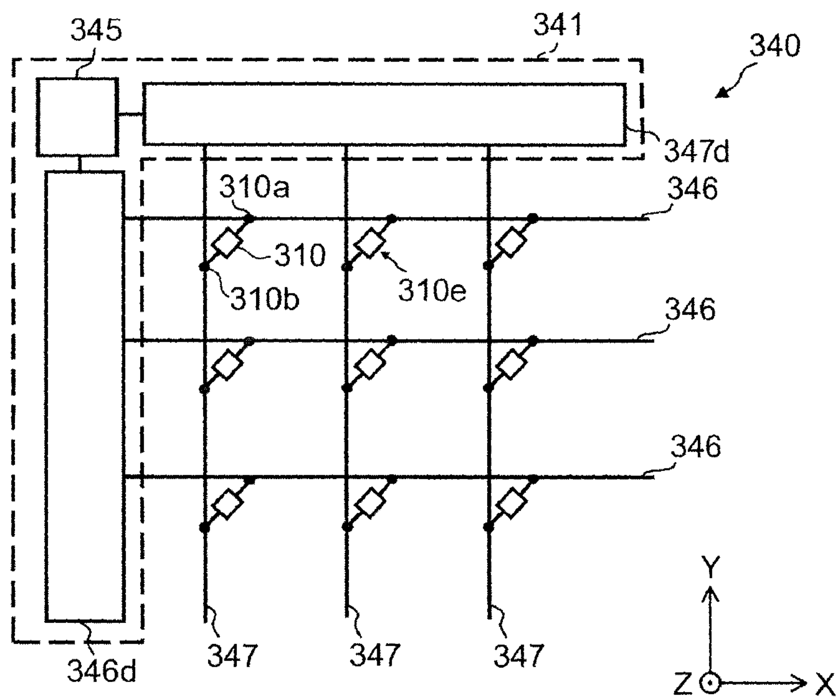


FIG. 58

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

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 15/388,629, filed on Dec. 22, 2016, which is a continuation of U.S. patent application Ser. No. 14/197,448, filed on Mar. 5, 2014, and is based upon and claims the benefit of priority from Japanese Patent Application No. 2013-124111, filed on Jun. 12, 2013; the entire contents of each of the above applications are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a pressure sensor, an acoustic microphone, a blood pressure sensor, and a touch panels.

BACKGROUND

Pressure sensors that use MEMS (Micro Electro Mechanical Systems) technology include, for example, a piezo resistance-change type and an electrostatic-capacitance type. On the other hand, a pressure sensor that uses spin technology has been proposed. In the pressure sensor using spin technology, a resistance change corresponding to the strain is sensed. For the pressure sensor using spin technology, a highly-sensitive pressure sensor is desired.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A to FIG. **1**D are schematic views illustrating a pressure sensor according to the first embodiment;

FIG. **2**A to FIG. **2**I are schematic perspective views illustrating operations of the pressure sensor;

FIG. **3**A to FIG. **3**C are schematic views illustrating the operation of the pressure sensor according to the first embodiment;

FIG. **4**A to FIG. **4**C are schematic views illustrating the operation of a pressure sensor of a reference example;

FIG. **5**A to FIG. **5**F are schematic views illustrating the configuration and characteristics of the pressure sensor according to the first embodiment;

FIG. **6**A to FIG. **6**D are schematic views illustrating the configuration and characteristics of a pressure sensor of a reference example;

FIG. **7** is a schematic plan view illustrating the pressure sensor;

FIG. **8**A to FIG. **8**D are graphs illustrating characteristics of the pressure sensors;

FIG. **9**A and FIG. **9**B are graphs illustrating characteristics of the pressure sensor;

FIG. **10**A to FIG. **10**D are schematic views illustrating the configuration and characteristics of another pressure sensor according to the first embodiment;

FIG. **11**A to FIG. **11**C are schematic views illustrating the configuration and characteristics of a pressure sensor of a reference example;

FIG. **12** is a schematic plan view illustrating the pressure sensor;

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

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

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

FIG. **16**A to FIG. **16**D are schematic views illustrating a pressure sensor according to a second embodiment;

FIG. **17**A and FIG. **17**B are schematic views illustrating the configuration and characteristics of the pressure sensor according to the second embodiment;

FIG. **18**A and FIG. **18**B are schematic views illustrating the configuration and characteristics of a pressure sensor of a reference example;

FIG. **19** is a schematic plan view illustrating a pressure sensor;

FIG. **20**A to FIG. **20**D are graphs illustrating the characteristics of the pressure sensors;

FIG. **21**A and FIG. **21**B are schematic views illustrating the configuration and characteristics of another pressure sensor according to the second embodiment;

FIG. **22** is a schematic view illustrating another pressure sensor according to the second embodiment

FIG. **23**A and FIG. **23**B are schematic plan views illustrating other pressure sensors according to the second embodiment;

FIG. **24**A to FIG. **24**F are schematic plan views illustrating other pressure sensors according to the second embodiment;

FIG. **25**A and FIG. **25**B are schematic plan views illustrating other pressure sensors according to the second embodiment;

FIG. **26** is a schematic perspective view illustrating another pressure sensor according to the second embodiment;

FIG. **27**A and FIG. **27**B are schematic views illustrating the configuration and characteristics of another pressure sensor according to the second embodiment;

FIG. **28** is a schematic perspective view illustrating a pressure sensor according to a third embodiment;

FIG. **29** is a schematic perspective view illustrating another pressure sensor according to the third embodiment;

FIG. **30** is a schematic perspective view illustrating another pressure sensor according to the third embodiment;

FIG. **31** is a schematic perspective view illustrating another pressure sensor according to the third embodiment;

FIG. **32** is a schematic perspective view illustrating another pressure sensor according to the third embodiment;

FIG. **33** is a schematic perspective view illustrating the sensing element used in the embodiment;

FIG. **34** is a schematic perspective view illustrating another sensing element used in the embodiment;

FIG. **35** is a schematic perspective view illustrating another sensing element used in the embodiment;

FIG. **36** is a schematic perspective view illustrating another sensing element used in the embodiment;

FIG. **37** is a schematic perspective view illustrating another sensing element used in the embodiment;

FIG. **38** is a schematic perspective view illustrating another sensing element used in the embodiment;

FIG. **39** is a schematic perspective view illustrating another sensing element used in the embodiment;

FIG. **40**A to FIG. **40**E are schematic cross-sectional views in order of the processes, illustrating the method for manufacturing the pressure sensor according to the embodiment;

FIG. **41**A to FIG. **41**C are schematic views illustrating the configuration of a pressure sensor **440** according to a fourth embodiment;

FIG. **42**A, FIG. **42**B, FIG. **43**A, FIG. **43**B, FIG. **44**A, FIG. **44**B, FIG. **45**A, FIG. **45**B, FIG. **46**A, FIG. **46**B, FIG. **47**A, FIG. **47**B, FIG. **48**A, FIG. **48**B, FIG. **49**A, FIG. **49**B, FIG. **50**A, FIG. **50**B, FIG. **51**A, FIG. **51**B, FIG. **52**A, FIG. **52**B, FIG. **53**A, and FIG. **53**B are schematic views illustrating the method for manufacturing the pressure sensor **441** according to the fifth embodiment;

FIG. **54** is a flowchart illustrating the method for manufacturing the pressure sensor **441** according to the fifth embodiment;

FIG. **55** is a schematic view illustrating a microphone **610** according to a sixth embodiment;

FIG. **56** is a schematic cross-sectional view illustrating the acoustic microphone according to the seventh embodiment;

FIG. **57**A and FIG. **57**B are schematic views illustrating the blood pressure sensor according to the eighth embodiment; and

FIG. **58** is a schematic view illustrating the touch panel according to the ninth embodiment.

DETAILED DESCRIPTION

According to one embodiment, a pressure sensor includes a film part, and a sensing unit. The film part is supported by a support unit, and is flexible. A first length of the film part in a first direction in a film surface of the film part is longer than a second length of the film part in a second direction perpendicular to the first direction in the film surface. A circumscribing rectangle is configured to circumscribe a configuration of the film surface. The circumscribing rectangle has a first side extending in the first direction to have the first length, a second side extending in the first direction to be separated from the first side, a third side extending in the second direction to be connected to one end of the first side and one end of the second side, the third side having the second length shorter than the first length, a fourth side extending in the second direction to be separated from the third side and connected to one other end of the first side and one other end of the second side, the fourth side having the second length, and a centroid of the circumscribing rectangle. The circumscribing rectangle includes a first region enclosed by the first side, a first line segment and a second line segment. The first line segment connects the centroid to the one end of the first side. The second line segment connects the centroid to the one other end of the first side. The sensing unit includes a plurality of sensing elements provided on a portion of the film surface overlapping the first region. Each of the plurality of sensing elements includes a first magnetic layer, a second magnetic layer provided between the first magnetic layer and the film part, and a spacer layer provided between the first magnetic layer and the second magnetic layer, the spacer layer being nonmagnetic. Positions of at least two of the plurality of sensing elements along the first direction are different from each other.

According to one embodiment, a pressure sensor includes a film part, and a sensing unit. The film part is supported by a support unit, and is flexible. A first length of the film part in a first direction in a film surface of the film part is longer than a second length of the film part in a second direction perpendicular to the first direction in the film surface. A configuration of the film surface has a first side extending in the first direction, a second side extending in the first direction to be separated from the first side, a distance between the first side and the second side being the second length, a third side extending in the second direction, and a fourth side extending in the second direction to be separated from the third side, a distance between the third side and the fourth side being the first length. The film surface has a central portion, and a peripheral portion provided around the central portion, the peripheral portion having a first element disposition region provided along the first side. The sensing unit includes a plurality of sensing elements provided on the first element disposition region of the film surface. Each of the plurality of sensing elements includes a first magnetic layer, a second magnetic layer provided between the first magnetic layer and the film part, and a spacer layer provided between the first magnetic layer and the second magnetic layer, the spacer layer being nonmagnetic. Positions of at least two of the plurality of sensing elements along the first direction are different from each other.

According to one embodiment, a pressure sensor includes a film part, and a sensing unit. The film part is supported by a support unit, and is flexible. A first length of the film part in a first direction in a film surface of the film part is longer than a second length of the film part in a second direction perpendicular to the first direction in the film surface. A configuration of the film surface is a flattened circle having the first direction as a major axis and the second direction as a minor axis. The film surface has a central portion, and a peripheral portion provided around the central portion. The peripheral portion has a first element disposition region provided along an arc along the major axis. The sensing unit includes a plurality of sensing elements provided on the first element disposition region of the film surface. Each of the plurality of sensing elements includes a first magnetic layer, a second magnetic layer provided between the first magnetic layer and the film part, and a spacer layer provided between the first magnetic layer and the second magnetic layer, the spacer layer being nonmagnetic. Positions of at least two of the plurality of sensing elements along the first direction are different from each other.

According to one embodiment, a pressure sensor includes a film part, and a sensing unit. The film part is supported by a support unit, and is flexible. A first length of a film surface of the film part in a first direction in the film surface is longer than a second length of the film surface in a second direction perpendicular to the first direction in the film surface. The film surface has a central portion, and a peripheral portion provided around the central portion. The sensing unit includes a sensing element provided on the central portion. The sensing element includes a first magnetic layer, a second magnetic layer provided between the first magnetic layer and the film part, and a spacer layer provided between the first magnetic layer and the second magnetic layer.

According to one embodiment, an acoustic microphone including the pressure sensor is provided,

According to one embodiment, a blood pressure sensor including the pressure sensor **1** is provided,

According to one embodiment, a touch panel including the pressure sensor is provided,

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

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

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

First Embodiment

FIG. 1A to FIG. 1D are schematic views illustrating a pressure sensor according to the first embodiment.

FIG. 1A is a schematic perspective view. FIG. 1B is a cross-sectional view along line A1-A2 of FIG. 1A and FIG. 1C. FIG. 1C is a schematic plan view. FIG. 1D is a schematic plan view of a film part included in the pressure sensor.

As shown in FIG. 1A to FIG. 1C, the pressure sensor **110** according to the embodiment includes the film part **70*d*** and a sensing unit **50*u***. In the example, a support unit **70*s*** is provided.

The support unit **70*s*** is, for example, a substrate. The film part **70*d*** is supported by the support unit **70*s***. The film part **70*d*** is flexible. The film part **70*d*** is, for example, a diaphragm. The film part **70*d*** may be integral with the support unit **70*s*** or may be a separate entity. The film part **70*d*** may include the same material as the support unit **70*s*** or a material that is different from that of the support unit **70*s***. A portion of the substrate that is used to form the support unit **70*s*** may be removed; and the film part **70*d*** may be the thin portion of the substrate.

The thickness of the film part **70*d*** is thinner than the thickness of the support unit **70*s***. The film part **70*d*** and the support unit **70*s*** may include the same material; and in the case where the film part **70*d*** and the support unit **70*s*** are integral, the thin portion is used to form the film part **70*d***; and the thick portion is used to form the support unit **70*s***.

The support unit **70*s*** may have a through-hole piercing the support unit **70*s*** in the thickness direction; and the film part **70*d*** may be provided to cover the through-hole. In such a case, for example, the film of the material used to form the film part **70*d*** may extend onto a portion of the support unit **70*s*** other than the through-hole. In such a case, the portion of the film of the material used to form the film part **70*d*** that overlaps the through-hole is used to form the film part **70*d***.

The film part **70*d*** has an outer edge **70*r***. In the case where the film part **70*d*** and the support unit **70*s*** include the same material and are integral, the outer edge of the thin portion is used to form the outer edge **70*r*** of the film part **70*d***. In the case where the support unit **70*s*** has a through-hole piercing the support unit **70*s*** in the thickness direction and the film part **70*d*** is provided to cover the through-hole, the outer edge of the portion of the film of the material used to form the film part **70*d*** that overlaps the through-hole is used to form the outer edge **70*r*** of the film part **70*d***.

The support unit **70*s*** may continuously support the outer edge **70*r*** of the film part **70*d*** or may support a portion of the outer edge **70*r*** of the film part **70*d***.

A direction perpendicular to a plane including the outer edge **70*r*** is taken as a Z-axis direction. One direction perpendicular to the Z-axis direction is taken as an X-axis direction. A direction perpendicular to the Z-axis direction and the X-axis direction is taken as a Y-axis direction.

One direction in a film surface **70*fs*** of the film part **70*d*** is taken as a first direction. The first direction is, for example, the X-axis direction. A direction perpendicular to the first direction in the film surface **70*fs*** is taken as a second direction. The second direction is, for example, the Y-axis direction.

In the embodiment, the planar configuration of the film part **70*d*** is an anisotropic configuration.

For example, as illustrated in FIG. 1D, the film part **70*d*** has a first length L1 in the first direction (the X-axis direction) and a second length L2 in the second direction (the Y-axis direction). The first length L1 is longer than the second length L2. The first length L1 is the maximum length of the film part **70*d*** in the first direction. The second length L2 is the maximum length of the film part **70*d*** in the second direction.

In the example, the planar configuration of the film part **70*d*** is substantially rectangular. In other words, the film surface **70*fs*** has first to fourth sides **70*s*1** to **70*s*4**. The first side **70*s*1** is provided along the first direction. The second side **70*s*2** is provided along the first direction to be separated from the first side **70*s*1**. The distance between the first side **70*s*1** and the second side **70*s*2** is, for example, the second length L2. The third side **70*s*3** is provided along the second direction to be connected to one end **70*s*11** of the first side **70*s*1** and one end **70*s*21** of the second side **70*s*2**. The fourth side **70*s*4** is provided along the second direction to be separated from the third side **70*s*3** and connected to the other end **70*s*12** of the first side **70*s*1** and the other end **70*s*22** of the second side **70*s*2**. The distance between the third side **70*s*3** and the fourth side **70*s*4** is, for example, the first length. As described below, these sides may be connected to each other by corner portions having linear configurations or curved configurations.

As shown in FIG. 1D, the film surface **70*fs*** of the film part **70*d*** has a central portion **70*c*** and a peripheral portion **70*p***. The peripheral portion **70*p*** is provided around the central portion **70*c***. The peripheral portion **70*p*** is provided around the central portion **70*c*** when the film part **70*d*** is projected onto a plane (e.g., the X-Y plane) parallel to the film surface **70*fs***.

The sensing unit **50*u*** is provided on the central portion **70*c*** of the film part **70*d***.

In the specification of the 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 with another component inserted therebetween.

The sensing unit **50*u*** includes a sensing element **50**. In the example, the sensing unit **50*u*** includes multiple sensing elements **50** (e.g., first to fifth sensing elements **50*a*** to **50*e***, etc.). The number of the sensing elements **50** provided in the sensing unit **50*u*** may be 1.

As shown in FIG. 1B, the sensing element **50** includes a first magnetic layer **10**, a second magnetic layer **20**, and a spacer layer **30**. The second magnetic layer **20** is provided between the first magnetic layer **10** and the film part **70*d***. The spacer layer **30** is provided between the first magnetic layer **10** and the second magnetic layer **20**. The spacer layer **30** may include, for example, a nonmagnetic material.

A first interconnect **61** and a second interconnect **62** are provided in the pressure sensor **110**. The first interconnect **61** is connected to one selected from the sensing elements **50**. The second interconnect **62** is connected to one selected from the sensing elements **50**. For example, an inter-layer insulating film **63** is provided between the first interconnect **61** and the second interconnect **62** to electrically insulate the first interconnect **61** from the second interconnect **62**. A voltage is applied between the first interconnect **61** and the second interconnect **62**; and the voltage is applied to the sensing elements **50** via the first interconnect **61** and the second interconnect **62**. The film part **70*d*** deforms when pressure is applied to the pressure sensor **110**. The electrical resistance of the sensing elements **50** changes as the film part **70*d*** deforms. The pressure can be sensed by sensing the change of the electrical resistance via the first interconnect **61** and the second interconnect **62**.

For example, as shown in FIG. 1D, a centroid **70*dc*** of the film surface **70*fs*** substantially overlaps the centroid of the central portion **70*c***. The centroid of the film part **70*d*** substantially overlaps the centroid of the central portion **70*c***

when projected onto the X-Y plane. For example, a centroid **70***cc* of the central portion **70***c* is aligned with or proximal to the centroid **70***dc* of the film surface **70***fs*. The distance between the centroid **70***cc* of the central portion **70***c* and the centroid **70***dc* of the film surface **70***fs* is, for example, not more than 1/10 of the second length L2.

The central portion **70***c* where the sensing unit **50***u* is provided is disposed at the central portion of the film surface **70***fs*. As shown in FIG. **1**D, for example, a third length L3 of the central portion **70***c* in the first direction is not more than 0.3 times the first length L1. A fourth length L4 of the central portion **70***c* in the second direction is not more than 0.3 times the second length L2. The region other than the central portion **70***c* is used as the peripheral portion **70***p*.

In the pressure sensor **110** according to the embodiment, the planar configuration of the film part **70***d* (the configuration of the film surface **70***fs*) is an anisotropic configuration; and the sensing unit **50***u* is provided on the central portion **70***c* of such a film part **70***d*. Thereby, a highly-sensitive pressure sensor can be provided.

An example of the pressure sensor **110** will now be described.

The support unit **70***s* may include, for example, a substrate having a plate configuration. For example, a hollow portion **70***h* is provided in the interior of the substrate.

The support unit **70***s* may include, for example, a semiconductor material such as silicon, etc., a conductive material such as a metal, etc., or an insulating material. The support unit **70***s* may include, for example, silicon oxide, silicon nitride, etc. For example, the interior of the hollow portion **70***h* is in a reduced-pressure state (a vacuum state). A gas such as air, etc., or a liquid may be filled into the interior of the hollow portion **70***h*. The interior of the hollow portion **70***h* is designed such that the film part can deflect. The interior of the hollow portion **70***h* may communicate with external ambient air.

The film part **70***d* is provided on the hollow portion **70***h*. For example, a portion of the substrate used to form the support unit **70***s* that is patterned to be thin may be used as the film part **70***d*. The thickness (the length in the Z-axis direction) of the film part **70***d* is thinner than the thickness (the length in the Z-axis direction) of the substrate.

The film part **70***d* deflects when pressure is applied to the film part **70***d*. The pressure corresponds to the pressure to be sensed by the pressure sensor **110**. The pressure that is applied also includes pressure due to sound waves, ultrasonic waves, etc. In the case where pressure due to sound waves, ultrasonic waves, etc., is sensed, the pressure sensor **110** functions as a microphone.

The film part **70***d* includes, for example, an insulating material. The film part **70***d* includes, for example, at least one selected from silicon oxide, silicon nitride, and silicon oxynitride. The film part **70***d* may include, for example, a semiconductor material such as silicon, etc. The film part **70***d* may include, for example, a metal material.

The thickness of the film part **70***d* is, for example, not less than 0.1 micrometer (μm) and not more than 3 μm. It is favorable for the thickness to be not less than 0.2 μm and not more than 1.5 μm. The film part **70***d* may include, for example, a stacked body of a silicon oxide film having a thickness of 0.2 μm and a silicon film having a thickness of 0.4 μm.

The first magnetic layer **10** and the second magnetic layer **20** include, for example, ferromagnetic layers. The first magnetic layer **10** is, for example, a magnetization free layer. The second magnetic layer **20** is, for example, a reference layer. A magnetization fixed layer or a magnetization free layer is used as the reference layer. For example, the change of the magnetization of the first magnetic layer **10** may be set to be easier than the change of the magnetization of the second magnetic layer **20**. Thus, for example, as described below, the relative angle between the magnetization of the first magnetic layer **10** and the magnetization of the second magnetic layer **20** can be caused to change easily when the pressure is applied.

An example of the operations of the sensing element **50** will now be described. In the following example, the second magnetic layer **20** is a magnetization fixed layer.

In the pressure sensor **110** of the embodiment, strain occurs in the sensing element **50** when the film part **70***d* deflects due to the pressure from outside. The sensing element **50** functions to convert the change of the strain into a change of the electrical resistance.

The operation of the sensing element **50** functioning as a strain sensor is based on, for example, the application of an "inverse-magnetostriction effect" and a "magnetoresistance effect". The "inverse-magnetostriction effect" is obtained in the ferromagnetic layer included in the magnetization free layer. The "magnetoresistance effect" occurs in the stacked film of the reference layer, the spacer layer, and the magnetization free layer.

The "inverse-magnetostriction effect" is a phenomenon in which the magnetization of a ferromagnet is changed by the strain applied to the ferromagnet. In other words, the magnetization direction of the magnetization free layer changes when an external strain is applied to the stacked film of the sensing element **50**. As a result, the relative angle between the magnetization of the reference layer and the magnetization of the magnetization free layer changes. In such a case, the change of the electrical resistance is caused by a "magnetoresistance effect (MR effect)". The MR effect includes, for example, a GMR (Giant magnetoresistance) effect, a TMR (Tunneling magnetoresistance) effect, etc. The MR effect occurs by causing a current to flow in the stacked film and by reading the change of the relative angle of the orientation of the magnetization as the electrical resistance change. For example, strain is applied to the sensing element **50** by strain being applied to the stacked film. Due to the strain, the orientation of the magnetization of the magnetization free layer changes; and the relative angle between the orientation of the magnetization of the magnetization free layer and the orientation of the magnetization of the reference layer changes. In other words, the MR effect occurs due to the inverse-magnetostriction effect.

In the case where the ferromagnetic material of the magnetization free layer has a positive magnetostriction constant, the direction of the magnetization changes such that the angle between the direction of the magnetization and the direction of the tensile strain becomes small and the angle between the direction of the magnetization and the direction of the compressive strain becomes large. In the case where the ferromagnetic material of the magnetization free layer has a negative magnetostriction constant, the direction of the magnetization changes such that the angle between the direction of the magnetization and the direction of the tensile strain becomes large and the angle between the direction of the magnetization and the direction of the compressive strain becomes small.

An example of the change of the magnetization will now be described for the case where the ferromagnetic material of the magnetization free layer has a positive magnetostriction constant.

FIG. **2**A to FIG. **2**I are schematic perspective views illustrating operations of the pressure sensor.

FIG. 2A to FIG. 2C illustrate states in which a "strain in the perpendicular direction" is applied to the sensing element **50**. The "strain in the perpendicular direction" is a strain that is anisotropic (hereinbelow, called anisotropic strain) in a direction perpendicular to the stacking direction (e.g., the direction from the second magnetic layer **20** toward the first magnetic layer **10**) and perpendicular to the direction of the magnetization of the magnetization fixed layer.

FIG. 2D to FIG. 2F illustrate states in which a "strain in the parallel direction" is applied to the sensing element **50**. The "strain in the parallel direction" is strain that is anisotropic (anisotropic strain) in a direction perpendicular to the stacking direction and parallel to the direction of the magnetization of the magnetization fixed layer.

FIG. 2G to FIG. 2I illustrate states in which an "isotropic strain" is applied to the sensing element **50**. The "isotropic strain" is an isotropic strain in a plane perpendicular to the stacking direction.

FIG. 2B, FIG. 2E, and FIG. 2H correspond to states in which the strain is not applied. FIG. 2A, FIG. 2D, and FIG. 2G correspond to states in which a tensile strain ts is applied. FIG. 2C, FIG. 2F, and FIG. 2I correspond to states in which a compressive strain cs is applied.

In the case where the tensile strain ts is applied as "strain in the perpendicular direction" as illustrated in FIG. 2A, the angle (the relative angle of the magnetizations) between the direction of a magnetization **10***m* of the magnetization free layer (the first magnetic layer **10**) and the direction of a magnetization **20***m* of the magnetization fixed layer (the second magnetic layer **20**) becomes smaller than that in the state in which the strain is not applied (the state of FIG. 2B). As a result, the electrical resistance of the sensing element **50** decreases.

In the case where the compressive strain cs is applied as "strain in the perpendicular direction" as illustrated in FIG. 2C, the relative angle of the magnetization becomes larger than that in the state in which the strain is not applied (the state of FIG. 2B). As a result, the electrical resistance increases.

In the case where the tensile strain ts is applied as "strain in the parallel direction" as illustrated in FIG. 2D, the relative angle of the magnetization becomes larger than that in the state in which the strain is not applied (the state of FIG. 2E). As a result, the electrical resistance of the sensing element **50** increases.

In the case where the compressive strain cs is applied as "strain in the parallel direction" as illustrated in FIG. 2F, the relative angle of the magnetization becomes smaller than that in the state in which the strain is not applied (the state of FIG. 2E). As a result, the electrical resistance of the sensing element **50** decreases.

Thus, the relationship of the increase or decrease of the relative angle of the magnetization with respect to the strain for the "strain in the parallel direction" is the reverse of the relationship for the strain in the perpendicular direction. The change of the electrical resistance with respect to the polarity of the strain has the reverse polarity between the "strain in the parallel direction" and the "strain in the perpendicular direction".

In the case where the "isotropic strain" is applied as illustrated in FIG. 2G to FIG. 2I, the direction of the magnetization **10***m* of the magnetization free layer does not change. Therefore, the electrical resistance does not change for the strain of the two polarities of the tensile strain is and the compressive strain cs.

Thus, in the sensing element **50**, the change of the electrical resistance that is obtained is different according to the orientation of the strain that is applied.

In the pressure sensor **110** according to the embodiment, the planar configuration of the film part **70***d* is an anisotropic configuration. For example, the length (the first length L1) of the film part **70***d* along a first axis **70***x* (an axis in the film surface **70***fs*) passing through the centroid **70***dc* of the film surface **70***fs* is longer than the length (the second length L2) of the film part **70***d* along a second axis **70***y* orthogonal to the first axis **70***x* and passing through the centroid **70***dc* of the film surface **70***fs*. The sensing unit **50***u* is disposed in the central portion **70***c* (proximal to the centroid **70***dc*). For example, the multiple sensing elements **50** are provided together proximally to the centroid **70***dc* of the film surface **70***fs*.

FIG. 3A to FIG. 3C are schematic views illustrating the operation of the pressure sensor according to the first embodiment.

FIG. 3A is a schematic perspective view of the film part **70***d* of the pressure sensor **110** according to the embodiment. FIG. 3B is a cross-sectional view along line A1-A2 of FIG. 3A. FIG. 3C is a cross-sectional view along line B1-B2 of FIG. 3A. FIG. 3B and FIG. 3C illustrate the state in which the pressure is applied to the film part **70***d* and the film part **70***d* deforms and deflects.

As shown in FIG. 3A, the planar configuration of the film part **70***d* is, for example, an anisotropic configuration such as a rectangle, etc. The dotted lines in FIG. 3B and FIG. 3C schematically illustrate the state of the film part **70***d* when the pressure is not applied. For example, the film part **70***d* is parallel to the X-Y plane when the pressure is not applied. The solid lines in FIG. 3B and FIG. 3C schematically illustrate the state of the film part **70***d* when pressure Fz is applied to the film part **70***d*. As illustrated in these drawings, the film part **70***d* deflects when the pressure Fz is applied to one surface of the film part **70***d*. At this time, the strain occurring in the surface of the film part **70***d* is different between the major-axis direction and the minor-axis direction. The strain occurring in the minor-axis direction is larger than the strain occurring in the major-axis direction. This is because the curvature radius in the minor-axis direction is smaller than the curvature radius in the major-axis direction for the surface of the film part **70***d* that is deformed.

Thus, in the case where the planar configuration of the film part **70***d* is the anisotropic configuration, the strain occurring in the film part **70***d* is different between the major-axis direction (the first direction) and the minor-axis direction (the second direction). Therefore, in the pressure sensor **110**, an anisotropic strain is obtained also in the central portion **70***c* (the vicinity of the centroid **70***dc*) of the film surface **70***fs*. In the embodiment, the anisotropic strain is obtained in a wide region on the film part **70***d*.

FIG. 4A to FIG. 4C are schematic views illustrating the operation of a pressure sensor of a reference example.

FIG. 4A is a schematic perspective view of the film part **70***d* of the pressure sensor **119** of the reference example. FIG. 4B is a cross-sectional view along line A1-A2 of FIG. 4A. FIG. 4C is a cross-sectional view along line B1-B2 of FIG. 4A. FIG. 4B and FIG. 4C illustrate the state in which the pressure is applied to the film part **70***d* and the film part **70***d* deforms and deflects.

In the pressure sensor **119** of the reference example as shown in FIG. 4A, the planar configuration of the film part **70***d* is isotropic, e.g., in the example, a circle. In such a case, as illustrated in FIG. 4B and FIG. 4C, the strain occurring in

the surface of the film part **70***d* is isotropic when the pressure Fz is applied and the film part **70***d* deforms. Accordingly, in the pressure sensor **119** of the reference example, the strain occurring in the surface is isotropic at the centroid **70***dc* vicinity of the film surface **70***fs*.

In other words, the region where the anisotropic strain occurs on the film part **70***d* is wider for the film part **70***d* (the pressure sensor **110**) having the anisotropic configuration than for the film part **70***d* (the pressure sensor **119**) having the isotropic configuration.

The sensing element **50** is disposed on the film part **70***d*. When the film part **70***d* deflects due to the external pressure, the strain is applied to the sensing element **50**; and as a result, in the sensing element **50**, the external pressure is sensed as the change of the electrical resistance. As described above, in the sensing element **50**, the change of the electrical resistance with respect to the strain is different according to the direction of the strain applied to the sensing element **50**. By providing the sensing element **50** on the film part **70***d* having the anisotropic configuration, the surface area of the region where the anisotropic strain is applied to the sensing element **50** can be increased. For example, the anisotropic strain can be large by using the film part **70***d* having the anisotropic configuration. Further, the degrees of freedom of the disposition of the sensing element **50** increase because the surface area of the region of the film part **70***d* where the anisotropic strain is applied can be increased. Further, because the surface area can be increased, the number of the sensing elements **50** that can be disposed in the region can be increased. For example, the number of the sensing elements having a similar change of electrical resistance (e.g., having the same polarity) due to the pressure can be increased. According to the embodiment, the sensing sensitivity of the pressure can be increased.

FIG. **5**A to FIG. **5**F are schematic views illustrating the configuration and characteristics of the pressure sensor according to the first embodiment.

These drawings illustrate simulation results of characteristics of the pressure sensor **110**. FIG. **5**A is a schematic perspective view of the film part **70***d*. FIG. **5**B and FIG. **5**C illustrate the deflection amount uz of the film part **70***d* when the pressure is applied to the film part **70***d*. In FIG. **5**B and FIG. **5**C, the vertical axis is the deflection amount uz (μm). The horizontal axis of FIG. **5**B is a position dx (μm) in the X-axis direction. The horizontal axis of FIG. **5**C is a position dy (μm) in the Y-axis direction. The references of the position dx and the position dy are the centroid **70***dc* of the film surface **70***fs*.

FIG. **5**D and FIG. **5**E illustrate strain ε occurring in the film part **70***d* to which the pressure is applied. In FIG. **5**D and FIG. **5**E, the vertical axis is the strain ε (no units). The horizontal axis of FIG. **5**D is the position dx; and the horizontal axis of FIG. **5**E is the position dy. In these drawings, the strain ε is positive for tensile strain; and the strain ε is negative for compressive strain. These drawings show a first strain εx which is the strain in the X-axis direction, a second strain εy which is the strain in the Y-axis direction, and the difference (an anisotropic strain Δε) between the first strain εx and the second strain εy. The anisotropic strain Δε is the difference (i.e., εx−εy) between the first strain εx and the second strain εy. The anisotropic strain Δε contributes to the change of the direction of the magnetization of the magnetization free layer of the sensing element **50**.

FIG. **5**F illustrates the distribution in the X-Y plane of the anisotropic strain Δε occurring in the film part **70***d*.

In the example as shown in FIG. **5**A, the planar configuration of the film part **70***d* is a rectangle. The sensing elements **50** (not-shown in the drawing) are disposed at the centroid **70***dc* vicinity of the film surface **70***fs*. In the example, the length (the first length L1) of the long side of the film part **70***d* is 625 μm. The length (the second length L2) of the short side is 400 μm. A thickness Lt of the film part **70***d* is 2 μm.

In the example, the outer edge **70***r* of the film part **70***d* is set to be a fixed end that is completely constrained. In the example, analysis of the strain occurring in the front surface of the film part **70***d* is performed by finite element analysis. The analysis is performed by applying Hooke's law to each of the components subdivided by the finite element method.

In the simulation, the material of the film part **70***d* is assumed to be silicon. The Young's modulus of the film part **70***d* is 165 GPa; and the Poisson's ratio of the film part **70***d* is 0.22. The simulation determines the strain ε of the front surface of the film part **70***d* when a uniform pressure of 13.33 kPa is applied from the back surface of the film part **70***d*. In the finite element method, the planar mesh size in the X-Y plane is 5 μm; and the mesh size in the thickness direction is 2 μm.

In the major-axis direction and the minor-axis direction as shown in FIG. **5**B and FIG. **5**C, the film part **70***d* at the centroid **70***dc* vicinity of the film surface **70***fs* has a convex configuration (an upward protrusion). At the outer edge **70***r* vicinity of the film part **70***d*, the film part **70***d* has a concave configuration (a downward protrusion). The concave configuration at the outer edge **70***r* vicinity is due to the warp at the fixed end vicinity. Tensile strain occurs in the front surface of the film part **70***d* (the diaphragm) in the region where the film part **70***d* is warped in the convex configuration. Conversely, compressive strain occurs in the front surface of the film part **70***d* in the region where the warped is in the concave configuration.

As shown in FIG. **5**D and FIG. **5**E, the first strain εx and the second strain εy are tensile strains at the centroid **70***dc* where the warp is in the convex configuration. The first strain εx and the second strain εy are compressive strains at the outer edge **70***r* vicinity where the warp is in the concave configuration. The anisotropic strain Δε at the centroid **70***dc* is in compression; and compressive strain in the major-axis direction (the X-axis direction) exists. In other words, tensile anisotropic strain exists in the minor-axis direction (the Y-axis direction). Anisotropic strain that is similar to the anisotropic strain obtained at the centroid **70***dc* exists in a wide area from the centroid **70***dc* to the outer edge **70***r* of the film surface **70***fs*.

FIG. **5**F illustrates the results of the analysis of the anisotropic strain Δε shown in FIG. **5**D and FIG. **5**E for the entire surface of the film part **70***d*. In the contour diagram shown in FIG. **5**F, the lines labeled with the characters "10%" to "90%" respectively illustrate the positions where the anisotropic strain Δε is 10% to 90% of the value (the absolute value) of the anisotropic strain Δε at the centroid **70***dc*. It can be seen from FIG. **5**F that an anisotropic strain Δε that is equivalent to that of the centroid **70***dc* (not less than 70% of the value at the centroid **70***dc*) can be obtained in a wide region at the centroid **70***dc* vicinity by using the film part **70***d* having the anisotropic configuration. In the embodiment, the sensing element **50** (the multiple sensing elements **50**) can be disposed in the area where the equivalent anisotropic strain Δε is obtained. Thereby, a highly-sensitive pressure sensor is obtained.

An anisotropic strain occurrence region **70***a* is the region where the anisotropic strain is substantially 0.7 times (70%

of) the value of the maximum anisotropic strain $\Delta\varepsilon$ obtained in the film part **70**d. In the example shown in FIG. **5**D, the maximum anisotropic strain $\Delta\varepsilon$ is obtained at the centroid **70**dc. The anisotropic strain occurrence region **70**a is the region on the inner side of the line labeled with the characters "70%" illustrated in FIG. **5**F.

In the case where the planar configuration of the film part **70**d is a rectangle as shown in FIG. **5**F, the configuration of the anisotropic strain occurrence region **70**a also substantially is a rectangle. The anisotropic strain occurrence region **70**a is caused to correspond to the central portion **70**c of the embodiment.

It can be seen from FIG. **5**F that the centroid **70**dc of the film surface **70**fs substantially overlaps the centroid of the anisotropic strain occurrence region **70**a. For example, the distance between the centroid **70**dc of the film surface **70**fs and the centroid of the anisotropic strain occurrence region **70**a is, for example, not more than 1/10 of the second length L2.

Then, for example, the length of the anisotropic strain occurrence region **70**a in the X-axis direction (corresponding to the third length L3 of the central portion **70**c in the first direction) is not more than 0.3 times the first length L1. The length of the anisotropic strain occurrence region **70**a in the Y-axis direction (corresponding to the fourth length L4 of the central portion **70**c in the second direction) is not more than 0.3 times the second length L2.

In the embodiment, the sensing element **50** is disposed in such an anisotropic strain occurrence region **70**a. For example, the centroid of the sensing element **50** overlaps the anisotropic strain occurrence region **70**a when the sensing element **50** is projected onto the X-Y plane. In the case where multiple sensing elements **50** are provided, the centroids of the multiple sensing elements **50** overlap the anisotropic strain occurrence region **70**a when projected onto the X-Y plane. Thereby, a highly-sensitive pressure sensor can be provided.

FIG. **6**A to FIG. **6**D are schematic views illustrating the configuration and characteristics of a pressure sensor of a reference example.

These drawings illustrate simulation results of characteristics of the pressure sensor **119**a of the reference example. In the pressure sensor **119**a, the first length L1 of the film part **70**d is 500 μm; and the second length L2 also is 500 μm. In other words, the planar configuration of the film part **70**d is a square. Otherwise, the pressure sensor **119**a is similar to the pressure sensor **110**. The conditions of the simulation also are similar to those of the pressure sensor **110**.

FIG. **6**A is a schematic perspective view of the film part **70**d. In FIG. **6**B, the vertical axis is the deflection amount uz; and the horizontal axis is the position dx (μm). In FIG. **6**C, the vertical axis is the strain ε (no units); and the horizontal axis is the position dx. In the example, the planar configuration of the film part **70**d is a square; and the characteristics in the Y-axis direction are the same as the characteristics in the X-axis direction. FIG. **6**D shows the anisotropic strain $\Delta\varepsilon$. In the example, there are no contours illustrated in the contour diagram of FIG. **6**D because anisotropic strain is not obtained at the centroid **70**dc vicinity.

As shown in FIG. **6**B, the film part **70**d has a convex configuration at the centroid **70**dc vicinity of the film surface **70**fs; and the film part **70**d has a concave configuration at the outer edge **70**r vicinity.

As shown in FIG. **6**C, the first strain εx and the second strain εy are tensile strains at the centroid **70**dc where the warp is in the convex configuration and compressive strains at the outer edge **70**r vicinity where the warp is in the concave configuration. The anisotropic strain $\Delta\varepsilon$ at the centroid **70**dc is zero. This is because the square film part **70**d is isotropic in the X-Y plane.

Therefore, as shown in FIG. **6**D, the region where the anisotropic strain is obtained does not exist at the centroid **70**dc vicinity. Accordingly, in the pressure sensor **119**a, the change of the electrical resistance cannot be obtained even in the case where the sensing element **50** is disposed at the centroid **70**dc vicinity of the film surface **70**fs.

As described above, the anisotropic strain cannot be obtained at the centroid **70**dc vicinity in the square film part **70**d (the pressure sensor **119**a) that is isotropic in the X-Y plane. Conversely, the anisotropic strain $\Delta\varepsilon$ can be obtained in a wide region at the centroid **70**dc vicinity in the rectangular film part **70**d (the pressure sensor **110**) having the anisotropic configuration in the X-Y plane. Thus, the configuration to obtain the anisotropic strain in a large surface area of the central portion **70**c including the centroid **70**dc was discovered. In the embodiment, the film part **70**d having the anisotropic configuration is used. Then, stress can be sensed with high sensitivity by disposing the sensing element **50** in the central portion **70**c of the film part **70**d.

For example, similar anisotropic strains are applied to the multiple sensing elements **50** by disposing the multiple sensing elements **50** at the centroid **70**dc vicinity of the rectangular film part **70**d having the anisotropic configuration. Therefore, multiple sensing elements **50** having a similar change of electrical resistance (e.g., having the same polarity) due to the pressure can be obtained. For example, the S/N ratio can be increased by connecting the sensing elements **50** electrically in series. Further, a highly-sensitive pressure sensor can be provided by setting the bias voltage to be an appropriate value.

An example of the characteristics of the pressure sensor will now be described in more detail.

FIG. **7** is a schematic plan view illustrating the pressure sensor.

FIG. **7** illustrates a coordinate system of the film part **70**d of the pressure sensor **110**. In the example, the planar configuration of the film part **70**d is a rectangle. In other words, the first length L1 (the length in the X-axis direction) is longer than the second length L2 (the length in the Y-axis direction). The coordinates (x, y) of the centroid of the film surface **70**fs are taken to be (0, 0). The coordinates of one point of the outer edge **70**r of the film part **70**d in the X-axis direction are (L1/2, 0). The coordinates of one point of the outer edge **70**r of the film part **70**d in the Y-axis direction are (0, L2/2).

In the case where the planar configuration of the film part **70**d is a rectangle, the planar configuration of the anisotropic strain occurrence region **70**a also is a rectangle. The length in the first direction (the length in the X-axis direction) of the anisotropic strain occurrence region **70**a is a length L3a; and the length in the second direction (the length in the Y-axis direction) of the anisotropic strain occurrence region **70**a is a length L4a. The coordinates of one point PXa in the X-axis direction of the outer edge of the anisotropic strain occurrence region **70**a are (L3a/2, 0). The coordinates of one point PYa in the Y-axis direction of the outer edge of the anisotropic strain occurrence region **70**a are (0, L4a/2).

An example of the characteristics for different aspect ratios AR of the film part **70**d for the case where the planar configuration of the film part **70**d is such a rectangle will now be described. The aspect ratio AR is the ratio of the second length L2 to the first length L1 (i.e., AR=L2/L1).

FIG. **8**A to FIG. **8**D are graphs illustrating characteristics of the pressure sensors.

These drawings show the characteristics for the pressure sensors having the first to sixth configurations recited below.

In the first configuration, the first length L1 is 2500 μm; the second length L2 is 100 μm; and the aspect ratio AR is 0.04.

In the second configuration, the first length L1 is 1580 μm; the second length L2 is 158 μm; and the aspect ratio AR is 0.1.

In the third configuration, the first length L1 is 1000 μm; the second length L2 is 250 μm; and the aspect ratio AR is 0.25.

In the fourth configuration, the first length L1 is 625 μm; the second length L2 is 400 μm; and the aspect ratio AR is 0.64. The fourth configuration corresponds to the configuration described in regard to FIG. **5**A to FIG. **5**F.

In the fifth configuration, the first length L1 is 560 μm; the second length L2 is 448 μm; and the aspect ratio AR is 0.8.

In the sixth configuration, the first length L1 is 500 μm; the second length L2 is 500 μm; and the aspect ratio AR is 1. The sixth configuration corresponds to the configuration described in regard to FIG. **6**A to FIG. **6**D.

The surface area of the film part **70***d* is constant at 250,000 μm^2 for each of these configurations.

For these configurations, analysis of the strain occurring in the front surface of the film part **70***d* is performed by finite element analysis. The conditions of the finite element method are the same as the conditions described in regard to FIG. **5**A to FIG. **5**F.

The vertical axis of FIG. **8**A is an anisotropic strain $\Delta\varepsilon 0$ (the absolute value of the anisotropic strain) at the centroid **70***dc* of the film surface **70***fs*. The horizontal axis is the aspect ratio AR of the planar configuration of the film part **70***d* (the configuration of the film surface **70***fs*). FIG. **8**A shows the characteristics of the first to sixth configurations.

As shown in FIG. **8**A, for the sixth configuration for which the aspect ratio AR is 1, the anisotropic strain $\Delta\varepsilon 0$ at the centroid **70***dc* is zero; and the anisotropic strain does not occur.

Conversely, for the first to fifth configurations for which the aspect ratio AR is less than 1, the absolute value of the anisotropic strain $\Delta\varepsilon 0$ is greater than 0. In other words, the anisotropic strain is obtained at the centroid **70***dc*. From this result, it can be seen that a highly-sensitive pressure sensor is obtained by providing the sensing element **50** at the centroid **70***dc* vicinity in the case where the aspect ratio AR is less than 1 and the film part **70***d* has an anisotropic configuration.

It can be seen from FIG. **8**A that the anisotropic strain $\Delta\varepsilon 0$ having a large absolute value is obtained when the aspect ratio AR is not less than 0.1 and not more than 0.8. The anisotropic strain $\Delta\varepsilon 0$ having an even larger absolute value is obtained when the aspect ratio AR is not less than 0.25 and not more than 0.64. From the aspect of obtaining the anisotropic strain $\Delta\varepsilon 0$ having a large absolute value at the centroid **70***dc*, it is favorable for the aspect ratio AR to be not less than 0.1 and not more than 0.8, and more favorable to be not less than 0.25 and not more than 0.64.

In the first to fifth configurations as well, it was found that the configuration of the region (the anisotropic strain occurrence region **70***a*) where the anisotropic strain is equivalent to the centroid **70***dc* is a rectangle similarly to the description regarding FIG. **5**D.

The ratio of the surface area of the anisotropic strain occurrence region **70***a* to the surface area of the film part **70***d* is a surface area ratio Ra. In the example, the surface area of the anisotropic strain occurrence region **70***a* is the product of the length L3a and the length L4a. The surface area of the film part **70***d* is the product of the first length L1 and the second length L2.

In FIG. **8**B, the vertical axis is the surface area ratio Ra; and the horizontal axis is the aspect ratio AR.

It can be seen from FIG. **8**B that for the square film part **70***d* (the sixth configuration) for which the aspect ratio is 1, the surface area ratio Ra is zero; and there is no region at the centroid **70***dc* vicinity where the anisotropic strain is obtained. Conversely, for the rectangular film parts **70***d* for which the aspect ratio AR is less than 1, the surface area ratio Ra is greater than zero. In other words, a region exists at the centroid **70***dc* vicinity where the anisotropic strain is obtained. The surface area ratio Ra increases as the aspect ratio AR decreases (the difference between the first length L1 and the second length L2 increases). From the aspect of widening the region on the film part **70***d* where the anisotropic strain is obtained, it is favorable for the aspect ratio AR to be not more than 0.64, and more favorable to be not more than 0.25.

The position of the outer edge of the anisotropic strain occurrence region **70***a* (the coordinates referring to FIG. **7**) will now be described.

The vertical axis of FIG. **8**C is the normalized coordinate (a distance Xa) of the one point PXa of the outer edge of the anisotropic strain occurrence region **70***a* in the X-axis direction. The distance Xa corresponds to (L3a)/(L1).

The vertical axis of FIG. **8**D is the normalized coordinate (a distance Ya) of the one point PYa of the outer edge of the anisotropic strain occurrence region **70***a* in the Y-axis direction. The distance Ya corresponds to (L4a)/(L2).

In these drawings, the horizontal axis is the aspect ratio AR.

When the aspect ratio AR is 1 (the sixth configuration), the anisotropic strain occurrence region **70***a* does not exist. The distance Xa and the distance Ya are zero for this case for convenience in FIG. **8**C and FIG. **8**D.

In the case where the aspect ratio AR is less than 1 as shown in FIG. **8**C and FIG. **8**D, the distance Xa and the distance Ya are larger than zero; and the anisotropic strain occurrence region **70***a* is obtained.

It can be seen from these drawings that in the case where the aspect ratio AR is not less than 0.8 but less than 1, it is favorable to have the ranges

$$|Xa| \leq (L1/2) \times \{-0.8 \times (L2/L1) + 0.8\}, \text{ and}$$

$$|Ya| \leq (L2/2) \times \{-2.5 \times (L2/L1) + 2.5\}.$$

On the other hand, in the case where the aspect ratio AR is less than 0.8, it is favorable to have the ranges

$$|Xa| \leq (L1/2) \times \{-0.8 \times (L2/L1) + 0.8\}, \text{ and}$$

$$|Ya| \leq (L2/2) \times \{0.375 \times (L2/L1) + 0.2\}.$$

Namely, a first hatching region R1 that is illustrated by the light hatching in FIG. **8**C corresponds to the conditions of the anisotropic strain occurrence region **70***a*. The first hatching region R1 is represented by first formula recited below.

$$Xa \leq -0.8\text{AR} + 0.8 \quad (1)$$

Because the distance Xa is L3a/L1 and AR is L2/L1, the second formula recited below is obtained.

$$L3a \leq L1\{-0.8 \times (L2/L1) + 0.8\} \quad (2)$$

On the other hand, in FIG. **8**D, a second hatching region R2 that is illustrated by the light hatching or a third hatching region R3 that is illustrated by the dark hatching corresponds

to the conditions of the anisotropic strain occurrence region **70***a*. The second hatching region R2 is represented by third formula recited below.

$$Ya \leq 0.375\text{AR}+0.2 \tag{3}$$

Because the distance Ya is L4a/L2 and AR is L2/L1, the fourth formula recited below is obtained.

$$L4a \leq L2\{0.375\text{AR}+0.2\} \tag{4}$$

The third hatching region R3 is represented by fifth formula recited below.

$$Ya \leq -2.5\text{AR}+2.5 \tag{5}$$

Accordingly, the sixth formula recited below is obtained.

$$L4a \leq L2\{-2.5\text{AR}+2.5\} \tag{6}$$

In other words, in the case where the aspect ratio AR is not less than 0.8 but less than 1, the conditions of the first formula, the second formula, the fifth formula, and the sixth formula are favorable.

On the other hand, in the case where the aspect ratio AR is less than 0.8, the conditions of the first formula, the second formula, the third formula, and the fourth formula are favorable.

In the embodiment, for example, the central portion **70***c* is set to correspond to the anisotropic strain occurrence region **70***a*. In other words, the third length L3 of the central portion **70***c* is set to correspond to the length L3a of the anisotropic strain occurrence region **70***a*; and the fourth length L4 of the central portion **70***c* is set to correspond to the length L4a of the anisotropic strain occurrence region **70***a*. The outer edge **70***r* of the central portion **70***c* is set to be the outer edge of the anisotropic strain occurrence region **70***a*.

Accordingly, in the case where the aspect ratio AR (L2/L1) is not less than 0.8 but less than 1, the central portion **70***c* is set to satisfy the seventh formula recited below.

$$L3=L1\times\{-0.8\times(L2/L1)+0.8\} \tag{7}$$

In such a case, the third length L3 may be set to be substantially equal to the right side of the seventh formula. In other words, the third length L3 is set to be not less than 0.8 times and not more than 1.2 times the right side of the seventh formula.

In other words, in the case where the aspect ratio AR (L2/L1) is not less than 0.8 but less than 1, it is favorable for the third length L3 to be not less than 0.8 times and not more than 1.2 times L1×{−0.8×(L2/L1)+0.8}.

Similarly, in the case where the aspect ratio AR (L2/L1) is not less than 0.8 but less than 1, the central portion **70***c* is set to satisfy the eighth formula recited below.

$$L4=L2\times\{-2.5\times(L2/L1)+2.5\} \tag{8}$$

In such a case as well, the fourth length L4 may be set to be substantially equal to the right side of the eighth formula. In other words, the fourth length L4 is set to be not less than 0.8 times and not more than 1.2 times the right side of the eighth formula.

In other words, in the case where the aspect ratio AR (L2/L1) is not less than 0.8 but less than 1, it is favorable for the fourth length L4 to be not less than 0.8 times and not more than 1.2 times L2×{−2.5×(L2/L1)+2.5}.

On the other hand, in the case where the aspect ratio AR (L2/L1) is less than 0.8, the ninth formula and the tenth formula recited below are obtained.

$$L3=L1\times\{-0.8\times(L2/L1)+0.8\} \tag{9}$$

$$L4=L2\times\{0.375\times(L2/L1)+0.2\} \tag{10}$$

Accordingly, in the case where the aspect ratio AR (L2/L1) is less than 0.8, it is favorable for the third length to be not less than 0.8 times and not more than 1.2 times L1×{−0.8×(L2/L1)+0.8}. Also, it is favorable for the fourth length L4 to be not less than 0.8 times and not more than 1.2 times L2×{0.375×(L2/L1)+0.2}.

By satisfying such conditions, a larger anisotropic strain is obtained; and a highly-sensitive pressure sensor is obtained more reliably.

Even when the thickness Lt of the film part **70***d* is changed in the case where the planar configuration of the film part **70***d* is a rectangle, the characteristics of the anisotropic strain occurrence region **70***a* are similar to the characteristics described in regard to FIG. **8**A to FIG. **8**D. For example, at least in the case where the thickness Lt of the film part **70***d* is not less than 0.01 μm and not more than 20 μm, it is favorable for the settings to substantially satisfy the seventh to tenth formulas. In the embodiments described below as well, similar results are obtained in the case where the thickness Lt of the film part **70***d* is changed.

An example of the characteristics for different materials of the film part **70***d* in the case where the planar configuration of the film part **70***d* is a rectangle will now be described. The Young's modulus is different for different materials. In the example, the characteristics are simulated by changing the Young's modulus of the film part **70***d*.

FIG. **9**A and FIG. **9**B are graphs illustrating characteristics of the pressure sensor. In the contour diagram of FIG. **9**A and FIG. **9**B, the lines labeled with the characters of "10%" to "90%" respectively illustrate the positions where the anisotropic strain Δε is 10% to 90% of the value (the absolute value) of the anisotropic strain Δε at the centroid **70***dc*. These illustrations also are similar for the contour diagrams described below.

FIG. **9**A illustrates the results calculated for the anisotropic strain occurrence region **70***a* for the case where the Young's modulus of the film part **70***d* is 0.01 GPa. The value of the Young's modulus corresponds to the case where the material of the film part **70***d* is rubber. FIG. **9**B illustrates the results calculated for the anisotropic strain occurrence region **70***a* for the case where the Young's modulus of the film part **70***d* is 1200 GPa. The value corresponds to the case where the material of the film part **70***d* is diamond. Other than the Young's modulus, the calculation conditions are similar to the conditions of the results of FIG. **5**A to FIG. **5**F.

Even in the case of the calculation using the Young's modulus of 0.01 GPa or 1200 GPa as shown in FIG. **9**A and FIG. **9**B, it can be seen that the calculation results for the anisotropic strain occurrence region **70***a* of the film part **70***d* are equivalent to the calculation results for 165 GPa shown in FIG. **5**F.

Thus, even in the case where the material of the film part **70***d* is changed, the characteristics of the anisotropic strain occurrence region **70***a* are similar to the characteristics described in regard to FIG. **8**A to FIG. **8**D. Accordingly, at least in the case where the Young's modulus of the film part **70***d* is not less than 0.01 GPa and not more than 1200 GPa, it is favorable for the settings to substantially satisfy the seventh to tenth formulas.

As described above, FIG. **9**A and FIG. **9**B show examples in which the film parts **70***d* have different Young's moduli. In the case where the film parts **70***d* have different Poisson's ratios as well, similar anisotropic strain occurrence regions **70***a* can be obtained. In the embodiments described below as well, a similar anisotropic strain occurrence region **70***a* can

be obtained even in the case where at least one selected from the Young's modulus and the Poisson's ratio of the film part **70***d* is changed.

In the embodiment, the planar configuration of the film part **70***d* is not limited to a rectangle if the planar configuration of the film part **70***d* is an anisotropic configuration; and various modifications are possible. An example of the case where the planar configuration of the film part **70***d* is a flattened circle (e.g., an ellipse) will now be described.

FIG. **10**A to FIG. **10**D are schematic views illustrating the configuration and characteristics of another pressure sensor according to the first embodiment.

These drawings illustrate simulation results of characteristics of the pressure sensor **111** according to the embodiment. FIG. **10**A is a schematic perspective view of the film part **70***d*. FIG. **10**B and FIG. **10**C illustrate the strain ε occurring in the film part **70***d* to which the pressure is applied. In FIG. **10**B and FIG. **10**C, the vertical axis is the strain ε. The horizontal axis of FIG. **10**B is the position dx; and the horizontal axis of FIG. **10**C is the position dy. FIG. **10**D illustrates the distribution in the X-Y plane of the anisotropic strain $\Delta\varepsilon$ occurring in the film part **70***d*.

As shown in FIG. **10**A, the planar configuration of the film part **70***d* (the configuration of the film surface **70***fs*) is a flattened circle (also including an ellipse). In other words, the configuration of the film part **70***d* projected onto the X-Y plane is a flattened circle having the first direction (in the example, the X-axis direction) as the major axis and the second direction (in the example, the Y-axis direction) as the minor axis. The configuration of the film surface **70***fs* is a flattened circle having the first direction as the major axis and the second direction as the minor axis.

In the example, the sensing element **50** (not-shown in the drawing) is disposed at the centroid **70***dc* vicinity of the film surface **70***fs* which is the ellipse. In the example, the length (the first length L1) of the major axis of the film part **70***d* is 704 μm; and the length (the second length L2) of the minor axis is 452 μm. The thickness Lt of the film part **70***d* is 2 μm. The conditions of the simulation are the same as the conditions described above.

In the pressure sensor **111** as well, the film part **70***d* has a convex configuration at the centroid **70***dc* vicinity of the film surface **70***fs* in the major-axis direction and the minor-axis direction. The outer edge **70***r* vicinity has a concave configuration due to the warp at the fixed end vicinity. Tensile strain occurs in the front surface of the film part **70***d* in the region of the warp in the convex configuration; and compressive strain occurs in the front surface of the film part **70***d* in the region of the warp in the concave configuration.

In such a case as well, it can be seen from FIG. **10**B and FIG. **10**C that the first strain εx and the second strain εy are tensile strains at the centroid **70***dc* where the warp is in the convex configuration. The anisotropic strain $\Delta\varepsilon$ is a compressive strain at the centroid **70***dc*. A compressive strain in the major-axis direction (the X-axis direction) exists at the centroid **70***dc*. In other words, a tensile anisotropic strain exists in the minor-axis direction (the Y-axis direction). In such a case as well, an anisotropic strain that is similar to the anisotropic strain obtained at the centroid **70***dc* exists in a wide area from the centroid **70***dc* to the outer edge **70***r*.

FIG. **10**D shows the anisotropic strain occurrence region **70***a*. As described above, the anisotropic strain occurrence region **70***a* is the region where the anisotropic strain is 0.7 times the value (the absolute value) of the maximum anisotropic strain $\Delta\varepsilon$ obtained in the film part **70***d* (the anisotropic strain $\Delta\varepsilon 0$ at the centroid **70***dc*). As shown in FIG. **10**D, an anisotropic strain $\Delta\varepsilon$ that is equivalent to that at the centroid **70***dc* can be obtained in a wide area (the anisotropic strain occurrence region **70***a*) at the centroid **70***dc* vicinity by using the film part **70***d* having the anisotropic configuration. The sensing element **50** (the multiple sensing elements **50**) is disposed in the anisotropic strain occurrence region **70***a*. Thereby, a highly-sensitive pressure sensor is obtained.

The aspect ratio AR of the pressure sensor **111** illustrated in FIG. **10**A is the same as the aspect ratio AR of the pressure sensor **110** illustrated in FIG. **5**A. Comparing these pressure sensors, the surface area of the anisotropic strain occurrence region **70***a* is greater for the pressure sensor **111** (the elliptical film part **70***d*) than for the pressure sensor **110** (the rectangular film part **70***d*).

In the case where the planar configuration of the film part **70***d* is a flattened circle (including an ellipse) as shown in FIG. **10**D, the configuration of the anisotropic strain occurrence region **70***a* also is a flattened circle (or substantially a circle). In such a case as well, the anisotropic strain occurrence region **70***a* is set to correspond to the central portion **70***c* of the embodiment.

In such a case as well, the centroid **70***dc* of the film surface **70***fs* substantially overlaps the centroid of the anisotropic strain occurrence region **70***a*. For example, the distance between the centroid **70***dc* of the film surface **70***fs* and the centroid of the anisotropic strain occurrence region **70***a* is, for example, not more than 1/10 of the second length L2.

In such a case as well, for example, the length of the anisotropic strain occurrence region **70***a* in the X-axis direction (corresponding to the third length L3 of the central portion **70***c* in the first direction) is not more than 0.3 times the first length L1. The length of the anisotropic strain occurrence region **70***a* in the Y-axis direction (corresponding to the fourth length L4 of the central portion **70***c* in the second direction) is not more than 0.3 times the second length L2.

Even in the case where the planar configuration of the film part **70***d* is a flattened circle, the pressure can be sensed with high sensitivity by disposing the sensing element **50** in such an anisotropic strain occurrence region **70***a*.

FIG. **11**A to FIG. **11**C are schematic views illustrating the configuration and characteristics of a pressure sensor of a reference example.

These drawings illustrate simulation results of characteristics of the pressure sensor **119***b* of the reference example. In the pressure sensor **119***b*, the planar configuration of the film part **70***d* is a circle; and the first length L1 and the second length L2 are 564 μm. Otherwise, the pressure sensor **119***b* of the reference example is similar to the pressure sensor **111**. The conditions of the simulation also are similar to those of the pressure sensor **111**. The surface area of the film part **70***d* of the pressure sensor **119***b* is the same as the surface area of the film part **70***d* of the pressure sensor **111**. In the example, a strain εr in the radial direction and a strain $\varepsilon\theta$ in the circumferential direction of the film part are determined. The anisotropic strain $\Delta\varepsilon$ is $\varepsilon r-\varepsilon\theta$.

It can be seen from FIG. **11**B that the anisotropic strain $\Delta\varepsilon$ at the centroid **70***dc* is zero. This is because the circular film part **70***d* is isotropic in the X-Y plane.

There are no contours illustrated in the contour diagram of FIG. **11**C because the anisotropic strain $\Delta\varepsilon$ is not obtained at the centroid **70***dc* vicinity. In other words, the region at the centroid **70***dc* vicinity of the circle film surface **70***fs* where the anisotropic strain is obtained does not exist. Therefore, the change of the electrical resistance cannot be obtained even in the case where the sensing element **50** is disposed at the centroid **70***dc* vicinity.

Thus, the anisotropic strain can be applied to the sensing element **50** by disposing the sensing element **50** in a region (the central portion **70***c*) of the film surface **70***fs* including the centroid **70***dc* by using the film part **70***d* that is a flattened circle (e.g., an ellipse). Then, by providing multiple sensing elements **50** in this region, a similar change of electrical resistance (e.g., having the same polarity) due to the pressure occurs. The S/N ratio can be increased by, for example, connecting the multiple sensing elements **50** electrically in series. Further, a highly-sensitive pressure sensor is obtained by setting the bias voltage to be an appropriate value.

An example of the characteristics of the pressure sensor will now be described in more detail for the case where the planar configuration of the film part **70***d* is a flattened circle.

FIG. **12** is a schematic plan view illustrating the pressure sensor.

FIG. **12** illustrates the coordinate system of the film part **70***d* of the pressure sensor **111**. In the example, the planar configuration of the film part **70***d* is an ellipse. In such a case as well, the coordinates of the outer edge of the film part **70***d* and the outer edge of the anisotropic strain occurrence region **70***a* can be defined similarly to those of the description regarding FIG. **7**. The aspect ratio AR of the film part **70***d* also can be defined similarly.

An example of the characteristics of pressure sensors having seventh to twelfth configurations such as those recited below will now be described for the case where the planar configuration of the film part **70***d* is an ellipse.

In the seventh configuration, the first length L1 (the length of the major axis) is 2820 μm; the second length L2 (the length of the minor axis) is 112 μm; and the aspect ratio AR is 0.04.

In the eighth configuration, the first length L1 is 1784 μm; the second length L2 is 178 μm; and the aspect ratio AR is 0.1.

In the ninth configuration, the first length L1 is 1000 μm; the second length L2 is 250 μm; and the aspect ratio AR is 0.25.

In the tenth configuration, the first length L1 is 704 μm; the second length L2 is 452 μm; and the aspect ratio AR is 0.64. The tenth configuration corresponds to the configuration described in regard to FIG. **10**A to FIG. **10**D.

In the eleventh configuration, the first length L1 is 630 μm; the second length L2 is 504 μm; and the aspect ratio AR is 0.8.

In the twelfth configuration, the first length L1 is 564 μm; the second length L2 also is 564 μm; and the aspect ratio AR is 1. The twelfth configuration corresponds to the configuration described in regard to FIG. **11**A to FIG. **11**C.

The surface area of the film part **70***d* is constant at 250,000 μm^2 for each of these configurations.

Results of the simulation of the characteristics for the seventh to twelfth configurations having different aspect ratios AR using conditions (conditions such as the thickness of the film part **70***d*, material parameters, the mesh subdivision, etc.) similar to those recited above are as follows.

For the twelfth configuration for which the aspect ratio AR is 1, the anisotropic strain does not occur at the centroid **70***dc*. Conversely, for the seventh to eleventh configurations for which the aspect ratio AR is less than 1, the anisotropic strain is obtained at the centroid **70***dc*. A highly-sensitive pressure sensor is obtained by providing the sensing element **50** at the centroid **70***dc* vicinity of the film part **70***d* having the anisotropic configuration.

The aspect ratio AR dependence of the strain for the case where the planar configuration of the film part **70***d* is a flattened circle is similar to that of the case where the planar configuration is a rectangle. Thereby, from the aspect of increasing the value (the absolute value) of the anisotropic strain at the centroid **70***dc*, it is favorable for the aspect ratio AR of the film part **70***d* to be not less than 0.1 and not more than 0.8, and more favorable to be not less than 0.25 and not more than 0.64.

By examining the anisotropic strain occurrence region **70***a* for the film part **70***d* having an elliptical configuration of different aspect ratios AR, it was found that the characteristics are similar to the characteristics of the film part **70***d* having a rectangular configuration.

For example, the ratio (the surface area ratio Ra) of the surface area of the anisotropic strain occurrence region **70***a* to the surface area of the film part **70***d* increases as the aspect ratio decreases (the difference between the first length L1 and the second length L2 increases). Thereby, from the aspect of increasing the surface area of the anisotropic strain occurrence region **70***a*, it is favorable for the aspect ratio AR to be not more than 0.64, and more favorable to be not more than 0.25.

Even in the case where the planar configuration of the film part **70***d* is a flattened circle, in the case where the aspect ratio AR (L2/L1) is not less than 0.8 but less than 1, it is favorable for the settings to satisfy the seventh formula and the eighth formula recited above. Accordingly, even in the case where the planar configuration of the film part **70***d* is a flattened circle, in the case where the aspect ratio AR (L2/L1) is not less than 0.8 but less than 1, it is favorable for the third length L3 to be not less than 0.8 times and not more than 1.2 times $L1\times\{-0.8\times(L2/L1)+0.8\}$. Also, it is favorable for the fourth length L4 to be not less than 0.8 times and not more than 1.2 times $L2\times\{-2.5\times(L2/L1)+2.5\}$.

Even in the case where the planar configuration of the film part **70***d* is a flattened circle, it is favorable for the settings to satisfy the ninth formula and the tenth formula recited above. In other words, in the case where the aspect ratio AR (L2/L1) is less than 0.8, it is favorable for the third length to be not less than 0.8 times and not more than 1.2 times $L1\times\{-0.8\times(L2/L1)+0.8\}$. It is favorable for the fourth length L4 to be not less than 0.8 times and not more than 1.2 times $L2\times\{0.375\times(L2/L1)+0.2\}$.

By satisfying such conditions, an anisotropic strain having a larger absolute value is obtained; and a highly-sensitive pressure sensor is obtained more reliably.

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

These drawings illustrate the planar configuration of the film part **70***d*.

In a pressure sensor **112** according to the embodiment as shown in FIG. **13**A, the planar configuration of the film part **70***d* is substantially rectangular (rectangle); and corner portions **70***sc* of the film part **70***d* have curved configurations. In other words, the film part **70***d* has the first to fourth sides **70***s***1** to **70***s***4**; and the sides are connected by the corner portions **70***sc* having the curved configurations.

In a pressure sensor **113** according to the embodiment as shown in FIG. **13**B, the film part **70***d* has the first to fourth sides **70***s***1** to **70***s***4**; and the sides are connected by the corner portions **70***sc* having linear configurations.

Thus, in the embodiment, two sides may be connected by the corner portions **70***sc*. This state also is included in the state in which two sides are connected.

In a pressure sensor **114** according to the embodiment as shown in FIG. **13**C, the planar configuration of the film part **70***d* is a parallelogram, e.g., in the example, a diamond. In other words, the film part **70***d* includes the first to fourth sides **70***s***1** to **70***s***4**. The first side **70***s***1** and the second side

70*s*2 are along the first direction (e.g., the X-axis direction); and the third side 70*s*3 and the fourth side 70*s*4 are along a third direction that is tilted with respect to the first direction. The third direction is non-parallel to the first direction and non-orthogonal to the first direction. In the example as well, the sides may be connected by the corner portions 70*sc* having curved configurations or linear configurations.

In the pressure sensors **112** to **114** as well, the planar configuration of the film part 70*d* is an anisotropic configuration. In other words, for example, the length of the film part 70*d* along the first axis 70*x* passing through the centroid 70*dc* of the film surface 70*fs* is longer than the length of the film part 70*d* along the second axis 70*y* intersecting (e.g., orthogonal to) the first axis 70*x* to pass through the centroid 70*dc* of the film surface 70*fs*. The sensing element **50** is disposed in such a central portion 70*c* of the film part 70*d*. According to the pressure sensors **112** to **114** as well, highly-sensitive pressure sensors are obtained.

In the embodiment, the configuration of the anisotropic strain occurrence region 70*a* corresponds to the planar configuration of the film part 70*d*. In the case where the planar configuration of the film part 70*d* is a rectangle, the anisotropic strain occurrence region 70*a* is a rectangular area at the vicinity of the centroid 70*dc* of the film surface 70*fs*. In the case where the planar configuration of the film part 70*d* is a flattened circle, the anisotropic strain occurrence region 70*a* is a flattened circular area at the vicinity of the centroid 70*dc* of the film surface 70*fs*. In the case where the planar configuration of the film part 70*d* is a diamond, the anisotropic strain occurrence region 70*a* is a diamond-like area at the vicinity of the centroid 70*dc* of the film surface 70*fs*. The anisotropic strain occurrence regions 70*a* are used as the central portion 70*c* of the film part 70*d*.

In the embodiment, multiple sensing elements may be provided in the sensing unit 50*u*.

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

These drawings show examples of the connection state of the multiple sensing elements.

As shown in FIG. **14**A, the multiple sensing elements **50** are connected in series. In the case where N sensing elements of the multiple sensing elements **50** are connected in series, the electrical signal that is obtained is N times that of the case where the number of the sensing elements **50** is 1. On the other hand, the thermal noise and the Schottky noise increase by a factor of $N^{1/2}$. In other words, the SN ratio (signal-noise ratio (SNR)) increases by a factor of $N^{1/2}$. By increasing the number N of the sensing elements **50** connected in series, the SN ratio can be increased without causing the size of the film part 70*d* to become large.

By using the film part 70*d* having the anisotropic configuration in the embodiment, the change (e.g., the polarity) of the electrical resistance due to the pressure is similar between the multiple sensing elements **50** disposed together at the centroid 70*dc* vicinity of the film part 70*d*. Therefore, it is possible to add the signals of the multiple sensing elements **50**.

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

In the case where the value of the bias voltage is 1 V or more, the design of the electronic circuit that processes the electrical signal obtained from the sensing elements **50** is easy and practically favorable. In the embodiment, the sensing element **50** can be multiply disposed to obtain electrical signals having the same polarity when the pressure is applied. Therefore, the SN ratio can be increased as recited above by connecting the sensing elements **50** in series.

In the electronic circuit that processes the electrical signals obtained from the sensing elements **50**, it is undesirable for the bias voltage (the voltage across terminals) to exceed 10 V. In the embodiment, the bias voltage and the number N of the sensing elements **50** connected in series are set to be in appropriate voltage ranges.

For example, in the case where the multiple sensing elements **50** are connected electrically in series, it is favorable for the voltage to be not less than 1 V and not more than 10 V. For example, the voltage that is applied between the terminals of the multiple sensing elements **50** connected electrically 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.

To generate the voltage, it is favorable for the number N of the sensing elements **50** connected in series to be not less than 20 and not more than 200 in the case where the bias voltage applied to one sensing element **50** is 50 mv. In the case where the bias voltage applied to the one sensing element **50** is 150 mV, it is favorable for the number N of the sensing elements **50** connected in series to be not less than 7 and not more than 66.

As shown in FIG. **14**B, at least a portion of the multiple sensing elements **50** may be connected electrically in parallel.

As shown in FIG. **14**C, the multiple sensing elements **50** may be connected such that the multiple sensing elements **50** form a Wheatstone bridge circuit. Thereby, for example, temperature compensation of the sensing characteristics can be performed.

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

These drawings show examples of connections of the multiple sensing elements **50**.

As shown in FIG. **15**A, the sensing elements **50** and via contacts **65** are provided between a lower electrode 60*b* (e.g., the second interconnect **62**) and an upper electrode 60*a* (e.g., the first interconnect **61**) in the case where the multiple sensing elements **50** are connected electrically in series. Thereby, the conduction direction is in one direction. The current conducted through the multiple sensing elements **50** is downward or upward. In this connection, the signal-noise characteristics of the multiple sensing elements **50** can be similar to each other.

As shown in FIG. **15**B, the sensing elements **50** are disposed between the lower electrode 60*b* and the upper electrode 60*a* without the via contacts **65** being provided. In the example, the direction of the current conducted through the sensing element **50** is reversed between two mutually-adjacent sensing elements **50**. For this connection, the density of the disposition of the multiple sensing elements **50** is high.

As shown in FIG. **15**C, the multiple sensing elements **50** are provided between one lower electrode 60*b* and one upper electrode 60*a*. The multiple sensing elements **50** are connected in parallel.

Second Embodiment

FIG. **16**A to FIG. **16**D are schematic views illustrating a pressure sensor according to a second embodiment.

FIG. **16**A is a schematic perspective view. FIG. **16**B is a cross-sectional view along line A**1**-A**2** of FIG. **16**A and FIG. **16**C. FIG. **16**C is a schematic plan view. FIG. **16**D is a schematic plan view of the film part included in the pressure sensor.

As shown in FIG. **16**A to FIG. **16**C, the pressure sensor **120** according to the embodiment also includes the film part **70***d* and the sensing unit **50***u*. The support unit **70***s* is provided in the example. The film part **70***d* is supported by the support unit **70***s* and is flexible. The sensing unit **50***u* includes the multiple sensing elements **50** (e.g., the first to fifth sensing elements **50***a* to **50***e*, etc.). The multiple sensing elements **50** are provided on the film part **70***d*. In the example as well, each of the multiple sensing elements **50** includes the first magnetic layer **10**, the second magnetic layer **20** provided between the first magnetic layer **10** and the film part **70***d*, and the spacer layer **30** provided between the first magnetic layer **10** and the second magnetic layer **20**. The spacer layer **30** may include, for example, a magnetic material. The disposition of the sensing unit **50***u* of the pressure sensor **120** is different from that of the pressure sensor **110**.

The positions of at least two of the multiple sensing elements **50** along the first direction (e.g., the X-axis direction) are different from each other. In the example, the multiple sensing elements **50** are arranged along the outer edge **70***r* of the film part **70***d*. Otherwise, the pressure sensor **120** is similar to the pressure sensor **110**; and a description is therefore omitted.

As shown in FIG. **16**C, an element disposition region **75** (e.g., a first element disposition region **76** and a second element disposition region **77**) is provided in the film part **70***d* of the pressure sensor **120**. The element disposition region **75** extends along the outer edge of the film part **70***d*. The multiple sensing elements **50** are provided on the element disposition region **75**.

The element disposition region **75** is provided on the peripheral portion **70***p* of the film part **70***d*. In other words, the film part **70***d* includes the central portion **70***c* and the peripheral portion **70***p*. The peripheral portion **70***p* is provided around the central portion **70***c*. The multiple sensing elements **50** are provided on the element disposition region **75** of the peripheral portion **70***p* of the film part **70***d*.

In other words, instead of being arranged in a radial configuration from the central portion **70***c* toward the peripheral portion **70***p*, the multiple sensing elements **50** may be arranged along the outer edge **70***r* of the peripheral portion **70***p*.

In the example, the planar configuration of the film part **70***d* is an anisotropic configuration. In other words, the first length L1 of the film part **70***d* in the first direction (e.g., the X-axis direction) in the film surface **70***fs* is longer than the second length L2 of the film part **70***d* in the second direction (e.g., the Y-axis direction which is a direction perpendicular to the first direction in the film surface **70***fs*).

In such a case, the positions of at least two of the multiple sensing elements **50** provided inside the element disposition region **75** along the first direction (e.g., the X-axis direction) are different from each other. In the example, the multiple sensing elements **50** are arranged along the first direction (in the example, the X-axis direction) inside the element disposition region **75**.

In the embodiment, for example, two most proximal sensing elements **50** of the multiple sensing elements are arranged along the outer edge **70***r*.

In the example, the planar configuration of the film part **70***d* is substantially rectangular.

In other words, as shown in FIG. **16**D, the film part **70***d* has the first to fourth sides **70***s***1** to **70***s***4**. The first side **70***s***1** is provided along the first direction (e.g., the X-axis direction). The second side **70***s***2** is provided along the first direction to be separated from the first side **70***s***1**. The third side **70***s***3** is provided along the second direction (e.g., the Y-axis direction) to be connected to the one end **70***s***11** of the first side **70***s***1** and the one end **70***s***21** of the second side **70***s***2**. The fourth side **70***s***4** is provided along the second direction to be separated from the third side **70***s***3** and connected to the other end **70***s***12** of the first side **70***s***1** and the other end **70***s***22** of the second side **70***s***2**. As described below, the sides may be connected to each other by corner portions having linear configurations or curved configurations.

Thus, in the case where the planar configuration of the film part **70***d* is substantially rectangular, the element disposition region **75** is provided to extend along a side of the rectangle. In the example, the peripheral portion **70***p* of the film part **70***d* includes the first element disposition region **76** provided along the first side **70***s***1**. The multiple sensing elements **50** are provided on the first element disposition region **76**; and the positions along the first direction (e.g., the X-axis direction) of the multiple sensing elements **50** (at least two of the multiple sensing elements **50**) are different from each other. In the example, the multiple sensing elements **50** that are provided on the first element disposition region **76** are arranged along the first side **70***s***1**.

In the example, the peripheral portion **70***p* of the film part **70***d* includes the second element disposition region **77** provided along the second side **70***s***2**. The multiple sensing elements **50** are further provided on the second element disposition region **77**. The positions along the first direction (e.g., the X-axis direction) of the multiple sensing elements **50** (at least two of the multiple sensing elements **50**) provided on the second element disposition region **77** are different from each other. In the example, the multiple sensing elements **50** that are provided on the second element disposition region **77** are arranged along the second side **70***s***2**.

Thus, in the pressure sensor **120** according to the embodiment, the positions along the first direction (e.g., the X-axis direction) of at least two of the multiple sensing elements **50** are different from each other and are arranged, for example, along the first direction. Thereby, in the multiple sensing elements **50**, a similar resistance change occurs for the pressure that is applied. According to the embodiment, a highly-sensitive pressure sensor can be provided.

In the pressure sensor **120**, for example, the multiple sensing elements **50** are disposed in at least one selected from the first element disposition region **76** and the second element disposition region **77**. In other words, the first element disposition region **76** may be provided; and the second element disposition region **77** may not be provided. Or, the second element disposition region **77** may be provided; and the first element disposition region **76** may not be provided.

For example, any of the configurations described in regard to FIG. **14**A to FIG. **14**C and FIG. **15**A to FIG. **15**C are applicable to the connections of the multiple sensing elements **50** in the embodiment.

In the pressure sensor **120**, the planar configuration of the film part **70***d* is an anisotropic configuration. Also, the multiple sensing elements **50** are provided together on the element disposition region **75** of the film part **70***d*. The element disposition region **75** is a region at the minor-axis end portion vicinity of the film part **70***d*.

As described in regard to the first embodiment, in the case where the planar configuration of the film part **70***d* is an anisotropic configuration, strains that are different between the major-axis direction and the minor-axis direction of the film part **70***d* occur in the surface of the film part **70***d* when the film part **70***d* deflects due to the pressure being applied from one surface of the film part **70***d*. The strain occurring in the minor-axis direction is greater than the strain occurring in the major-axis direction. The region on the film part **70***d* where the anisotropic strain occurs is wider for the film part **70***d* having the anisotropic configuration than for the film part **70***d* having the isotropic configuration. This tendency also is confirmed at the end portion vicinity of the film part **70***d* on the minor axis side.

The anisotropic strain having the large absolute value occurs in a wider region at the end portion on the minor axis side of the film part **70***d* having the anisotropic configuration than at the end portion of the film part **70***d* having the isotropic configuration. Therefore, the number of the sensing elements **50** for which a similar change of electrical resistance (e.g., having the same polarity) occurs due to the pressure can be increased. Thereby, a highly-sensitive pressure sensor can be provided.

The SN ratio can be increased by connecting the multiple sensing elements **50** in series. In the embodiment as well, the sensing elements **50** can be disposed to obtain electrical signals having the same polarity when the pressure is applied. Thereby, the SN ratio can be increased. In the embodiment, for example, the bias voltage and the number N of the sensing elements **50** connected in series are set to be in appropriate voltage ranges. For example, it is favorable for the voltage when the multiple sensing elements **50** are connected electrically in series to be not less than 1 V and not more than 10 V. For example, in the case where the bias voltage applied to one sensing element **50** is 50 mV, it is favorable for the number N of the sensing elements **50** connected in series to be not less than 20 and not more than 200. In the case where the bias voltage applied to the one sensing element **50** is 150 mV, it is favorable for the number N of the sensing elements **50** connected in series to be not less than 7 and not more than 66.

At least a portion of the multiple sensing elements **50** may be connected electrically in parallel. The multiple sensing elements **50** may be connected such that the multiple sensing elements **50** form a Wheatstone bridge circuit. Thereby, for example, temperature compensation of the sensing characteristics can be performed.

In the example, the planar configuration of the element disposition region **75** (the planar configurations of the first element disposition region **76** and the second element disposition region **77**) is substantially rectangular.

For example, the length (a fifth length L5) of the first element disposition region **76** in the first direction (e.g., the X-axis direction) is not more than 0.5 times the first length L1. The width (a sixth length L6) of the first element disposition region **76** in the second direction (e.g., the Y-axis direction) is not more than 0.1 times the second length L2.

The X-axis direction center of the first element disposition region **76** is substantially aligned with the X-axis direction center of the film part **70***d*. For example, the distance in the first direction between the center of the first element disposition region **76** in the first direction (e.g., the X-axis direction) and the first-direction center of the film part **70***d* is not more than 1/10 of the second length L2.

Similarly, for example, the length (a seventh length L7) of the second element disposition region **77** in the first direction (e.g., the X-axis direction) is not more than 0.5 times the first length L1. The width (an eighth length L8) of the second element disposition region **77** in the second direction (e.g., the Y-axis direction) is not more than 0.1 times the second length L2.

The X-axis direction center of the second element disposition region **77** is substantially aligned with the X-axis direction center of the film part **70***d*. For example, the distance in the first direction between the center of the second element disposition region **77** in the first direction (e.g., the X-axis direction) and the first-direction center of the film part **70***d* is not more than 1/10 of the second length L2.

An example of the characteristics in the case where the planar configuration of the film part **70***d* is a rectangle and the multiple sensing elements **50** are disposed together at the end portion vicinity of the film part **70***d* on the minor axis side will now be described.

FIG. **17**A and FIG. **17**B are schematic views illustrating the configuration and characteristics of the pressure sensor according to the second embodiment.

These drawings illustrate simulation results of characteristics of the pressure sensor **120**. FIG. **17**A is a schematic perspective view of the film part **70***d*. FIG. **17**B illustrates the distribution in the X-Y plane of the anisotropic strain $\Delta\varepsilon$ occurring in the film part **70***d*.

In the example as shown in FIG. **17**A, the planar configuration of the film part **70***d* is a rectangle. In the example, the length (the first length L1) of the film part **70***d* in the major-axis direction is 625 μm; the length (the second length L2) in the minor-axis direction is 400 μm; and the thickness Lt is 2 μm.

The analysis of the strain occurring in the front surface of the film part **70***d* is performed for such a film part **70***d*. The conditions of the finite element method of the analysis are similar to those described in regard to the first embodiment. The dependence of the displacement of the film part **70***d* on the distance from the centroid **70***dc* is the same as the results (FIG. **5**D and FIG. **5**E) described in regard to the first embodiment. An end portion anisotropic strain occurrence region **75***a* is the area where the anisotropic strain is not less than 0.4 times (i.e., 40% of) the maximum value of the anisotropic strain (the absolute value) obtained at the end portion of the film part **70***d* on the minor axis side. Because two end portions exist, the end portion anisotropic strain occurrence region **75***a* includes a first end portion anisotropic strain occurrence region **76***a* and a second end portion anisotropic strain occurrence region **77***a*.

FIG. **17**B is a contour diagram illustrating the first end portion anisotropic strain occurrence region **76***a* and the second end portion anisotropic strain occurrence region **77***a*.

It can be seen from FIG. **17**B that the first end portion anisotropic strain occurrence region **76***a* and the second end portion anisotropic strain occurrence region **77***a* occur at the vicinity of the two minor-axis direction end portions by using the film part **70***d* having the anisotropic configuration. The surface areas of these regions are large. The surface area of the end portion anisotropic strain occurrence region **75***a* (the sum of the surface area of the first end portion anisotropic strain occurrence region **76***a* and the surface area of the second end portion anisotropic strain occurrence region **77***a*) is about 8500 μm^2.

Thus, an anisotropic strain that is equivalent to that of the minor-axis direction end portion can be obtained in a wide area at the end portion vicinity. In the embodiment, the multiple sensing elements **50** are disposed in the area where the equivalent anisotropic strain is obtained. In other words, for example, the first end portion anisotropic strain occur-

rence region **76***a* is set to be the first element disposition region **76**; and the second end portion anisotropic strain occurrence region **77***a* is set to be the second element disposition region **77**. A highly-sensitive pressure sensor is obtained by disposing the multiple sensing elements **50** in such regions.

It can be seen from FIG. **17**B that in the case where the film part **70***d* has a rectangle configuration, the configuration of the end portion anisotropic strain occurrence region **75***a* (the configurations of the first end portion anisotropic strain occurrence region **76***a* and the second end portion anisotropic strain occurrence region **77***a*) also is substantially rectangular.

The length (corresponding to the fifth length L5) of the first end portion anisotropic strain occurrence region **76***a* in the X-axis direction is not more than 0.5 times the first length L1. The width (corresponding to the sixth length L6) of the first end portion anisotropic strain occurrence region **76***a* in the Y-axis direction is not more than 0.1 times the second length L2. The first end portion anisotropic strain occurrence region **76***a* has substantially line symmetry around an axis passing through the centroid **70***dc* of the film surface **70***fs* parallel to the second direction. For example, the distance in the X-axis direction between the X-axis direction center of the first end portion anisotropic strain occurrence region **76***a* and the X-axis direction center of the film part **70***d* is not more than 1/10 of the second length L2.

Similarly, the length (corresponding to the seventh length L7) of the second end portion anisotropic strain occurrence region **77***a* in the X-axis direction is not more than 0.5 times the first length L1. The width (corresponding to the eighth length L8) of the second end portion anisotropic strain occurrence region **77***a* in the Y-axis direction is not more than 0.1 times the second length L2. For example, the distance in the X-axis direction between the X-axis direction center of the second end portion anisotropic strain occurrence region **77***a* and the X-axis direction center of the film part **70***d* is not more than 1/10 of the second length L2.

The first element disposition region **76** is set to correspond to such a first end portion anisotropic strain occurrence region **76***a*; and the second element disposition region **77** is set to correspond to such a second end portion anisotropic strain occurrence region **77***a*. In the embodiment, the multiple sensing elements **50** are disposed along the outer edge **70***r* of the film part **70***d* on such regions. For example, the centroids of the multiple sensing elements **50** overlap these regions when the multiple sensing elements **50** are projected onto the X-Y plane. Thereby, a highly-sensitive pressure sensor is obtained.

In the embodiment, the multiple sensing elements **50** are provided in at least one selected from the first end portion anisotropic strain occurrence region **76***a* and the second end portion anisotropic strain occurrence region **77***a*.

FIG. **18**A and FIG. **18**B are schematic views illustrating the configuration and characteristics of a pressure sensor of a reference example.

These drawings illustrate simulation results of characteristics of the pressure sensor **119***b* of the reference example. FIG. **18**A is a schematic perspective view of the film part **70***d*. FIG. **18**B illustrates the distribution in the X-Y plane of the anisotropic strain $\Delta\varepsilon$ occurring in the film part **70***d*.

In the pressure sensor **119***b* of the reference example as shown in FIG. **18**A, the planar configuration of the film part **70***d* is a circle. The diameter (the first length L1 and the second length L2) of the planar configuration of the film part **70***d* is 564 μm; and the thickness Lt of the film part **70***d* is 2 μm. The strain of the pressure sensor **119***b* is as described in regard to FIG. **11**B. The end portion anisotropic strain occurrence region **75***a* (the area where the anisotropic strain is not less than 0.4 times (i.e., 40% of) the maximum value of the absolute value of the anisotropic strain obtained at the end portion of the film part **70***d* on the minor axis side) is determined from the analysis results of the strain.

FIG. **18**B is a contour diagram of the end portion anisotropic strain occurrence region **75***a*. In the reference example, the surface areas of the first end portion anisotropic strain occurrence region **76***a* and the second end portion anisotropic strain occurrence region **77***a* are small. The surface area of the end portion anisotropic strain occurrence region **75***a* (the sum of the surface area of the first end portion anisotropic strain occurrence region **76***a* and the surface area of the second end portion anisotropic strain occurrence region **77***a*) is about 5000 μm^2.

The surface area of the film part **70***d* is the same for the pressure sensor **120** and the pressure sensor **119***b*. The ratio of the surface area of the end portion anisotropic strain occurrence region **75***a* to the surface area of the film part **70***d* is higher for the pressure sensor **120** than for the pressure sensor **119***b*.

Thus, by using the film part **70***d* having the anisotropic configuration (e.g., the rectangle), the region (the end portion anisotropic strain occurrence region **75***a*) where the large anisotropic strain is obtained can be larger than in the case where the isotropic circular film part **70***d* is used. In the embodiment, the multiple sensing elements **50** are disposed in this region.

In the pressure sensor **120**, the multiple sensing elements **50** are disposed together along the minor-axis direction outer edge **70***r* of the rectangular film part **70***d* having the anisotropic configuration. Thereby, a similar anisotropic strain (e.g., having the same polarity) is applied to the multiple sensing elements **50**. In the embodiment, the multiple sensing elements **50** that have similar change of electrical resistance (e.g., having the same polarity) due to the pressure can be disposed in this region. The S/N ratio can be increased by connecting the sensing elements, for example, electrically in series. Further, a highly-sensitive pressure sensor can be provided by setting the bias voltage to be an appropriate value.

An example of the characteristics will now be described for different aspect ratios of the film part **70***d* in the case where the planar configuration of the film part **70***d* is a rectangle and the multiple sensing elements **50** are disposed together at the minor-axis direction end portion vicinity of the film part. The first end portion anisotropic strain occurrence region **76***a* of the end portion anisotropic strain occurrence region **75***a* will now be described.

FIG. **19** is a schematic plan view illustrating a pressure sensor.

FIG. **19** illustrates the coordinate system of the film part **70***d* of the pressure sensor **120**. The coordinates (x, y) of the centroid of the film surface **70***fs* are (0, 0). The coordinates of one point of the outer edge **70***r* of the film part **70***d* in the X-axis direction are (L1/2, 0). The coordinates of one point of the outer edge **70***r* of the film part **70***d* in the Y-axis direction are (0, L2/2).

The length of the first end portion anisotropic strain occurrence region **76***a* in the first direction (the length in the X-axis direction) is a length L5a; and the length of the first end portion anisotropic strain occurrence region **76***a* in the second direction (the length in the Y-axis direction) is a length L6a. The difference between the second length L2 and the length L6a is ΔL6a (i.e., $\Delta L6a = L2 - 2 \times L6a$). The coordinates of one point PXa1 of the outer edge of the first

end portion anisotropic strain occurrence region **76**_a_ in the X-axis direction are (L5a/2, L2/2). The coordinates of one point PYa1 in the Y-axis direction of the outer edge on the centroid **70**_dc_ side of the first end portion anisotropic strain occurrence region **76**_a_ are (0, ΔL6a/2).

An example of the characteristics will now be described for different aspect ratios AR of the film part **70**_d_ for the case where the planar configuration of the film part **70**_d_ is such a rectangle.

FIG. **20**A to FIG. **20**D are graphs illustrating the characteristics of the pressure sensors.

These drawings show the characteristics of the pressure sensors having the first to sixth configurations described above. These drawings also show the characteristics of a pressure sensor of a thirteenth configuration.

In the thirteenth configuration, the planar configuration of the film part **70**_d_ is a circle. Namely, the first length L1 is 564 μm; the second length L2 is 564 μm; and the aspect ratio AR is 1. The thirteenth configuration corresponds to the configuration described in regard to FIG. **18**A and FIG. **18**B.

In the first to fifth configurations, the planar configuration of the film part **70**_d_ is a rectangle and has an anisotropic configuration. In the sixth configuration, the planar configuration of the film part **70**_d_ is a square. In the thirteenth configuration, the planar configuration of the film part **70**_d_ is a circle. In FIG. **20**A to FIG. **20**D, the values for the first to sixth configurations are illustrated by the solid symbols. In FIG. **20**A and FIG. **20**B, the values for the thirteenth configuration are illustrated by the unfilled round symbols.

Analysis of the strain occurring in the front surface of the film part **70**_d_ is performed by finite element analysis for these configurations. The conditions of the finite element method are the same as the conditions described in regard to FIG. **5**A to FIG. **5**F.

In FIG. **20**A, the vertical axis is an anisotropic strain Δεe (the absolute value of the anisotropic strain) at the end portion of the film part **70**_d_. The horizontal axis is the aspect ratio AR of the planar configuration of the film part **70**_d_. For the thirteenth configuration (the unfilled round symbols), the absolute value of the anisotropic strain Δεe at the end portion is small. Conversely, for the first to sixth configurations (the solid symbols), the absolute value of the anisotropic strain Δεe at the end portion is large. Thus, compared to the case where the planar configuration of the film part **70**_d_ is a circle, an anisotropic strain Δεe having a large absolute value is obtained for the first to sixth configurations having planar configurations that are rectangular or square.

From FIG. **20**A, from the aspect of increasing the absolute value of the anisotropic strain Δεe at the end portion of the film part **70**_d_, it is favorable for the aspect ratio AR of the film part **70**_d_ to be not less than 0.25 but less than 1.0, and more favorable to be not less than 0.64 but less than 1.0.

The first end portion anisotropic strain occurrence region **76**_a_ (the area where the anisotropic strain is not less than 0.4 times (i.e., 40% of) the maximum value of the anisotropic strain obtained at the end portion of the film part **70**_d_ on the minor axis side) was analyzed for the first to sixth configurations. As a result, it was found that the planar configuration of the first end portion anisotropic strain occurrence region **76**_a_ is a rectangle.

In FIG. **20**B, the vertical axis is the ratio (the surface area ratio Ra) of the surface area of the first end portion anisotropic strain occurrence region **76**_a_ to the surface area of the film part **70**_d_. The horizontal axis is the aspect ratio AR. It can be seen from FIG. **20**B that the surface area ratio Ra is higher (greater) for the first to sixth configurations than for the thirteenth configuration. The surface area ratio Ra increases as the aspect ratio AR decreases (as the difference between the first length L1 and the second length L2 increases). From the aspect of widening the region on the film part **70**_d_ where the anisotropic strain is obtained, it is favorable for the aspect ratio AR to be not more than 0.8, and more favorable to be not more than 0.25.

The position of the outer edge of the first end portion anisotropic strain occurrence region **76**_a_ (the coordinates referring to FIG. **19**) will now be described.

The vertical axis of FIG. **20**C is the normalized coordinate (a distance Xa1) of the point PXa1 in the X-axis direction on the outer edge of the first end portion anisotropic strain occurrence region **76**_a_. The distance Xa1 corresponds to (L5a)/(L1).

The vertical axis of FIG. **20**D is the normalized coordinate (a distance Ya1) of the point PYa1 in the Y-axis direction on the centroid **70**_dc_ side on the outer edge of the first end portion anisotropic strain occurrence region **76**_a_. The distance Ya1 corresponds to (ΔL6a)/(L2).

In these drawings, the horizontal axis is the aspect ratio AR. FIG. **20**C and FIG. **20**D show the results for the first to sixth configurations.

It can be seen from these drawings that the distance Xa1 and the distance Ya1 are greater than zero for the first to sixth configurations. In other words, the first end portion anisotropic strain occurrence region **76**_a_ is obtained for these configurations.

It can be seen from these drawings that in the case where the aspect ratio AR is not less than 0.8 but less than 1, it is favorable that

$$|Xa1| \leq (L1/2)\times 0.5, \text{ and}$$

$$|Ya1| \geq (L2/2)\times 0.9.$$

On the other hand, in the case where the aspect ratio AR is less than 0.8, it is favorable that

$$|Xa1| \leq (L1/2)\times\{-0.375\times(L2/L1)+0.8\}, \text{ and}$$

$$|Ya1| \geq (L2/2)\times\{0.125\times(L2/L1)+0.8\}.$$

In FIG. **20**C, a fourth hatching region R4 that is the light hatching and a fifth hatching region R5 that is the dark hatching correspond to the conditions of the first end portion anisotropic strain occurrence region **76**_a_. In FIG. **20**D, a sixth hatching region R6 that is the light hatching and a seventh hatching region R7 that is the dark hatching correspond to the conditions of the first end portion anisotropic strain occurrence region **76**_a_.

The fourth hatching region R4 is represented by the eleventh formula recited below, i.e., the twelfth formula recited below.

$$Xa1 \leq -0.375AR+0.8 \tag{11}$$

$$L5a \leq L1\times\{-0.375(L2/L1)+0.8\} \tag{12}$$

The fifth hatching region R5 is represented by the thirteenth formula recited below, i.e., the fourteenth formula recited below.

$$Xa1 \leq 0.5 \tag{13}$$

$$L5a \leq 0.5L1 \tag{14}$$

The sixth hatching region R6 is represented by the fifteenth formula recited below, i.e., the sixteenth formula recited below.

$$Ya1 \geq 0.125AR+0.8 \tag{15}$$

$$L6a \leq (L2/2)\{1-0.125(L2/L1)+0.8\} \tag{16}$$

The seventh hatching region R7 is represented by the seventeenth formula recited below, i.e., the eighteenth formula recited below.

$$Ya1 \geq 0.9 \quad (17)$$

$$L6a \leq 0.05L2 \quad (18)$$

In other words, in the case where the aspect ratio AR is less than 0.8, the conditions of the eleventh formula, the twelfth formula, the fifteenth formula, and the sixteenth formula are favorable.

On the other hand, in the case where the aspect ratio AR is not less than 0.8 but less than 1, the conditions of the thirteenth formula, the fourteenth formula, the seventeenth formula, and the eighteenth formula are favorable.

In other words, in the case where the aspect ratio AR is less than 0.8, it is favorable for the length (the length L5a) of the first element disposition region **76** in the first direction to be not more than $L1\times\{-0.375\times(L2/L1)+0.8\}$. It is favorable for the width (the length L6a) of the first element disposition region **76** in the second direction to be not more than $(L2/2)\times\{1-0.125\times(L2/L1)+0.8\}$. It is favorable for the first-direction center of the first element disposition region **76** to substantially overlap the first-direction center of the film part **70***d* and for the distance in the first direction between the first-direction center of the first element disposition region **76** and the first-direction center of the film part **70***d* to be, for example, 1/10 of the second length L2.

On the other hand, in the case where the aspect ratio AR is not less than 0.8 but less than 1, it is favorable for the width (the length L5a) of the first element disposition region **76** in the first direction to be not more than 0.5 times the second length L2. It is favorable for the width (the length L6a) of the first element disposition region **76** in the second direction to be not more than 0.05 times the second length L2.

The characteristics of the second element disposition region are similar to the characteristics of the first element disposition region **76** recited above.

An example of the characteristics in the case where the planar configuration of the film part **70***d* is an ellipse and the multiple sensing elements **50** are disposed together at the minor-axis direction end portion vicinity of the film part **70***d* will now be described.

FIG. **21**A and FIG. **21**B are schematic views illustrating the configuration and characteristics of another pressure sensor according to the second embodiment.

These drawings illustrate simulation results of characteristics of the pressure sensor **121** according to the embodiment. FIG. **21**A is a schematic perspective view of the film part **70***d*. FIG. **21**B illustrates the distribution in the X-Y plane of the anisotropic strain $\Delta\varepsilon$ occurring in the film part **70***d*.

As shown in FIG. **21**A, the planar configuration of the film part **70***d* is a flattened circle (also including an ellipse). The sensing element **50** (not-shown in the drawing) is disposed at the minor axis (the second direction) end portion of the film part **70***d*. In the example, the length (the first length L1) of the major axis of the film part **70***d* is 704 μm; and the length (the second length L2) in the minor axis is 452 μm. The thickness Lt of the film part **70***d* is 2 μm. The conditions of the simulation are the same as the conditions described above.

The dependence of the strain of the front surface of the film part **70***d* on the distance from the centroid is as illustrated in FIG. **10**B and FIG. **10**C described above.

FIG. **21**B is a contour diagram illustrating the end portion anisotropic strain occurrence region **75***a* (the first end portion anisotropic strain occurrence region **76***a* and the second end portion anisotropic strain occurrence region **77***a*). As described above, an anisotropic strain that is not less than 0.4 times (i.e., 40% of) the anisotropic strain $\Delta\varepsilon e$ (corresponding to the maximum value) occurring at the end portion of the film part **70***d* is obtained in the end portion anisotropic strain occurrence region **75***a*. As shown in FIG. **21**B, by using the film part **70***d* having the anisotropic configuration, an anisotropic strain that is equivalent to that of the end portion can be obtained in a wide area at the minor-axis direction end portion vicinity. The surface area of the end portion anisotropic strain occurrence region **75***a* (the sum of the surface area of the first end portion anisotropic strain occurrence region **76***a* and the surface area of the second end portion anisotropic strain occurrence region **77***a*) is about 6600 μm^2.

On the other hand, as described above, in the pressure sensor **119***b* in which the planar configuration of the film part **70***d* is a circle, the surface area of the end portion anisotropic strain occurrence region **75***a* is about 5000 μm^2. The surface area of the film part **70***d* is the same between in the pressure sensor **121** and the pressure sensor **119***b*. The ratio of the surface area of the end portion anisotropic strain occurrence region **75***a* to the surface area of the film part **70***d* is higher for the pressure sensor **121** than for the pressure sensor **119***b*.

Thus, in the embodiment, the configuration of the film surface **70***fs* may be a flattened circle (including an ellipse). For example, the configuration of the film part **70***d* projected onto a plane (e.g., the X-Y plane) parallel to the film surface **70***fs* of the film part **70***d* may be a flattened circle (including an ellipse). In the flattened circle, the first direction (e.g., the X-axis direction) is taken to be the major axis; and the second direction (e.g., the Y-axis direction) is taken to be the minor axis.

As illustrated in FIG. **21**A and FIG. **21**B, the peripheral portion **70***p* of the film part **70***d* has an arc **75***b* (a major-axis arc) along the major axis. The arc **75***b* along the major axis includes, for example, a first arc **76***b* and a second arc **77***b*. The first element disposition region **76** is provided along the first arc **76***b*. The second element disposition region **77** is provided along the second arc **77***b*.

At least two of the multiple sensing elements **50** are arranged along the major-axis arc (the first arc **76***b*) in the first element disposition region **76**. At least two other elements of the multiple sensing elements **50** are arranged along the major-axis arc (the second arc **77***b*) in the second element disposition region **77**.

According to such a pressure sensor **120**, a highly-sensitive pressure sensor can be provided.

In the example, the multiple sensing elements **50** may be provided in at least one selected from the first end portion anisotropic strain occurrence region **76***a* and the second end portion anisotropic strain occurrence region **77***a*.

An example of the characteristics of the case where the planar configuration of the film part **70***d* is an ellipse and the multiple sensing elements **50** are disposed together at the minor-axis direction end portion vicinity of the film part **70***d* will now be described.

A tendency that is similar to that of the rectangular film part **70***d* is obtained when analyzing the aspect ratio AR dependence of the anisotropic strain for the seventh to eleventh configurations described above. From the aspect of increasing the absolute value of the anisotropic strain, it is favorable for the aspect ratio AR to be not less than 0.25 but less than 1.0, and more favorable to be not less than 0.64 but less than 1.0.

In the seventh to eleventh configurations, the ratio (the surface area ratio) of the surface area of the end portion anisotropic strain occurrence region **75***a* to the surface area of the film part **70***d* is larger than that of the thirteenth configuration. The surface area ratio increases as the aspect ratio AR decreases (the difference between the first length L1 and the second length L2 increases). From the aspect of widening the region on the film part **70***d* where the anisotropic strain is obtained, it is favorable for the aspect ratio AR to be not more than 0.8, and more favorable to be not more than 0.25.

FIG. **22** is a schematic view illustrating another pressure sensor according to the second embodiment.

FIG. **22** illustrates the coordinate system of the film part **70***d* of the pressure sensor **121**. In the case where the planar configuration of the film part **70***d* is an ellipse, the coordinates of the first end portion anisotropic strain occurrence region **76***a* may be substantially similar to those of the pressure sensor **120** illustrated in FIG. **19**.

Using such coordinates, the characteristics were examined for the coordinates of the first end portion anisotropic strain occurrence region **76***a* in the case where the planar configuration of the film part **70***d* is an ellipse. As a result, it was found that the characteristics in the case where the film part **70***d* is an ellipse are similar to the characteristics in the case where the planar configuration is a rectangle.

Accordingly, in such a case as well, in the case where the aspect ratio AR is less than 0.8, it is favorable for the length (the length L5a) of the first element disposition region **76** in the first direction to be not more than $L1\times\{-0.375\times(L2/L1)+0.8\}$. It is favorable for the width (the length L6a) of the first element disposition region **76** in the second direction to be not more than $(L2/2)\times\{1-0.125\times(L2/L1)+0.8\}$. It is favorable for the first-direction center of the first element disposition region **76** to substantially overlap the first-direction center of the film part **70***d* and for the distance in the first direction between the first-direction center of the first element disposition region **76** and the first-direction center of the film part **70***d* to be, for example, not more than 1/10 of the second length L2.

On the other hand, in such a case as well, in the case where the aspect ratio AR is not less than 0.8 but less than 1, it is favorable for the length (the length L5a) of the first element disposition region **76** in the first direction to be not more than 0.5 times the second length L2. It is favorable for the width (the length L6a) of the first element disposition region **76** in the second direction to be not more than 0.05 times the second length L2.

The characteristics of the second element disposition region are similar to the characteristics of the first element disposition region **76**.

FIG. **23**A and FIG. **23**B are schematic plan views illustrating other pressure sensors according to the second embodiment.

These drawings illustrate the planar configuration of the film part **70***d*.

In a pressure sensor **122** according to the embodiment as shown in FIG. **23**A, the corner portions **70***sc* have curved configurations. In a pressure sensor **123** according to the embodiment as shown in FIG. **23**B, the corner portions **70***sc* have linear configurations. According to the pressure sensors **122** and **123** as well, a highly-sensitive pressure sensor is obtained.

FIG. **24**A to FIG. **24**F are schematic plan views illustrating other pressure sensors according to the second embodiment.

These drawings illustrate the disposition of the multiple sensing elements **50** in the element disposition region **75**. In the example, the first element disposition region **76** is illustrated as the element disposition region **75**. The disposition of the multiple sensing elements **50** in the second element disposition region **77** may be, for example, similar to the disposition of the multiple sensing elements **50** in the first element disposition region **76**.

In a pressure sensor **120***a* as shown in FIG. **24**A, the multiple sensing elements **50** are arranged along the X-axis direction (the direction along the long side of the film part **70***d*). In the example, the planar configuration of the sensing element **50** (the configuration of the sensing element **50** when the sensing element **50** is projected onto the X-Y plane) is a rectangle. The configuration of the sensing element **50** is, for example, a square.

As shown in FIG. **24**B, in a pressure sensor **120***b* as well, the multiple sensing elements **50** are arranged along the X-axis direction (the direction along the long side of the film part **70***d*). In the example, the planar configuration of the sensing element **50** is a circle. The planar configuration of the sensing element **50** may be a flattened circle. The planar configuration of the sensing element **50** may be a rectangle.

In a pressure sensor **120***c* as shown in FIG. **24**C, the multiple sensing elements **50** are arranged in multiple columns. In each of the columns, the multiple sensing elements **50** are arranged along the X-axis direction (the direction along the long side of the film part **70***d*). The disposition of the multiple sensing elements **50** is, for example, a staggered disposition. In the example, the planar configuration of the sensing element **50** is a circle. The planar configuration of the sensing element **50** may be a flattened circle. The planar configuration of the sensing element **50** may be a rectangle.

In pressure sensors **120***d* and **120***e* as shown in FIG. **24**D and FIG. **24**E, the distance between the outer edge **70***r* of the film part **70***d* and each of the multiple sensing elements **50** is different between the multiple sensing elements **50**. The multiple sensing elements **50** are arranged along an arc. In these examples, the planar configuration of the sensing element **50** is a circle. The planar configuration of the sensing element **50** may be a flattened circle. The planar configuration of the sensing element **50** may be a rectangle.

In the pressure sensor **120***d* illustrated in FIG. **24**D, the distance between the outer edge **70***r* and the sensing elements **50** disposed in the region of the X-axis direction central portion of the first element disposition region **76** is longer than the distance between the outer edge **70***r* and the sensing elements **50** disposed in the region of the X-axis direction end portion of the first element disposition region **76**.

In the pressure sensor **120***e* illustrated in FIG. **24**E, the distance between the outer edge **70***r* and the sensing elements **50** disposed in the region of the X-axis direction central portion of the first element disposition region **76** is shorter than the distance between the outer edge **70***r* and the sensing elements **50** disposed in the region of the X-axis direction end portion of the first element disposition region **76**.

In a pressure sensor **120***f* as shown in FIG. **24**F, the multiple sensing elements **50** are disposed arbitrarily inside the element disposition region **75**. In the example, the planar configuration of the sensing element **50** is a circle. The planar configuration of the sensing element **50** may be a flattened circle. The planar configuration of the sensing element **50** may be a rectangle.

Thus, in the embodiment, the multiple sensing elements **50** are disposed such that the positions along the first

direction (the X-axis direction) of at least two of the multiple sensing elements **50** provided in the element disposition region **75** (at least one selected from the first element disposition region **76** and the second element disposition region **77**) are different from each other.

FIG. **25**A and FIG. **25**B are schematic plan views illustrating other pressure sensors according to the second embodiment.

These drawings illustrate the element disposition region **75** (the first element disposition region **76** and the second element disposition region **77**) and the disposition of the multiple sensing elements **50**.

The first element disposition region **76** and the second element disposition region **77** are provided in pressure sensors **120***g* and **120***h* according to the embodiment as shown in FIG. **25**A and FIG. **25**B. The multiple sensing elements **50** are provided in each of these regions.

In the pressure sensor **120***g* as shown in FIG. **25**A, the multiple sensing elements **50** are along the X-axis direction (the direction along the length L1 of the film part **70***d*) in each of these regions.

In the pressure sensor **120***h* as shown in FIG. **25**B, the multiple sensing elements **50** are disposed in multiple columns along the X-axis direction (the direction along the length L1 of the film part **70***d*) in each of these regions. The number of the sensing elements **50** included in the multiple columns is different between the multiple columns. The multiple sensing elements **50** are disposed in a triangular configuration in each of these regions. One side of the triangle is provided along the X-axis direction.

As shown in FIG. **25**A and FIG. **25**B, a circumscribing rectangle **70***cr* is formable when the film part **70***d* is projected onto a plane (e.g., the X-Y plane) parallel to the film surface **70***fs*. The circumscribing rectangle **70***cr* circumscribes the configuration of the film surface **70***fs*. The configuration of the film surface **70***fs* has, for example, the configuration of the outer edge **70***r* of the film part **70***d* projected onto a plane parallel to the film surface **70***fs*. In the example, the planar configuration of the film part **70***d* is an anisotropic configuration and is a rectangle. The circumscribing rectangle **70***cr* also is a rectangle.

The circumscribing rectangle **70***cr* has the first side **70***s***1**, the second side **70***s***2**, the third side **70***s***3**, and the fourth side **70***s***4**. The second side **70***s***2** is separated from the first side **70***s***1**. The third side **70***s***3** is connected to the one end **70***s***11** of the first side **70***s***1** and the one end **70***s***21** of the second side **70***s***2**. The fourth side **70***s***4** is separated from the third side **70***s***3** and connected to the other end **70***s***12** of the first side **70***s***1** and the other end **70***s***22** of the second side **70***s***2**.

In the example, the first length of the film part **70***d* in the first direction (the X-axis direction) in the film surface **70***fs* of the film part **70***d* is longer than the second length of the film part **70***d* in the second direction (the Y-axis direction) perpendicular to the first direction in the film surface **70***fs*. Therefore, the circumscribing rectangle **70***cr* is a rectangle. The first side **70***s***1** and the second side **70***s***2** extend in the first direction (the X-axis direction). The third side **70***s***3** and the fourth side **70***s***4** extend in the second direction (the Y-axis direction). The length of the first side **70***s***1** is the same as the length of the second side **70***s***2**. The length of the third side **70***s***3** is shorter than the length of the first side **70***s***1** and shorter than the length of the second side **70***s***2**. The length of the fourth side **70***s***4** is shorter than the length of the first side **70***s***1** and shorter than the length of the second side **70***s***2**.

The circumscribing rectangle **70***cr* has a centroid **70***crd*. For example, the centroid **70***crd* overlaps the centroid **70***dc* of the film surface **70***fs*.

The circumscribing rectangle **70***cr* includes a first region **78***a*, a second region **78***b*, a third region **78***c*, and a fourth region **78***d*.

The first region **78***a* is the region enclosed by the first side **70***s***1**, the line segment connecting the centroid **70***crd* to the one end **70***s***11** of the first side **70***s***1**, and the line segment connecting the centroid **70***crd* to the other end **70***s***12** of the first side **70***s***1**.

The second region **78***b* is the region enclosed by the second side **70***s***2**, the line segment connecting the centroid **70***crd* to the one end **70***s***21** of the second side **70***s***2**, and the line segment connecting the centroid **70***crd* to the other end **70***s***22** of the second side **70***s***2**.

The third region **78***c* is the region enclosed by the third side **70***s***3**, the line segment connecting the centroid **70***crd* to the one end **70***s***11** of the first side **70***s***1**, and the line segment connecting the centroid **70***crd* to the one end **70***s***21** of the second side **70***s***2**.

The fourth region **78***d* is the region enclosed by the fourth side **70***s***4**, the line segment connecting the centroid **70***crd* to the other end **70***s***12** of the first side **70***s***1**, and the line segment connecting the centroid **70***crd* to the other end **70***s***22** of the second side **70***s***2**.

As shown in FIG. **25**A and FIG. **25**B, the multiple sensing elements **50** are provided on the portion of the film surface **70***fs* overlapping the first region **78***a*. The positions along the first direction (the X-axis direction) of at least two of the multiple sensing elements **50** provided in the region of the film surface **70***fs* overlapping the first region **78***a* are different from each other.

Also, in the example, the multiple sensing elements **50** are further provided on the portion of the film surface **70***fs* overlapping the second region **78***b*. In other words, multiple sensing elements **50** that are different from the at least two recited above provided on the portion of the film surface **70***fs* overlapping the first region **78***a* are disposed on the portion of the film surface **70***fs* overlapping the second region **78***b*. The positions along the first direction (the X-axis direction) of the at least two other sensing elements **50** disposed on the portion overlapping the second region **78***b* are different from each other.

As in the pressure sensor **121** described above, the circumscribing rectangle **70***cr* can be defined even in the case where the planar configuration of the film part **70***d* (the configuration of the film surface **70***fs*) is a flattened circle. As in the pressure sensors **122** and **123**, the circumscribing rectangle **70***cr* can be defined even in the case where the corner portions **70***sc* having curved configurations or linear configurations are provided in the planar configuration of the film part **70***d* (the configuration of the film surface **70***fs*). Also, the first to fourth regions **78***a* to **78***d* can be defined. In the pressure sensors **121** to **123** as well, the multiple sensing elements **50** are provided on the portion of the film surface **70***fs* overlapping the first region **78***a*. The positions along the first direction (the X-axis direction) of the at least two of the multiple sensing elements **50** provided in the region of the film surface **70***fs* overlapping the first region **78***a* are different from each other. Further, the multiple sensing elements **50** are provided on the portion of the film surface **70***fs* overlapping the second region **78***b*. The positions along the first direction (the X-axis direction) of the at least two other sensing elements **50** disposed on the portion overlapping the second region **78***b* are different from each other.

FIG. **26** is a schematic perspective view illustrating another pressure sensor according to the second embodiment.

In the pressure sensor **124** according to the embodiment as shown in FIG. **26**, the planar configuration of the film part **70***d* is a square. Otherwise, the pressure sensor **124** is similar to the pressure sensor **120**.

In the example, the film part **70***d* includes the first side **70***s***1** provided along the first direction (e.g., the X-axis direction), the second side **70***s***2** provided along the first direction to be separated from the first side **70***s***1**, the third side **70***s***3** provided along the second direction (e.g., the Y-axis direction) to be connected to the one end **70***s***11** of the first side **70***s***1** and the one end **70***s***21** of the second side **70***s***2**, and the fourth side **70***s***4** provided along the second direction to be separated from the third side **70***s***3** and connected to the other end **70***s***12** of the first side **70***s***1** and the other end **70***s***22** of the second side **70***s***2**.

The peripheral portion **70***p* of the film part **70***d* includes the first element disposition region **76** provided along the first side **70***s***1**. The multiple sensing elements **50** are arranged along the first side **70***s***1** in the first element disposition region **76**. According to the pressure sensor **124** as well, a highly-sensitive pressure sensor is obtained.

FIG. **27**A and FIG. **27**B are schematic views illustrating the configuration and characteristics of another pressure sensor according to the second embodiment.

FIG. **27**A is a schematic perspective view illustrating the film part **70***d* of the pressure sensor **124**. In the pressure sensor **124**, the first length L1 is 500 μm; the second length L2 also is 500 μm; and the thickness Lt is 2 μm.

FIG. **27**B illustrates the distribution in the X-Y plane of the anisotropic strain $\Delta\varepsilon$ occurring in the film part **70***d*.

As shown in FIG. **27**A, in the pressure sensor **124** as well, the end portion anisotropic strain occurrence region **75***a* having a large surface area is obtained.

In the pressure sensor **124** as well, the multiple sensing elements **50** are provided on the portions of the film surface **70***fs* overlapping the first region **78***a* and the second region **78***b*. Also, the positions along the first direction (the X-axis direction) of the at least two of the multiple sensing elements **50** provided in the regions of the film surface **70***fs* overlapping the first region **78***a* and the second region **78***b* are different from each other.

Third Embodiment

FIG. **28** is a schematic perspective view illustrating a pressure sensor according to a third embodiment.

As shown in FIG. **28**, the multiple sensing units **50***u* are provided in the pressure sensor **130** according to the embodiment. One sensing unit **50***u* is provided on the central portion **70***c* of the film part **70***d*. Another sensing unit **50***u* is provided on the first element disposition region **76**. One other sensing unit **50***u* is provided on the second element disposition region **77**. In the example, the first element disposition region **76** is provided along the first side **70***s***1** (the long side); and the second element disposition region **77** is provided along the second side **70***s***2** (the long side). The positions along the first direction of at least two of the multiple sensing elements **50** are different from each other.

FIG. **29** is a schematic perspective view illustrating another pressure sensor according to the third embodiment.

In the pressure sensor **131** according to the embodiment as shown in FIG. **29**, the multiple sensing units **50***u* are provided on the central portion **70***c*, the first element disposition region **76**, and the second element disposition region **77**. In the example, the first element disposition region **76** is provided along the third side **70***s***3** (the short side); and the second element disposition region **77** is provided along the fourth side **70***s***4** (the short side).

FIG. **30** is a schematic perspective view illustrating another pressure sensor according to the third embodiment.

In the pressure sensor **132** according to the embodiment as shown in FIG. **30**, the sensing unit **50***u* is provided on the central portion **70***c*. Further, element disposition regions are provided along the first to fourth sides **70***s***1** to **70***s***4**; and the sensing units **50***u* are provided on the element disposition regions.

FIG. **31** is a schematic perspective view illustrating another pressure sensor according to the third embodiment.

In the pressure sensor **133** according to the embodiment as shown in FIG. **31**, element disposition regions are provided along the first to fourth sides **70***s***1** to **70***s***4**; and the sensing units **50***u* are provided on the element disposition regions.

In the pressure sensors **130** to **133**, the planar configuration of the film part **70***d* is a rectangle. The planar configuration of the film part **70***d* may be an ellipse. Or, the planar configuration of the film part **70***d* may be a square.

FIG. **32** is a schematic perspective view illustrating another pressure sensor according to the third embodiment.

In the pressure sensor **134** according to the embodiment as shown in FIG. **32**, the planar configuration of the film part **70***d* is a square. Element disposition regions are provided along the first to fourth sides **70***s***1** to **70***s***4**; and the sensing units **50***u* are provided on the element disposition regions.

In the pressure sensors **130** to **134**, the multiple sensing elements **50** included in the sensing unit **50***u* are arranged along the sides (the first to fourth sides **70***s***1** to **70***s***4**, etc.) of the film part **70***d*.

An example of the sensing element used in the pressure sensors according to the first to third embodiments will now be described.

Herein, "material A/material B" indicates the state in which a layer of material B is provided on a layer of material A.

FIG. **33** is a schematic perspective view illustrating the sensing element used in the embodiment.

As shown in FIG. **33**, the sensing element **201** used in the embodiment includes a lower electrode **58***l*, a foundation layer **59**, a pinning layer **55***p*, a second magnetization fixed layer **52**, a magnetic coupling layer **55***x*, a first magnetization fixed layer **51**, the spacer layer **30**, a magnetization free layer **55***f*, a capping layer **55***c*, and an upper electrode **58***u* arranged in order.

In the example, the magnetization free layer **55***f* corresponds to the first magnetic layer **10**; and the first magnetization fixed layer **51** corresponds to the second magnetic layer **20**. The sensing element **201** is a bottom spin-valve type element.

The foundation layer **59** includes, for example, Ta/Ru. The thickness (the length in the Z-axis direction) of the Ta layer is, for example, 3 nm. The thickness of the Ru layer is, for example, 2 nm.

The pinning layer **55***p* includes, for example, an IrMn layer having a thickness of 7 nm. The second magnetization fixed layer **52** includes, for example, a $Co_{75}Fe_{25}$ layer having a thickness of 2.5 nm. The magnetic coupling layer **55***x* includes, for example, a Ru layer having a thickness of 0.9 nm.

The first magnetization fixed layer **51** includes, for example, a $Co_{40}Fe_{40}B_{20}$ layer having a thickness of 3 nm. The spacer layer **30** includes, for example, a MgO layer having a thickness of 1.5 nm. The magnetization free layer **55***f* includes, for example, $Co_{40}Fe_{40}B_{20}/Fe_{80}Ga_{20}$. The

thickness of the $Co_{40}Fe_{40}B_{20}$ layer is about 2 nm. The thickness of the $Fe_{80}Ga_{20}$ layer is 4 nm.

The capping layer **55**c includes, for example, Ta/Ru. The thickness of the Ta layer is, for example, 1 nm. The thickness of the Ru layer is, for example, 5 nm.

The lower electrode **58**l and the upper electrode **58**u include, for example, at least one selected from aluminum (Al), an aluminum copper alloy (Al—Cu), copper (Cu), silver (Ag), and gold (Au). A current can be caused to flow efficiently in the sensing element **50** by using such a material that has a relatively small electrical resistance as the lower electrode **58**l and the upper electrode **58**u.

The lower electrode **58**l may have a structure in which at least one layer selected from Al, Al—Cu, Cu, Ag, and Au is provided between a capping layer (not shown) and a foundation layer (not shown) that are for the lower electrode **58**l. For example, the lower electrode **58**l includes tantalum (Ta)/copper (Cu)/tantalum (Ta), etc. For example, the adhesion between the film part and the lower electrode **58**l can be improved by using Ta as the foundation layer for the lower electrode **58**l. Titanium (Ti), titanium nitride (TiN), etc., may be used as the foundation layer for the lower electrode **58**l.

Oxidization of the copper (Cu), etc., under the capping layer for the lower electrode **58**l can be prevented by using Ta as the capping layer. Titanium (Ti), titanium nitride (TiN), etc., may be used as the capping layer for the lower electrode **58**l.

The foundation layer **59** may include a stacked structure of a buffer layer (not shown) and a seed layer (not shown). For example, the buffer layer relaxes the irregularity of the surfaces of the lower electrode **58**l and the film part and improves the crystallinity of the layers stacked on the buffer layer. For example, at least one selected from the group consisting of tantalum (Ta), titanium (Ti), vanadium (V), tungsten (W), zirconium (Zr), hafnium (Hf), and chrome (Cr) is used as the buffer layer. An alloy including at least one material selected from these materials may be used as the buffer layer.

It is favorable for the thickness of the buffer layer to be not less than 1 nm and not more than 10 nm. It is more favorable for the thickness of the buffer layer to be not less than 1 nm and not more than 5 nm. The buffering effect is lost when the thickness of the buffer layer is too thin. The thickness of the sensing element **50** becomes excessively thick when the thickness of the buffer layer is too thick. A seed layer may be formed on the buffer layer; and the seed layer may have a buffering effect. The buffer layer may be omitted. The buffer layer includes, for example, a Ta layer having a thickness of 3 nm.

A not-shown seed layer controls the crystal orientation of the layers stacked on the seed layer. The seed layer controls the crystal grain size of the layers stacked on the seed layer. A metal or the like having a fcc structure (face-centered cubic structure), a hcp structure (hexagonal close-packed structure), or a bcc structure (body-centered cubic structure) is used as the seed layer.

By using ruthenium (Ru) having a hcp structure, NiFe having a fcc structure, or Cu having a fcc structure as the seed layer, for example, the crystal orientation of the spin-valve film on the seed layer can have a fcc (111) orientation. The seed layer includes, for example, a Cu layer having a thickness of 2 nm or a Ru layer having a thickness of 2 nm. To improve the crystal orientation of the layers formed on the seed layer, it is favorable for the thickness of the seed layer to be not less than 1 nm and not more than 5 nm. It is more favorable for the thickness of the seed layer to be not less than 1 nm and not more than 3 nm. Thereby, the function as the seed layer of improving the crystal orientation is sufficiently realized. On the other hand, for example, in the case where it is unnecessary to cause the layers formed on the seed layer to have a crystal orientation (e.g., in the case where an amorphous magnetization free layer **55**f is formed, etc.), the seed layer may be omitted. For example, a Cu layer having a thickness of 2 nm is used as the seed layer.

For example, the pinning layer **55**p provides unidirectional anisotropy to the ferromagnetic layer of the second magnetization fixed layer **52** formed on the pinning layer **55**p to fix the magnetization. The pinning layer **55**p includes, for example, an antiferromagnetic layer. The pinning layer **55**p includes, for example, at least one selected from the group consisting of IrMn, PtMn, PdPtMn, and RuRhMn. The thickness of the pinning layer **55**p is set appropriately to provide unidirectional anisotropy of sufficient strength.

In the case where PtMn or PdPtMn is used as the pinning layer **55**p, it is favorable for the thickness of the pinning layer **55**p to be not less than 8 nm and not more than 20 nm. It is more favorable for the thickness of the pinning layer **55**p to be not less than 10 nm and not more than 15 nm. The pinning layer **55**p that provides the unidirectional anisotropy can be thinner in the case where IrMn is used as the pinning layer **55**p than in the case where PtMn is used as the pinning layer **55**p. In such a case, it is favorable for the thickness of the pinning layer **55**p to be not less than 4 nm and not more than 18 nm. It is more favorable for the thickness of the pinning layer **55**p to be not less than 5 nm and not more than 15 nm. The pinning layer **55**p includes, for example, an $Ir_{22}Mn_{78}$ layer having a thickness of 7 nm.

A hard magnetic layer may be used as the pinning layer **55**p. For example, CoPt (having a proportion of Co of not less than 50 at. % and not more than 85 at. %), $(Co_x Pt_{100-x})_{100-y}Cr_y$ (x being not less than 50 at. % and not more than 85 at. % and y being not less than 0 at. % and not more than 40 at. %), FePt (having a proportion of Pt of not less than 40 at. % and not more than 60 at. %), etc., may be used as the hard magnetic layer.

The second magnetization fixed layer **52** includes, for example, a Co_xFe_{100-x} alloy (x being not less than 0 at. % and not more than 100 at. %), a 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 alloys. For example, at least one selected from the group consisting of Co, Fe, and Ni is used as the second magnetization fixed layer **52**. An alloy including at least one material selected from these materials may be used as the second magnetization fixed layer **52**. A $(Co_xFe_{100-x})_{100-y}B_y$ alloy (x being not less than 0 at. % and not more than 100 at. % and y being not less than 0 at. % and not more than 30 at. %) may be used as the second magnetization fixed layer **52**. By using an amorphous alloy of $(Co_xFe_{100-x})_{100-y}B_y$ as the second magnetization fixed layer **52**, the fluctuation between the sensing elements **50** can be suppressed even in the case where the sensing element **50** is small.

It is favorable for the thickness of the second magnetization fixed layer **52** to be, for example, not less than 1.5 nm and not more than 5 nm. Thereby, for example, the strength of the unidirectional anisotropic magnetic field due to the pinning layer **55**p can be stronger. For example, the strength of the antiferromagnetic coupling magnetic field between the second magnetization fixed layer **52** and the first magnetization fixed layer **51** via the magnetic coupling layer **55**x formed on the second magnetization fixed layer **52** can be stronger. It is favorable for the magnetic thickness of the second magnetization fixed layer **52** (the product of a

saturation magnetization Bs and a thickness t (Bs·t)) to be substantially equal to the magnetic thickness of the first magnetization fixed layer **51**.

For a thin film, the saturation magnetization of $Co_{40}Fe_{40}B_{20}$ is about 1.9 T (teslas). For example, the magnetic thickness of the first magnetization fixed layer **51** is 1.9 T×3 nm which is 5.7 Tnm in the case where a $Co_{40}Fe_{40}B_{20}$ layer having a thickness of 3 nm is used as the first magnetization fixed layer **51**. On the other hand, the saturation magnetization of $Co_{75}Fe_{25}$ is about 2.1 T. The thickness of the second magnetization fixed layer **52** to obtain a magnetic thickness that is equal to that recited above is 5.7 Tnm/2.1 T which is 2.7 nm. In such a case, it is favorable for the second magnetization fixed layer **52** to include $Co_{75}Fe_{25}$ having a thickness of about 2.7 nm. For example, a $Co_{75}Fe_{25}$ layer having a thickness of 2.5 nm is used as the second magnetization fixed layer **52**.

In the sensing element **201**, a synthetic pinned structure of the second magnetization fixed layer **52**, the magnetic coupling layer **55***x*, and the first magnetization fixed layer **51** is used. Instead, a single pinned structure made of one magnetization fixed layer may be used. In the case where the single pinned structure is used, for example, a $Co_{40}Fe_{40}B_{20}$ layer having a thickness of 3 nm is used as the magnetization fixed layer. The same material as the first magnetization fixed layer **51** described above may be used as the ferromagnetic layer used in the magnetization fixed layer of the single pinned structure.

The magnetic coupling layer **55***x* causes antiferromagnetic coupling to occur between the second magnetization fixed layer **52** and the first magnetization fixed layer **51**. The magnetic coupling layer **55***x* forms a synthetic pinned structure. For example, Ru is used as the magnetic coupling layer **55***x*. It is favorable for the thickness of the magnetic coupling layer **55***x* to be not less than 0.8 nm and not more than 1 nm. A material other than Ru may be used as the magnetic coupling layer if the material can cause sufficient antiferromagnetic coupling to occur between the second magnetization fixed layer **52** and the first magnetization fixed layer **51**. The thickness of the magnetic coupling layer **55***x* may be set to be a thickness not less than 0.8 nm and not more than 1 nm that corresponds to the second peak (2nd peak) of RKKY (Ruderman-Kittel-Kasuya-Yosida) coupling. Further, the thickness of the magnetic coupling layer **55***x* may be set to be a thickness not less than 0.3 nm and not more than 0.6 nm that corresponds to the first peak (1st peak) of RKKY coupling. For example, Ru having a thickness of 0.9 nm is used as the magnetic coupling layer **55***x*. Thereby, highly reliable coupling is obtained more stably.

The magnetic layer that is used in the first magnetization fixed layer **51** contributes directly to the MR effect. For example, a Co—Fe—B alloy is used as the first magnetization fixed layer **51**. Specifically, a $(Co_xFe_{100-x})_{100-y}B_y$ alloy (x being not less than 0 at. % and not more than 100 at. % and y being not less than 0 at. % and not more than 30 at. %) may be used as the first magnetization fixed layer **51**. In the case where an amorphous alloy of $(Co_xFe_{100-x})_{100-y}B_y$ is used as the first magnetization fixed layer **51**, for example, the fluctuation between the elements caused by the crystal grains can be suppressed even in the case where the sensing element is small.

The layer (e.g., a tunneling insulating layer (not shown)) that is formed on the first magnetization fixed layer **51** can be planarized. By planarizing the tunneling insulating layer, the defect density of the tunneling insulating layer can be reduced. Thereby, a higher MR ratio having a lower resistance per area is obtained. For example, in the case where MgO is used as the material of the tunneling insulating layer, the (100) orientation of the MgO layer formed on the tunneling insulating layer can be improved by using an amorphous alloy of $(Co_xFe_{100-x})_{100-y}B_y$. A higher MR ratio is obtained by improving the (100) orientation of the MgO layer. The $(Co_xFe_{100-x})_{100-y}B_y$ alloy crystallizes using the (100) plane of the MgO layer as a template in the annealing. Therefore, good crystal conformation between the MgO and $(Co_xFe_{100-x})_{100-y}B_y$ alloy is obtained. A higher MR ratio is obtained by obtaining good crystal conformation.

Other than the Co—Fe—B alloy, for example, an Fe—Co alloy may be used as the first magnetization fixed layer **51**.

The MR ratio increases as the thickness of the first magnetization fixed layer **51** increases. A thinner first magnetization fixed layer **51** is favorable to obtain a larger magnetization fixed field. A trade-off relationship between the MR ratio and the magnetization fixed field exists for the thickness of the first magnetization fixed layer **51**. In the case where the Co—Fe—B alloy is used as the first magnetization fixed layer **51**, it is favorable for the thickness of the first magnetization fixed layer **51** to be not less than 1.5 nm and not more than 5 nm. It is more favorable for the thickness of the first magnetization fixed layer **51** to be not less than 2.0 nm and not more than 4 nm.

Other than the materials described above, the first magnetization fixed layer **51** may include a $Co_{90}Fe_{10}$ alloy having a fcc structure, Co having a hcp structure, or a Co alloy having a hcp structure. At least one selected from the group consisting of Co, Fe, and Ni is used as the first magnetization fixed layer **51**. An alloy including at least one material selected from these materials is used as the first magnetization fixed layer **51**. For example, a higher MR ratio is obtained by using an FeCo alloy material having a bcc structure, a Co alloy including a cobalt composition not less than 50 at. %, or a material having a Ni composition not less than 50 at. % as the first magnetization fixed layer **51**. A Heusler magnetic alloy layer such as Co_2MnGe, Co_2FeGe, Co_2MnSi, Co_2FeSi, Co_2MnAl, Co_2FeAl, $Co_2MnGa_{0.5}Ge_{0.5}$, $Co_2FeGa_{0.5}Ge_{0.5}$, etc., may be used as the first magnetization fixed layer **51**. For example, a $Co_{40}Fe_{40}B_{20}$ layer having a thickness of 3 nm is used as the first magnetization fixed layer **51**.

The spacer layer **30** divides the magnetic coupling between the first magnetization fixed layer **51** and the magnetization free layer **55***f*. The spacer layer **30** includes a metal, an insulator, or a semiconductor. For example, Cu, Au, Ag, etc., may be used as the metal. In the case where the metal is used as the spacer layer **30**, the thickness of the spacer layer **30** is, for example, not less than about 1 nm and not more than about 7 nm. For example, magnesium oxide (MgO, etc.), aluminum oxide (Al_2O_3, etc.), titanium oxide (TiO, etc.), zinc oxide (ZnO, etc.), gallium oxide (Ga—O), etc., may be used as the insulator or the semiconductor. In the case where the insulator or the semiconductor is used as the spacer layer **30**, the thickness of the spacer layer **30** is, for example, not less than about 0.6 nm and not more than about 2.5 nm. For example, a CCP (Current-Confined-Path) spacer layer may be used as the spacer layer **30**. In the case where the CCP spacer layer is used as the spacer layer, for example, a structure in which copper (Cu) metal paths are formed in an insulating layer of aluminum oxide (Al_2O_3) is used. For example, a MgO layer having a thickness of 1.5 nm is used as the spacer layer **30**.

The magnetization free layer **55***f* includes a ferromagnet material. For example, an FeCo alloy, a NiFe alloy, etc., may be used as the material of the magnetization free layer **55***f*. Further, the magnetization free layer **55***f* may include a

Co—Fe—B alloy, an Fe—Co—Si—B alloy, an Fe—Ga alloy having a large λs (magnetostriction constant), an 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 and 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 and M4 being at least one selected from the group consisting of Ce, Pr, Nd, Sm, Tb, Dy, and Er), Ni, Fe—Al, ferrite (Fe_3O_4, $(FeCo)_3O_4$, etc.), and the like. The thickness of the magnetization free layer **55*f*** is, for example, not less than 2 nm.

The magnetization free layer **55*f*** may have a multilayered structure. The magnetization free layer **55*f*** may have, for example, a two-layer structure. In the case where a tunneling insulating layer of MgO is used as the spacer layer **30**, it is favorable to provide a layer of a Co—Fe—B alloy at the interface contacting the spacer layer **30**. Thereby, a high magnetoresistance effect is obtained. In such a case, the layer of the Co—Fe—B alloy may be provided on the spacer layer **30**; and an Fe—Co—Si—B alloy, an Fe—Ga alloy having a large λs, an 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 and 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 and M4 being at least one selected from the group consisting of Ce, Pr, Nd, Sm, Tb, Dy, and Er), Ni, Fe—Al, ferrite (Fe_3O_4, $(FeCo)_3O_4$, etc.), and the like may be formed on the layer of Co—Fe—B alloy. For example, the magnetization free layer **55*f*** includes $Co_{40}Fe_{40}B_{20}/Fe_{80}Ga_{20}$. The thickness of the $Co_{40}Fe_{40}B_{20}$ is, for example, 2 nm. The thickness of the $Fe_{80}Ga_{20}$ is, for example, 4 nm. λs is, for example, greater than 100 ppm.

The capping layer **55*c*** protects the layers provided under the capping layer **55*c***. The capping layer **55*c*** includes, for example, multiple metal layers. The capping layer **55*c*** includes, for example, a two-layer structure of a Ta layer and a Ru layer (Ta/Ru). The thickness of the Ta layer is, for example, 1 nm; and the thickness of the Ru layer is, for example, 5 nm. Other metal layers may be provided instead of the Ta layer and/or the Ru layer as the capping layer **55*c***. The configuration of the capping layer **55*c*** is arbitrary. The capping layer **55*c*** may include, for example, a nonmagnetic material. Other materials may be used as the capping layer **55*c*** if the layers provided under the capping layer **55*c*** can be protected.

FIG. **34** is a schematic perspective view illustrating another sensing element used in the embodiment.

As shown in FIG. **34**, the sensing element **202** used in the pressure sensor according to the embodiment includes the lower electrode **58*l***, the foundation layer **59**, the magnetization free layer **55*f***, the spacer layer **30**, the first magnetization fixed layer **51**, the magnetic coupling layer **55*x***, the second magnetization fixed layer **52**, the pinning layer **55*p***, the capping layer **55*c***, and the upper electrode **58*u*** arranged in order.

In the example, the magnetization free layer **55*f*** corresponds to the first magnetic layer **10**; and the first magnetization fixed layer **51** corresponds to the second magnetic layer **20**. The sensing element **202** is a top spin-valve type element.

The foundation layer **59** includes, for example, Ta/Ru. The thickness of the Ta layer is, for example, 3 nm. The thickness of the Ru layer is, for example, 2 nm.

The magnetization free layer **55*f*** includes, for example, $Fe_{80}Ga_{20}/Co_{40}Fe_{40}B_{20}$. The thickness of the $Fe_{80}Ga_{20}$ layer is, for example, 4 nm. The thickness of the $Co_{40}Fe_{40}B_{20}$ layer is, for example, 2 nm.

The spacer layer **30** includes, for example, a MgO layer having a thickness of 1.5 nm. The first magnetization fixed layer **51** includes, for example, $Co_{40}Fe_{40}B_{20}/Fe_{50}Co_{50}$. The thickness of the $Co_{40}Fe_{40}B_{20}$ layer is, for example, 2 nm. The thickness of the $Fe_{50}Co_{50}$ layer is, for example, 1 nm. The magnetic coupling layer **55*x*** includes, for example, a Ru layer having a thickness of 0.9 nm. The second magnetization fixed layer **52** includes, for example, a $Co_{75}Fe_{25}$ layer having a thickness of 2.5 nm. The pinning layer **55*p*** includes, for example, an IrMn layer having a thickness of 7 nm.

The capping layer **55*c*** includes Ta/Ru. The thickness of the Ta layer is, for example, 1 nm. The thickness of the Ru layer is, for example, 5 nm.

For example, the materials described in regard to the sensing element **201** may be used respectively in the layers included in the sensing element **202**.

FIG. **35** is a schematic perspective view illustrating another sensing element used in the embodiment.

As shown in FIG. **35**, the sensing element **203** used in the pressure sensor according to the embodiment includes the lower electrode **58*l***, the foundation layer **59**, the pinning layer **55*p***, the second magnetization fixed layer **52**, the magnetic coupling layer **55*x***, the first magnetization fixed layer **51**, the spacer layer **30**, the magnetization free layer **55*f***, a spacer layer **30*a***, a first magnetization fixed layer **51*a***, a magnetic coupling layer **55*xa***, a second magnetization fixed layer **52*a***, a pinning layer **55*pa***, the capping layer **55*c***, and the upper electrode **58*u*** arranged in order.

The magnetization free layer **55*f*** corresponds to the first magnetic layer **10**; and the first magnetization fixed layer **51** corresponds to the second magnetic layer **20**. In the sensing elements **201** and **202** described above, the magnetization fixed layer is disposed at one surface of the magnetization free layer **55*f***. In the sensing element **203**, the magnetization free layer **55*f*** is disposed between two magnetization fixed layers. The sensing element **203** is a dual spin-valve type element.

The foundation layer **59** includes, for example, Ta/Ru. The thickness of the Ta layer is, for example, 3 nm. The thickness of the Ru layer is, for example, 2 nm. The pinning layer **55*p*** includes, for example, an IrMn layer having a thickness of 7 nm. The second magnetization fixed layer **52** includes, for example, a $Co_{75}Fe_{25}$ layer having a thickness of 2.5 nm. The magnetic coupling layer **55*x*** includes, for example, a Ru layer having a thickness of 0.9 nm. The first magnetization fixed layer **51** includes, for example, a $Co_{40}Fe_{40}B_{20}$ layer having a thickness of 3 nm. The spacer layer **30** includes, for example, a MgO layer having a thickness of 1.5 nm.

The magnetization free layer **55*f*** includes, for example, $Co_{40}Fe_{40}B_{20}/Fe_{80}Ga_{20}/Co_{40}Fe_{40}B_{20}$. The thickness of the $Fe_{80}Ga_{20}$ layer is, for example, 4 nm. The thicknesses of the two $Co_{40}Fe_{40}B_{20}$ layers are, for example, 2 nm.

The spacer layer **30*a*** includes, for example, a MgO layer having a thickness of 1.5 nm. The first magnetization fixed layer **51*a*** includes, for example, $Co_{40}Fe_{40}B_{20}/Fe_{50}Co_{50}$.

The thickness of the $Co_{40}Fe_{40}B_{20}$ layer is, for example, 2 nm. The thickness of the $Fe_{50}Co_{50}$ layer is, for example, 1 nm. The magnetic coupling layer **55***xa* includes, for example, a Ru layer having a thickness of 0.9 nm. The second magnetization fixed layer **52***a* includes, for example, a $Co_{75}Fe_{25}$ layer having a thickness of 2.5 nm. The pinning layer **55***pa* includes, for example, an IrMn layer having a thickness of 7 nm.

The capping layer **55***c* includes Ta/Ru. The thickness of the Ta layer is, for example, 1 nm. The thickness of the Ru layer is, for example, 5 nm.

For example, the materials described in regard to the sensing element **201** may be used in the layers included in the sensing element **203**.

FIG. **36** is a schematic perspective view illustrating another sensing element used in the embodiment.

As shown in FIG. **36**, the sensing element **204** used in the pressure sensor according to the embodiment includes the lower electrode **58***l*, the foundation layer **59**, the pinning layer **55***p*, the first magnetization fixed layer **51**, the spacer layer **30**, the magnetization free layer **55***f*, the capping layer **55***c*, and the upper electrode **58***u* arranged in order.

The magnetization free layer **55***f* corresponds to the first magnetic layer **10**; and the first magnetization fixed layer **51** corresponds to the second magnetic layer **20**. In the sensing elements **201** and **202** described above, a structure that uses the second magnetization fixed layer **52**, the magnetic coupling layer **55***x*, and the first magnetization fixed layer **51** is used. In the sensing element **204**, a single pinned structure that uses a single magnetization fixed layer is used.

The foundation layer includes, for example, Ta/Ru. The thickness of the Ta layer is, for example, 3 nm. The thickness of the Ru layer is, for example, 2 nm. The pinning layer **55***p* includes, for example, an IrMn layer having a thickness of 7 nm. The first magnetization fixed layer **51** includes, for example, a $Co_{40}Fe_{40}B_{20}$ layer having a thickness of 3 nm. The spacer layer **30** includes, for example, a MgO layer having a thickness of 1.5 nm.

The magnetization free layer **55***f* includes, for example, $Co_{40}Fe_{40}B_{20}/Fe_{80}Ga_{20}$. The thickness of the $Fe_{80}Ga_{20}$ layer is, for example, 4 nm. The thickness of the $Co_{40}Fe_{40}B_{20}$ layer is, for example, 2 nm.

The capping layer **55***c* includes Ta/Ru. The thickness of the Ta layer is, for example, 1 nm. The thickness of the Ru layer is, for example, 5 nm.

For example, the materials described in regard to the sensing element **201** may be used in the layers included in the sensing element **204**.

FIG. **37** is a schematic perspective view illustrating another sensing element used in the embodiment.

As shown in FIG. **37**, the sensing element **205** used in the pressure sensor according to the embodiment includes the lower electrode **58***l*, the foundation layer **59**, a second magnetization free layer **55***fb*, the spacer layer **30**, a first magnetization free layer **55***fa*, the capping layer **55***c*, and the upper electrode **58***u* arranged in order.

The second magnetization free layer **55***fb* corresponds to the second magnetic layer **20**; and the first magnetization free layer **55***fa* corresponds to the first magnetic layer **10**. In the sensing elements **201** to **204** described above, the reference layer used in the second magnetic layer **20** is a magnetization fixed layer. In the sensing element **205**, the reference layer used in the second magnetic layer **20** is a magnetization free layer.

The foundation layer **59** includes, for example, Ta/Ru. The thickness of the Ta layer is, for example, 3 nm. The thickness of the Ru layer is, for example, 2 nm.

The second magnetization free layer **55***fb* includes, for example, a $Co_{40}Fe_{40}B_{20}$ layer having a thickness of 4 nm. The spacer layer **30** includes, for example, a MgO layer having a thickness of 1.5 nm.

The first magnetization free layer **55***fa* includes, for example, $Co_{40}Fe_{40}B_{20}$. The thickness of the $Co_{40}Fe_{40}B_{20}$ layer is, for example, 4 nm.

The capping layer **55***c* includes Ta/Ru. The thickness of the Ta layer is, for example, 1 nm. The thickness of the Ru layer is, for example, 5 nm.

For example, the materials described in regard to the sensing element **201** may be used in the layers included in the sensing element **205**.

As in the sensing element **205**, the relative angle between the magnetization of the second magnetization free layer and the magnetization of the first magnetization free layer changes due to the strain even in the case where the stacked structure of the second magnetization free layer **55***fb*, the spacer layer **30**, and the first magnetization free layer **55***fa* is used. Thereby, it is possible to function as a strain sensor. In such a case, the value of the magnetostriction of the second magnetization free layer **55***fb* and the value of the magnetostriction of the first magnetization free layer **55***fa* are designed to be different from each other. Thereby, the relative angle between the magnetization of the second magnetization free layer and the magnetization of the first magnetization free layer changes due to the strain.

FIG. **38** is a schematic perspective view illustrating another sensing element used in the embodiment.

As illustrated in FIG. **38**, an insulating layer **58***i* is provided in the sensing element **206**. Namely, two insulating layers **58***i* (insulating portions) that are separated from each other are provided between the lower electrode **58***l* and the upper electrode **58***u*; and a stacked body **57** is disposed between the two insulating layers **58***i*. The stacked body **57** is disposed between the lower electrode **58***l* and the upper electrode **58***u*. In the case of the sensing element **201**, the stacked body **57** includes the foundation layer **59**, the pinning layer **55***p*, the second magnetization fixed layer **52**, the magnetic coupling layer **55***x*, the first magnetization fixed layer **51**, the spacer layer **30**, the magnetization free layer **55***f*, and the capping layer **55***c*. In other words, the insulating layers **58***i* are provided to oppose the side walls of the stacked body **57**.

The insulating layers **58***i* may include, for example, aluminum oxide (e.g., Al_2O_3), silicon oxide (e.g., SiO_2), etc. Leak current around the stacked body **57** can be suppressed by the insulating layers **58***i*.

The insulating layers **58***i* recited above are applicable also to any of the sensing elements **201** to **205**.

FIG. **39** is a schematic perspective view illustrating another sensing element used in the embodiment.

As illustrated in FIG. **39**, a hard bias layer **58***h* is further provided in the sensing element **207**. Namely, two hard bias layers **58***h* (hard bias portions) that are separated from each other are provided between the lower electrode **58***l* and the upper electrode **58***u*; and the stacked body **57** is disposed between the two hard bias layers **58***h*. The insulating layers **58***i* are disposed between the hard bias layers **58***h* and the stacked body **57**. Also, in the example, the insulating layers **58***i* extend between the hard bias layers **58***h* and the lower electrode **58***l*.

The hard bias layers **58***h* cause at least one selected from the magnetization of the first magnetic layer **10** and the magnetization of the second magnetic layer **20** to be in the desired direction by the magnetization of the hard bias layers **58***h*. By the hard bias layers **58***h*, at least one selected from

the magnetization of the first magnetic layer **10** and the magnetization of the second magnetic layer can be set to be in the desired direction in the state in which the pressure is not applied to the film part **70***d*.

The hard bias layer **58***h* includes, for example, a hard ferromagnetic material having a relatively high magnetic anisotropy such as CoPt, CoCrPt, FePt, etc. The hard bias layer **58***h* may include a structure in which a layer of a soft magnetic material such as FeCo, Fe, etc., is stacked with an antiferromagnetic layer. In such a case, the magnetization is along a prescribed direction due to exchange coupling. The thickness of the hard bias layer **58***h* (the length along the direction from the lower electrode **58***l* toward the upper electrode **58***u*) is, for example, not less than 5 nm and not more than 50 nm.

The hard bias layer **58***h* and the insulating layer **58***i* recited above are applicable also to any of the sensing elements **201** to **205**.

The sensing elements **201** to **207** recited above can be used as the sensing element **50** according to the embodiment.

In the embodiment, the sensing element functions sufficiently as the pressure sensor even in the case where the sensing element is small. For example, the surface area (the surface area when projected onto the X-Y plane) of the sensing element **50** can be 1/100 of the surface area of the film part **70***d* or less. For example, in the case where the widths of the film part **70***d* (the first length L1 and the second length L2) are about 100 μm, the length of the sensing element **50** in the first direction when projected onto the X-Y plane can be 10 μm or less. For example, in the case of a circle, the diameter can be about 10 μm or less. For example, in the case where the width of the film part **70***d* is about 500 μm, the length of the sensing element **50** in the first direction when projected onto the X-Y plane can be 50 μm or less. For example, in the case of a circle, the diameter can be about 50 μm or less. For example, the length of the sensing element **50** in the first direction when projected onto the X-Y plane is not less than 0.1 μm and not more than 50 μm. By using a small sensing element **50**, the degrees of freedom of the number of the sensing elements **50** to be provided increase.

The planar configuration of the sensing element **50** may be a square, a rectangle, a flattened circle (including an ellipse), or a circle. The planar configuration of the sensing element **50** is arbitrary.

An example of a method for manufacturing a pressure sensor according to the embodiment will now be described. An example of a method for manufacturing the pressure sensor **110** is described below.

FIG. **40**A to FIG. **40**E are schematic cross-sectional views in order of the processes, illustrating the method for manufacturing the pressure sensor according to the embodiment.

As shown in FIG. **40**A, a thin film **90***d* is formed on a substrate **90***s* (e.g., a Si substrate). The substrate **90***s* is used to form the support unit **70***s*. The thin film **90***d* is used to form the film part **70***d*.

For example, a thin film **90***d* of SiO_x/Si is formed on the Si substrate by sputtering. A metal layer such as a SiO_x single layer, a SiN single layer, Al, etc., may be used as the thin film **90***d*. Or, a flexible plastic material such as polyimide, a paraxylene polymer, etc., may be used as the thin film **90***d*. SOI (Silicon On Insulator) substrates may be used as the substrate **90***s* and the thin film **90***d*. In the SOI, for example, a stacked film of SiO_2/Si is formed on the Si substrate by bonding the substrates.

The second interconnect **62** is formed as shown in FIG. **40**B. In this process, a conductive film that is used to form the second interconnect **62** is formed; and the conductive film is patterned by photolithography and etching. Lift-off is applicable in the case where an insulating film is filled around the second interconnect **62**. In the lift-off, for example, the insulating film is formed on the entire surface after etching the pattern of the second interconnect **62** and prior to peeling the resist; and the resist is removed subsequently.

The sensing element **50** is formed as shown in FIG. **40**C. In this process, a stacked film that is used to form the sensing element **50** is formed; and the stacked film is patterned by photolithography and etching. Lift-off is applicable in the case where the side wall of the stacked body **57** of the sensing element **50** is buried in the insulating layer **58***i*. In the lift-off, for example, the insulating layer **58***i* is formed on the entire surface after patterning the stacked body **57** and prior to peeling the resist; and the resist is removed subsequently.

The first interconnect **61** is formed as shown in FIG. **40**D. In this process, a conductive film that is used to form the first interconnect **61** is formed; and the conductive film is patterned by photolithography and etching. Lift-off is applicable in the case where an insulating film is filled around the first interconnect **61**. In the lift-off, the insulating film is formed on the entire surface after patterning the first interconnect **61** and prior to peeling the resist; and the resist is removed subsequently.

As shown in FIG. **40**E, the hollow portion **70***h* is made by performing etching from the back surface of the substrate **90***s*. Thereby, the film part **70***d* and the support unit **70***s* are formed. For example, in the case where the stacked film of SiO_x/Si is used as the thin film **90***d* used to form the film part **70***d*, deep patterning of the substrate **90***s* is performed from the back surface (the lower surface) of the thin film **90***d* toward the front surface (the upper surface) of the thin film **90***d*. Thereby, the hollow portion **70***h* is made. For example, a double-sided aligner exposure apparatus may be used to make the hollow portion **70***h*. Thereby, the hole pattern of the resist can be patterned in the back surface to match the position of the sensing element **50** of the front surface.

A Bosch process using, for example, RIE may be used to etch the Si substrate. In the Bosch process, for example, an etching process using SF_6 gas and a deposition process using C_4F_8 gas are repeated. Thereby, selective etching of the substrate **90***s* in the depth direction (the Z-axis direction) is performed while suppressing the etching of the side wall of the substrate **90***s*. For example, a SiO_x layer is used as the end point of the etching. In other words, the selectivity of the etching is used to stop the etching by using the SiO_x layer which is different from the Si. The SiO_x layer that functions as the etching stopper layer may be used as a portion of the film part **70***d*. After the etching, the SiO_x layer may be removed by processing such as, for example, anhydrous hydrogen fluoride, alcohol, etc.

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

Fourth Embodiment

FIG. **41**A to FIG. **41**C are schematic views illustrating the configuration of a pressure sensor **440** according to a fourth embodiment.

FIG. **41**A is a schematic perspective view; and FIG. **41**B and FIG. **41**C are block diagrams illustrating the configuration of the pressure sensor **440**.

As shown in FIG. **41**A and FIG. **41**B, a base unit **471**, a sensing element **450**, a semiconductor circuit unit **430**, an antenna **415**, an electrical interconnect **416**, a transmitting circuit **417**, and a receiving circuit **417***r* are provided in the pressure sensor **440**.

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

The transmitting circuit **417** performs a wireless transmission of data based on an electrical signal flowing in the sensing element **450** (**50***a*). At least a portion 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 a portion 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, for example, operating the electronic device **418***d*.

Also, as shown in FIG. **41**B, for example, a Manchester encoding unit **417***b* and an AD converter **417***a* that is connected to the sensing element **450** (**50***a*) may be provided in the transmitting circuit **417**. Further, a switching unit **417***c* may be provided to switch between transmitting and receiving. In such a case, a timing controller **417***d* may be provided; and the switching of the switching unit **417***c* may be controlled by the timing controller **417***d*. A data correcting unit **417***e*, a synchronizing unit **417***f*, a determining unit **417***g*, and a voltage-controlled oscillator **417***h* (VCO) may be further provided.

As shown in FIG. **41**C, a receiving unit **418** is provided in the electronic device **418***d* used in combination with the pressure sensor **440**. Electronic devices such as, for example, portable terminals, etc., may be used as the electronic device **418***d*.

In such a case, the electronic device **418***d* that includes the receiving unit **418** can be used in combination with the pressure sensor **440** that includes the transmitting circuit **417**.

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

In the example, the pressure sensor **440** further includes a fixing unit **467**. The fixing unit **467** fixes a film part **464** (**70***d*) to the base unit **471**. The thickness dimension of the fixing unit **467** may be thicker than that of the film part **464** such that the fixing unit **467** does not deflect even when the external pressure is applied.

For example, the fixing unit **467** may be provided at uniform spacing at the circumferential edge of the film part **464**.

Or, the fixing unit **467** may be provided continuously around the entire periphery of the film part **464** (**70***d*).

The fixing unit **467** may be formed from, for example, the same material as the base unit **471**. In such a case, the fixing unit **467** may be formed from, for example, silicon, etc.

It is also possible to form the fixing unit **467** from, for example, the same material as the film part **464** (**70***d*).

Fifth Embodiment

A method for manufacturing a pressure sensor **441** will now be described.

FIG. **42**A, FIG. **42**B, FIG. **43**A, FIG. **43**B, FIG. **44**A, FIG. **44**B, FIG. **45**A, FIG. **45**B, FIG. **46**A, FIG. **46**B, FIG. **47**A, FIG. **47**B, FIG. **48**A, FIG. **48**B, FIG. **49**A, FIG. **49**B, FIG. **50**A, FIG. **50**B, FIG. **51**A, FIG. **51**B, FIG. **52**A, FIG. **52**B, FIG. **53**A, and FIG. **53**B are schematic views illustrating the method for manufacturing the pressure sensor **441** according to the fifth embodiment.

FIG. **42**A to FIG. **53**A are schematic plan views; and FIG. **42**B to FIG. **53**B are schematic cross-sectional views.

Arrows X, Y, and Z illustrate mutually orthogonal directions in the drawings.

First, as shown in FIG. **42**A and FIG. **42**B, a semiconductor layer **512**M is formed at the front surface portion of a semiconductor substrate **531**. Continuing, an element-isolation insulation layer **512**I is formed on the upper surface of the semiconductor layer **512**M. Then, a gate **512**G is formed on the semiconductor layer **512**M with a not-shown insulating layer interposed. Continuing, a transistor **532** is formed by forming a source **512**S and a drain **512**D on two sides of the gate **512**G. Then, an inter-layer insulating film **514***a* is formed on the transistor **532**; and an inter-layer insulating film **514***b* is formed on the inter-layer insulating film **514***a*.

Continuing, trenches and holes are made in a portion of the inter-layer insulating films **514***a* and **514***b* in the region where the non-hollow portion is to be formed. Then, connecting pillars **514***c* to **514***e* are formed by filling a conductive material into the holes. In such a case, for example, the connecting pillar **514***c* is electrically connected to the source **512**S of one transistor **532**; and the connecting pillar **514***d* is electrically connected to the drain **512**D of the one transistor **532**. Also, for example, the connecting pillar **514***e* is electrically connected to the source **512**S of one other transistor **532**. Continuing, interconnect units **514***f* and **514***g* are formed by filling a conductive material into the trenches. The interconnect unit **514***f* is electrically connected to the connecting pillar **514***c* and the connecting pillar **514***d*. The interconnect unit **514***g* is electrically connected to the connecting pillar **514***e*. Continuing, an inter-layer insulating film **514***h* is formed on the inter-layer insulating film **514***b*.

Then, as shown in FIG. **43**A and FIG. **43**B, an inter-layer insulating film **514***i* that is made of silicon oxide (SiO_2) is formed on the inter-layer insulating film **514***h* by, for example, CVD (Chemical Vapor Deposition). Continuing, holes are made at prescribed positions of the inter-layer insulating film **514***i*; a conductive material (e.g., a metal material) is filled; and the upper surface is planarized by CMP (Chemical Mechanical Polishing). Thereby, a connecting pillar **514***j* that is connected to the interconnect unit **514***f* and a connecting pillar **514***k* that is connected to the interconnect unit **514***g* are formed.

Continuing as shown in FIG. **44**A and FIG. **44**B, a recess is made in the region of the inter-layer insulating film **514***i* where a hollow portion **570** is to be made; and a sacrificial layer **514***l* is filled into the recess. The sacrificial layer **514***l* may be formed of, for example, a material that can be formed at a low temperature. The material that can be formed at the low temperature is, for example, silicon-germanium (SiGe), etc.

Then, as shown in FIG. **45**A and FIG. **45**B, an insulating film **561***bf* that is used to form a film part **564** (**70***d*) is formed on the inter-layer insulating film **514***i* and the sacrificial layer **514***l*. The insulating film **561***bf* may be formed of, for example, silicon oxide (SiO_2), etc. A connecting pillar **561***fa* and a connecting pillar **562***fa* are formed by providing multiple holes in the insulating film **561***bf* and by filling a conductive material (e.g., a metal material) into

the multiple holes. The connecting pillar **561***fa* is electrically connected to the connecting pillar **514***k*; and the connecting pillar **562***fa* is electrically connected to the connecting pillar **514***j*.

Continuing as shown in FIG. **46**A and FIG. **46**B, a conductive layer **561***f* that is used to form an interconnect **557** is formed on the insulating film **561***bf*, the connecting pillar **561***fa*, and the connecting pillar **562***fa*.

Then, as shown in FIG. **47**A and FIG. **47**B, a stacked film **550***f* that is used to form the sensing element **50** is formed on the conductive layer **561***f*.

Continuing as shown in FIG. **48**A and FIG. **48**B, the stacked film **550***f* is patterned into a prescribed configuration; and an insulating film **565***f* that is used to form an insulating layer **565** is formed on the stacked film **550***f*. The insulating film **565***f* can be formed by, for example, silicon oxide (SiO_2), etc.

Then, as shown in FIG. **49**A and FIG. **49**B, a portion of the insulating film **565***f* is removed; and the conductive layer **561***f* is patterned into a prescribed configuration. Thereby, the interconnect **557** is formed. At this time, a portion of the conductive layer **561***f* becomes a connecting pillar **562***fb* that is electrically connected to the connecting pillar **562***fa*. Further, an insulating film **566***f* that is used to form an insulating layer **566** is formed on the connecting pillar **562***fb*.

Continuing as shown in FIG. **50**A and FIG. **50**B, an opening **566***p* is made in the insulating film **566***f*. Thereby, the connecting pillar **562***fb* is exposed.

Then, as shown in FIG. **51**A and FIG. **51**B, a conductive layer **562***f* that is used to form an interconnect **558** is formed on the upper surface. A portion of the conductive layer **562***f* is electrically connected to the connecting pillar **562***fb*.

Continuing as shown in FIG. **52**A and FIG. **52**B, the conductive layer **562***f* is patterned into a prescribed configuration. Thereby, the interconnect **558** is formed. The interconnect **558** is electrically connected to the connecting pillar **562***fb*.

Then, as shown in FIG. **53**A and FIG. **53**B, an opening **566***o* having a prescribed configuration is made in the insulating film **566***f*. The insulating film **561***bf* is patterned via the opening **566***o*; and the sacrificial layer **514***l* is removed via the opening **566***o*. Thereby, the hollow portion **570** is made. The removal of the sacrificial layer **514***l* may be performed by, for example, wet etching.

To form a fixing unit **567** to have a ring configuration, for example, the space between the film part **564** and the edge of the non-hollow portion above the hollow portion **570** may be filled with an insulating film.

Thus, the pressure sensor **441** is formed.

FIG. **54** is a flowchart illustrating the method for manufacturing the pressure sensor **441** according to the fifth embodiment.

Namely, FIG. **54** is a flowchart of the method for manufacturing the pressure sensor **441** illustrated in FIG. **42**A to FIG. **53**B.

First, as shown in FIG. **54**, the transistor **532** is formed on the semiconductor substrate **531** (step S**110**).

For example, the transistor **532** is formed as illustrated in FIG. **42**A and FIG. **42**B.

Then, an inter-layer insulating layer is formed on the semiconductor substrate **531**; and the sacrificial layer **514***l* is formed on the transistor **532** (step S**120**).

For example, the inter-layer insulating layers and the sacrificial layer **514***l* are formed as illustrated in FIG. **43**A to FIG. **44**B. For example, the inter-layer insulating film **514***i* is included in the inter-layer insulating layers.

Then, the insulating film **561***bf* that is used to form the film part **564** is formed on the inter-layer insulating layers (e.g., the inter-layer insulating film **514***i*) and the sacrificial layer **514***l* (step S**121**).

In some cases, the conductive layer **561***f* recited below also is used as the film part **564** (**70***d*). In such a case, step S**121** is omitted.

Then, the conductive layer **561***f* that is used to form the interconnect **557** is formed (step S**130**).

For example, the conductive layer **561***f* is formed as illustrated in FIG. **46**A and FIG. **46**B.

Then, the sensing element **550** that includes the first magnetic layer **10** is formed above the sacrificial layer **514***l* and on the conductive layer **561***f* (step S**140**).

For example, the sensing element **550** is formed as illustrated in FIG. **47**A to FIG. **48**B.

Then, the conductive layer **562***f* that is used to form the interconnect **558** is formed on the sensing element **550** (**50***a*) (step S**150**).

For example, the conductive layer **562***f* is formed as illustrated in FIG. **51**A to FIG. **52**B.

Continuing, buried interconnects are formed (step S**160**).

For example, an interconnect that electrically connects the conductive layer **561***f* to the semiconductor substrate **531** and an interconnect that electrically connects the conductive layer **562***f* to the semiconductor substrate **531** are formed inside the inter-layer insulating layers. For example, the buried interconnects are formed as illustrated in FIG. **42**A, FIG. **42**B, FIG. **43**A, FIG. **43**B, FIG. **45**A, FIG. **45**B, FIG. **49**A, and FIG. **49**B.

Step S**160** may be implemented, for example, once or multiple times in any process between step S**110** to step S**150** and after step S**150**.

Then, the sacrificial layer **514***l* is removed (step S**170**).

For example, the sacrificial layer **514***l* is removed as illustrated in FIG. **53**A and FIG. **53**B.

Thus, the pressure sensor is formed.

The content of the processes may be similar to that illustrated in FIG. **42**A to FIG. **53**B; and a detailed description is therefore omitted.

In each of the embodiments recited above, the magnetization direction of the magnetization free layer **55***f* (the first magnetic layer **10**) in the state (e.g., the initial state) in which the external pressure is not applied is, for example, different from the first direction and different from the second direction. In each of the embodiments, when the external pressure is applied, the direction of the anisotropic strain applied to the magnetization free layer is along the first direction or the second direction. Therefore, by setting the magnetization direction of the magnetization free layer **55***f* in the state in which the external pressure is not applied to be as described above, a change of the output with respect to both a positive pressure and a negative pressure can be obtained.

In each of the embodiments recited above, the surface area of the film part **70***d* is, for example, not less than 2500 μm^2 and not more than 640000 μm^2. In the case where the surface area of the film part **70***d* is too small, it is difficult to obtain a sufficiently large strain occurring due to the external pressure. By setting the surface area of the film part **70***d* to be 2500 μm^2 or more, a strain that is sufficiently large can be obtained. In the case where the surface area of the film part is too large, the strength of the film part becomes insufficient; and it is difficult to provide a high-reliability pressure sensor. By setting the surface area of the film part **70***d* to be not more than 640000 μm^2, high reliability is obtained. In the case where each of the embodiments recited above is applied to a microphone, the frequency characteristics in the

audible range degrade when the surface area of the film part is too large. It is favorable for the surface area of the film part **70***d* to be not more than 640000 μm^2, and more favorable to be not more than 360000 μm^2. Thereby, for example, good frequency characteristics in the audible range are obtained. From the reasons recited above, it is favorable to set the surface area of the film part **70***d* to be not less than 2500 μm^2 and not more than 640000 μm^2.

In each of the embodiments recited above, the second length of the film part **70***d* is, for example, not less than 20 μm and not more than 800 μm. In the case where the second length of the film part **70***d* is too short, it is difficult to obtain a strain occurring due to the external pressure that is sufficiently large. By setting the second length of the film part **70***d* to be 20 μm or more, a strain that is sufficiently large can be obtained. In the case where the second length of the film part **70***d* is too large, the strength of the film part becomes insufficient; and it is difficult to provide a highly-reliable pressure sensor. By setting the second length of the film part **70***d* to be 800 μm or less, a highly-reliable pressure sensor is obtained. In the case where each of the embodiments recited above is applied to a microphone, the frequency characteristics in the audible range degrade in the case where the second length of the film part **70***d* is too large. It is favorable for the second length of the film part **70***d* to be 800 μm or less, and more favorable to be 600 μm or less. Thereby, for example, good frequency characteristics in the audible range are obtained. From the reasons recited above, it is favorable for the second length of the film part **70***d* to be not less than 20 μm and not more than 800 μm.

Sixth Embodiment

FIG. **55** is a schematic view illustrating a microphone **610** according to a sixth embodiment.

As shown in FIG. **55**, the microphone **610** includes any pressure sensor (e.g., the pressure sensor **440**) according to the embodiments described above or a pressure sensor according to a modification of these pressure sensors. The microphone **610** that includes the pressure sensor **440** will now be described as an example.

The microphone **610** is embedded in the end portion of a personal digital assistant **710**. The film part **464** (**70***d*) of the pressure sensor **440** provided in the microphone **610** may be substantially parallel to, for example, the front surface of the personal digital assistant **710** where a display unit **620** is provided. The disposition of the film part **464** (**70***d*) is not limited to that illustrated and may be modified appropriately.

Because the microphone **610** includes the pressure sensor **440**, etc., high sensitivity with respect to frequencies in the wide band is possible.

Although the case where the microphone **610** is embedded in the personal digital assistant **710** is illustrated, this is not limited thereto. The microphone **610** also may be embedded in, for example, an IC recorder, a pin microphone, etc.

Seventh Embodiment

The embodiment relates to an acoustic microphone using the pressure sensors of the embodiments recited above.

FIG. **56** is a schematic cross-sectional view illustrating the acoustic microphone according to the seventh embodiment.

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

Any of the pressure sensors described in regard to the embodiments recited above or a pressure sensor according to a modification of these pressure sensors may be used as the pressure sensor **310**.

The acoustic microphone **320** responds to sound pressure. A highly-sensitive acoustic microphone **320** is obtained by using a highly-sensitive pressure sensor **310**. For example, the pressure sensor **310** is mounted on the printed circuit board **321**; and electrical signal lines are provided. The cover **323** is provided on the printed circuit board **321** to cover the pressure sensor **310**.

According to the embodiment, a highly-sensitive acoustic microphone can be provided.

Eighth Embodiment

The embodiment relates to a blood pressure sensor using the pressure sensors of the embodiments recited above.

FIG. **57**A and FIG. **57**B are schematic views illustrating the blood pressure sensor according to the eighth embodiment.

FIG. **57**A is a schematic plan view illustrating skin on the arterial vessel of a human. FIG. **57**B is a cross-sectional view along line H**1**-H**2** of FIG. **57**A.

In the embodiment, a blood pressure sensor **330** includes the pressure sensor **310**. The pressure sensor **310** includes any of the pressure sensors described in regard to the embodiments recited above or a pressure sensor according to a modification of these pressure sensors.

Thereby, highly-sensitive pressure sensing by a small pressure sensor is possible. The blood pressure sensor **330** can perform a continuous blood pressure measurement by the pressure sensor **310** being pressed onto skin **333** on an arterial vessel **331**.

According to the embodiment, a highly-sensitive blood pressure sensor can be provided.

Ninth Embodiment

The embodiment relates to a touch panel using the pressure sensors of the embodiments recited above.

FIG. **58** is a schematic view illustrating the touch panel according to the ninth embodiment.

In the embodiment, the pressure sensor **310** may be used in a touch panel **340**. The pressure sensor **310** includes any of the pressure sensors described in regard to the embodiments recited above or a pressure sensor according to a modification of these pressure sensors. The pressure sensor **310** is provided in the interior of the display and/or outside the display of the touch panel **340**.

For example, the touch panel **340** includes multiple first interconnects **346**, multiple second interconnects **347**, multiple pressure sensors **310**, and a controller **341**.

In the example, the multiple first interconnects **346** are arranged along the Y-axis direction. Each of the multiple first interconnects **346** extends along the X-axis direction. The multiple second interconnects **347** are arranged along the X-axis direction. Each of the multiple second interconnects **347** extends along the Y-axis direction.

The multiple pressure sensors **310** are provided respectively at the intersections between the multiple first interconnects **346** and the multiple second interconnects **347**. One pressure sensor **310** is used as one sensing component

310*e* for sensing. Herein, the intersections include the regions around the positions where the first interconnects **346** and the second interconnects **347** intersect.

Multiple one ends **310***a* of the multiple pressure sensors **310** are connected to the multiple first interconnects **346**. Multiple other ends **310***b* of the multiple pressure sensors **310** are connected to the multiple second interconnects **347**.

The controller **341** is connected to the multiple first interconnects **346** and the multiple second interconnects **347**.

For example, the controller **341** includes a first interconnect circuit **346***d* that is connected to the multiple first interconnects **346**, a second interconnect circuit **347***d* that is connected to the multiple second interconnects **347**, and a control circuit **345** that is connected to the first interconnect circuit **346***d* and the second interconnect circuit **347***d*.

The pressure sensor **310** can be miniature and can provide highly-sensitive pressure sensing. Therefore, it is possible to realize a high definition touch panel.

Other than the applications recited above, the pressure sensors according to the embodiments recited above are applicable to various pressure sensor devices such as atmospheric pressure sensors, air pressure sensors of tires, etc.

The embodiments include the following features.

Feature 1

A pressure sensor, comprising:

a film part supported by a support unit, the film part being flexible; and

a sensing unit,

a first length of a film surface of the film part in a first direction in the film surface being longer than a second length of the film surface in a second direction perpendicular to the first direction in the film surface,

the film surface having a central portion, and a peripheral portion provided around the central portion,

the sensing unit including a sensing element provided on the central portion, the sensing element including a first magnetic layer, a second magnetic layer provided between the first magnetic layer and the film part, and a spacer layer provided between the first magnetic layer and the second magnetic layer.

Feature 2

The sensor according to feature 1, wherein the film surface includes:

a first side along the first direction;

a second side along the first direction to be separated from the first side;

a third side along the second direction to be connected to one end of the first side and one end of the second side; and

a fourth side along the second direction to be separated from the third side and connected to the other end of the first side and the other end of the second side.

Feature 3

The sensor according to feature 1, wherein a configuration of the film surface is a flattened circle having the first direction as a major axis and the second direction as a minor axis.

Feature 4

The sensor according to any of features 1 to 3, wherein

a third length of the central portion in the first direction is not more than 0.3 times the first length,

a fourth length of the central portion in the second direction is not more than 0.3 times the second length, and

a distance between a centroid of the central portion and a centroid of the film surface is not more than 1/10 of the second length.

Feature 5

The sensor according to feature 4, wherein

L2/L1 is not less than 0.8 but less than 1,

L3 is not less than 0.8 times and not more than 1.2 times $L1\times\{-0.8\times(L2/L1)+0.8\}$, and

L4 is not less than 0.8 times and not more than 1.2 times $L2\times\{-2.5\times(L2/L1)+2.5\}$,

where the first length is L1, the second length is L2, the third length is L3, and the fourth length is L4.

Feature 6

The sensor according to feature 4, wherein

L2/L1 is less than 0.8,

L3 is not less than 0.8 times and not more than 1.2 times $L1\times\{-0.8\times(L2/L1)+0.8\}$, and

L4 is not less than 0.8 times and not more than 1.2 times $L2\times\{0.375\times(L2/L1)+0.2\}$,

where the first length is L1, the second length is L2, the third length is L3, and the fourth length is L4.

Feature 7

The sensor according to any of features 1 to 6, wherein the ratio of the second length to the first length is not less than 0.1 and not more than 0.8.

Feature 8

The sensor according to any of features 1 to 6, wherein the ratio of the second length to the first length is not less than 0.25 and not more than 0.64.

Feature 9

The sensor according to any of features 1 to 6, wherein the ratio of the second length to the first length is not more than 0.25.

Feature 10

The sensor according to any of features 1 to 9, wherein the sensing unit includes a plurality of the sensing elements.

Feature 11

The sensor according to any of features 1 to 10, wherein at least two of the multiple sensing elements are connected electrically in series.

Feature 12

A pressure sensor, comprising:

a film part supported by a support unit, the film part being flexible; and

a sensing unit,

the film surface of the film part having a central portion, and a peripheral portion provided around the central portion,

the sensing unit including a sensing element provided on the peripheral portion, the sensing element including a first magnetic layer, a second magnetic layer provided between the first magnetic layer and the film part,

a spacer layer provided between the first magnetic layer and the second magnetic layer,

the film part including:

a first side along a first direction;

a second side along the first direction to be separated from the first side;

a third side along a second direction to be connected to one end of the first side and one end of the second side; and

a fourth side along the second direction to be separated from the third side and connected to the other end of the first side and the other end of the second side,

the peripheral portion has a first element disposition region provided along the first side, and

positions in the first direction of at least two of the multiple sensing elements disposed in the first element disposition region are different from each other.

Feature 13

The sensor according to feature 12, wherein the at least two of the multiple sensing elements are connected electrically in series.

According to the embodiments, a pressure sensor, an acoustic microphone, a blood pressure sensor, and a touch panel that have high sensitivity can be provided.

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 similarly practice the invention by appropriately selecting specific configurations of components included in the pressure sensor, the acoustic microphone, the blood pressure sensor, and the touch panel such as the support unit, the film part, the sensing element, the first magnetic layer, the second magnetic layer, the spacer layer, etc., from known art; and such practice is within the scope of the invention to the extent that similar effects are obtained.

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.

Moreover, all pressure sensors, acoustic microphones, blood pressure sensors, and touch panels practicable by an appropriate design modification by one skilled in the art based on the pressure sensors, acoustic microphones, blood pressure sensors, and 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 sensor, comprising:

a film part supported by a support unit, the film part being flexible, the film part having a film surface; and

a sensing unit fixed to the film surface,

the sensing unit including a first sensing group, and a second sensing group,

the first sensing group including a plurality of first sensing elements, and the second sensing group including a plurality of second sensing elements,

the first sensing elements being arranged along a first direction,

the second sensing elements being arranged along the first direction, the second sensing elements being apart from the first sensing elements along a second direction crossing the first direction,

a distance in the first direction between two of the first sensing elements being shorter than a distance in the second direction between one of the first sensing elements and one of the second sensing elements, the two of the first sensing elements being closest among the first sensing elements,

a distance in the first direction between two of the second sensing elements being shorter than the distance in the second direction between one of the first sensing elements and one of the second sensing elements, the two of the second sensing elements being closest among the second sensing elements,

the first sensing elements being connected in series with each other, and the second sensing elements being connected in series with each other, each of the first sensing elements and the including a first magnetic layer, a second magnetic layer provided between the first magnetic layer and the film part, and a spacer layer provided between the first magnetic layer and the second magnetic layer,

a first end of the first sensing group being connected with a first node of a bridge circuit,

a second end of the first sensing group being connected with a second node of the bridge circuit,

a third end of the second sensing group being connected with a third node of the bridge circuit,

a fourth end of the second sensing group being connected with a fourth node of the bridge circuit,

the sensing unit further including a third sensing group and a fourth sensing group,

the third sensing group including a plurality of third sensing elements, and the fourth sensing group including a plurality of fourth sensing elements,

the third sensing elements being arranged along the second direction,

the fourth sensing elements being arranged along the second direction,

a distance in the second direction between two of the third sensing elements being shorter than a distance in the first direction between one of the third sensing elements and one of the fourth sensing elements, the two of the third sensing elements being closest among the third sensing elements,

a distance in the second direction between two of the fourth sensing elements being shorter than the distance in the first direction between one of the third sensing elements and one of the fourth sensing elements, the two of the fourth sensing elements being closest among the fourth sensing elements,

the third sensing elements being connected in series with each other, and the fourth sensing elements being connected in series with each other, each of the third sensing elements and the fourth sensing elements including the first magnetic layer, the second magnetic layer, and the spacer layer,

a fifth end of the third sensing group being connected with the second node,

a sixth end of the third sensing group being connected with the third node,

a seventh end of the fourth sensing group being connected with the first node, and

an eighth end of the fourth sensing group being connected with the fourth node.

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

a direction of a magnetization of the first magnetic layer in a state in which an external pressure is not applied to the sensor crosses the first direction and crosses the second direction.

3. The sensor according to claim **1**, wherein a direction of a magnetization of the first magnetic layer is changeable, and a direction of a magnetization of the second magnetic layer is fixed.

4. An acoustic microphone including the sensor according to claim **1**.

5. A blood pressure sensor including the sensor according to claim **1**.

6. A touch panel including the sensor according to claim **1**.

7. The sensor according to claim **1**, wherein the second direction is perpendicular to the first direction.

* * * * *

patsnap

专利名称(译)	压力传感器，声学麦克风，血压传感器和触摸屏		
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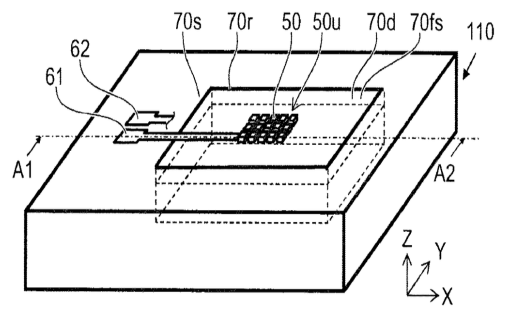
摘要(译)

根据一个实施例，压力传感器包括膜部分和传感单元。围绕薄膜部分的薄膜表面的构造的外接矩形具有第一侧，第二侧，连接到第一侧的一端和第二侧的一端的第三侧，连接到另一端的第四侧第一侧和第二侧的另一端，以及外接矩形的质心。外接矩形包括由第一侧面包围的第一区域，将质心连接到第一侧的一端的线段，以及第一侧的另一端。感测单元包括设置在与第一区域重叠的膜表面的一部分上的感测元件。每个传感元件包括第一，第二磁性层和间隔层。



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