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Shirotori et al.

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(54) **MAGNETIC SENSOR AND INSPECTION DEVICE**

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(30) **Foreign Application Priority Data**

Aug. 25, 2022 (JP) 2022-134113

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G01R 31/382 (2019.01)

(52) **U.S. Cl.**
CPC ***G01R 15/20*** (2013.01); ***G01R 31/382*** (2019.01)

(58) **Field of Classification Search**
CPC A61B 5/245; G01R 15/20; G01R 15/205; G01R 31/382; G01R 33/0011; G01R 33/0094; H10N 50/10
See application file for complete search history.

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Primary Examiner — Vinh P Nguyen
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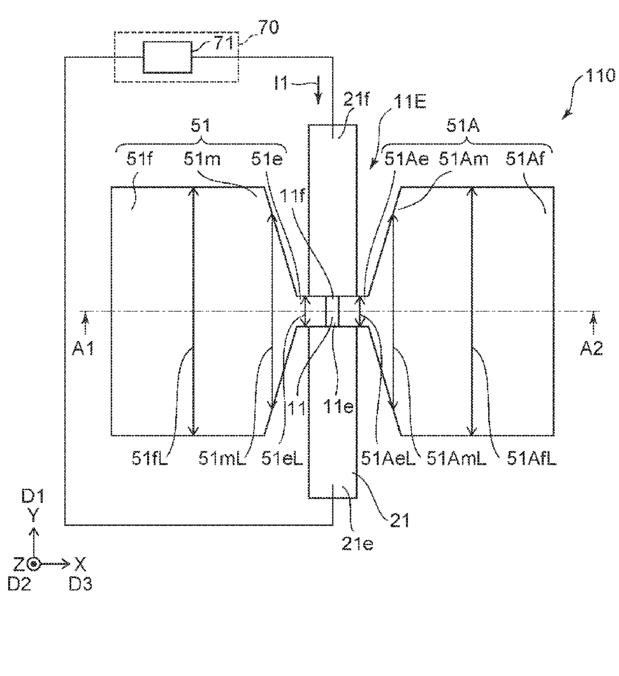
(57) **ABSTRACT**

According to one embodiment, a magnetic sensor includes a first element portion that includes a first magnetic element, a first conductive member, a first magnetic member and a first opposing magnetic member. The first magnetic element includes a first end portion and a first other end portion. A direction from the first end portion to the first other end portion is along a first direction. A second direction from the first conductive member to the first magnetic element crosses the first direction. A third direction from the first magnetic member to the first opposing magnetic member crosses a plane including the first and second directions. At least a part of the first magnetic element is between the first magnetic member and the first opposing magnetic member in position in the third direction. The first magnetic member includes a first other magnetic portion and a first magnetic portion.

20 Claims, 18 Drawing Sheets



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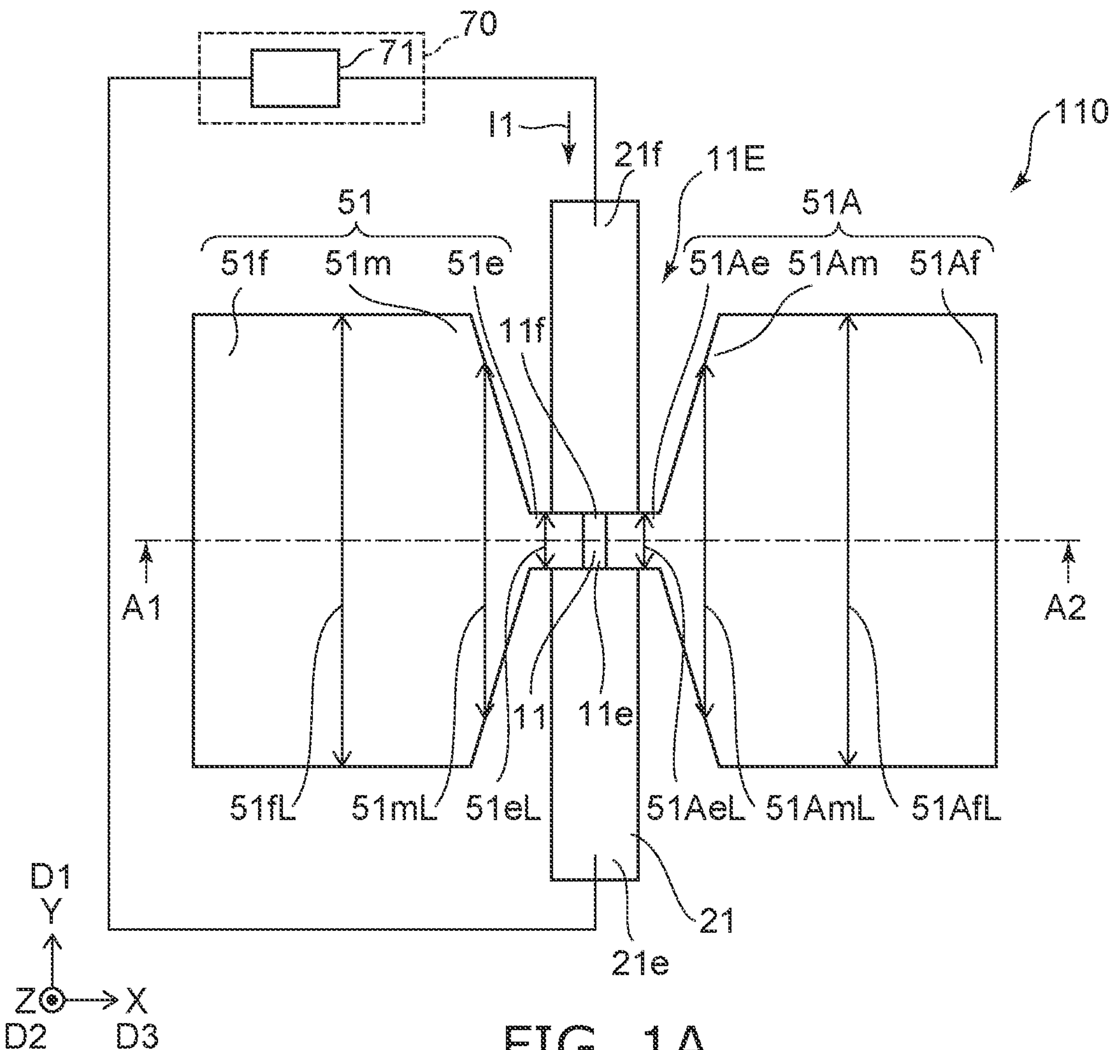
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11
11e
51fL
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D1
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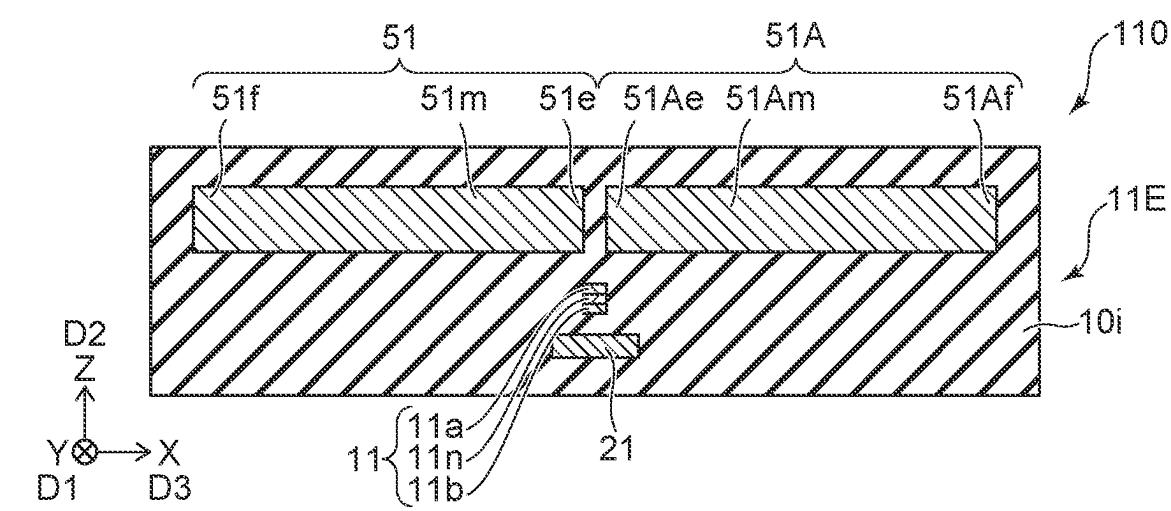
X
D2
D3

FIG. 1A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51Ae
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10i
D2
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D3
11
11a
11n
11b
21

FIG. 1B

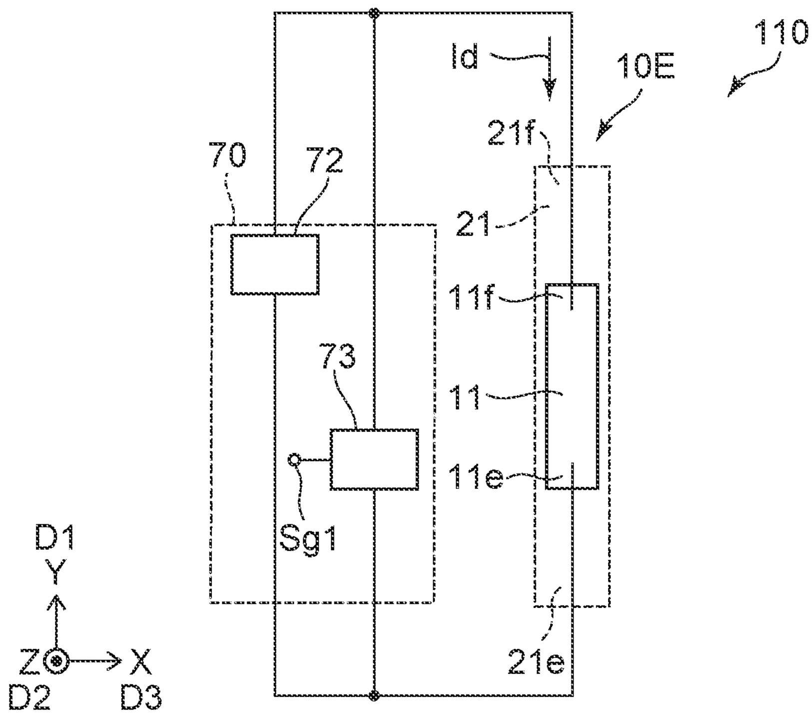
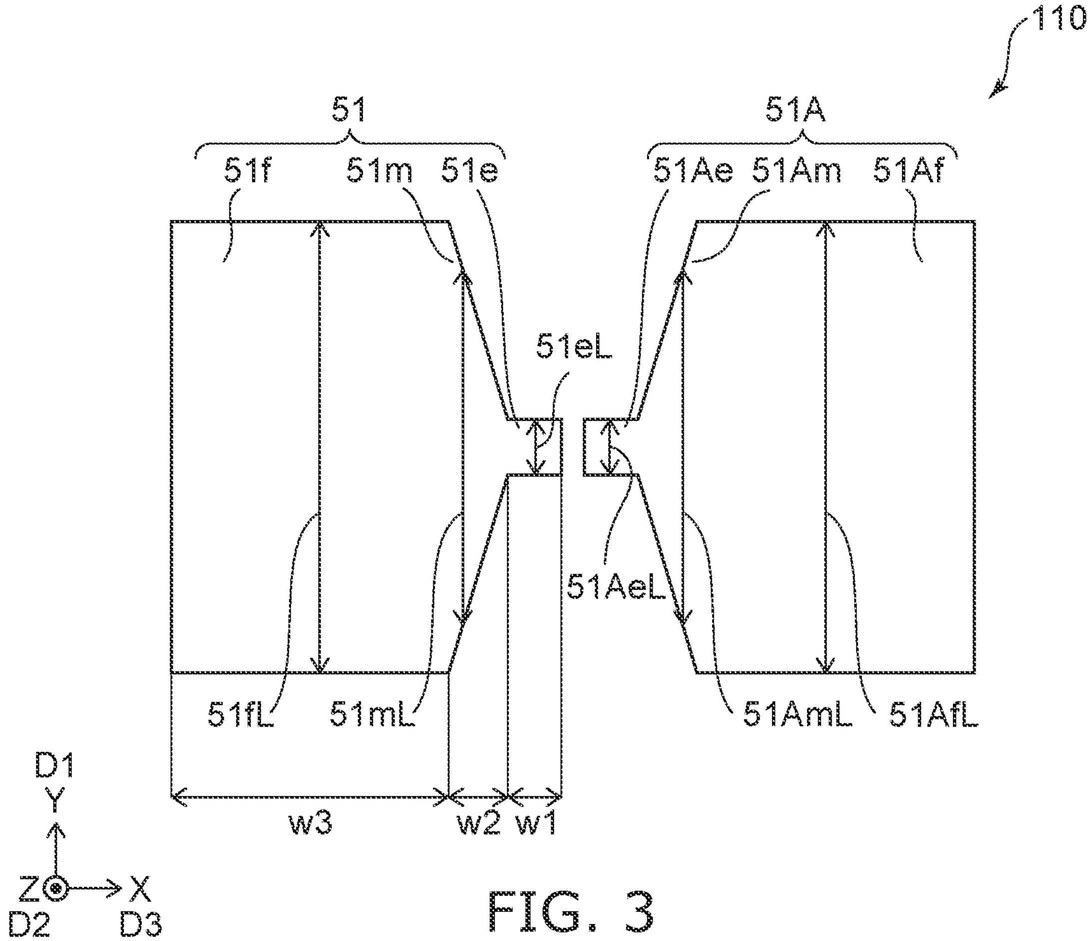


FIG. 2



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51m
51e
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51Am
51Af
51eL
51AeL
51fL
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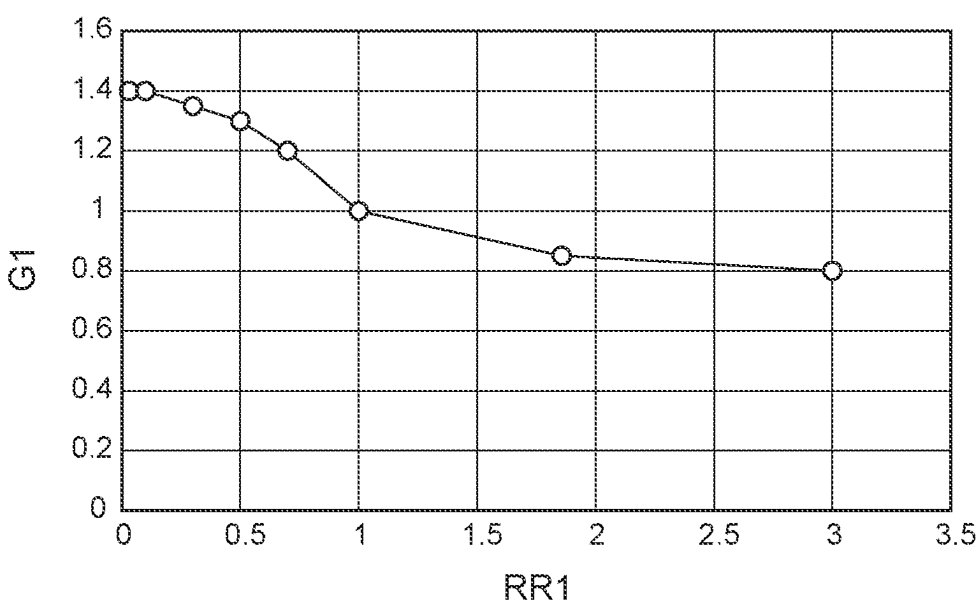
51AmL
51AfL
w3
w2
w1
D1
Y
Z
X
D2
D3

FIG. 3



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1.2
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0.6
0.4
0.2
0
0.5
1.5
2
2.5
3
3.5

FIG. 4

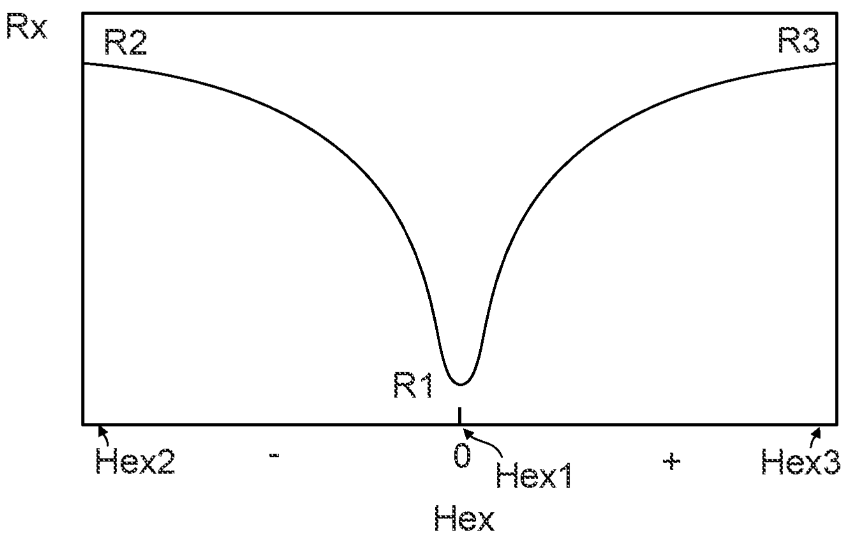


FIG. 5

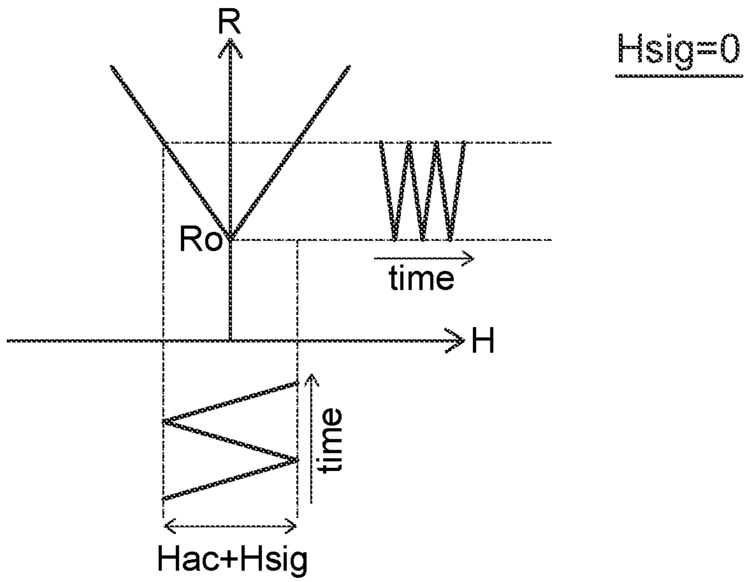


FIG. 6A

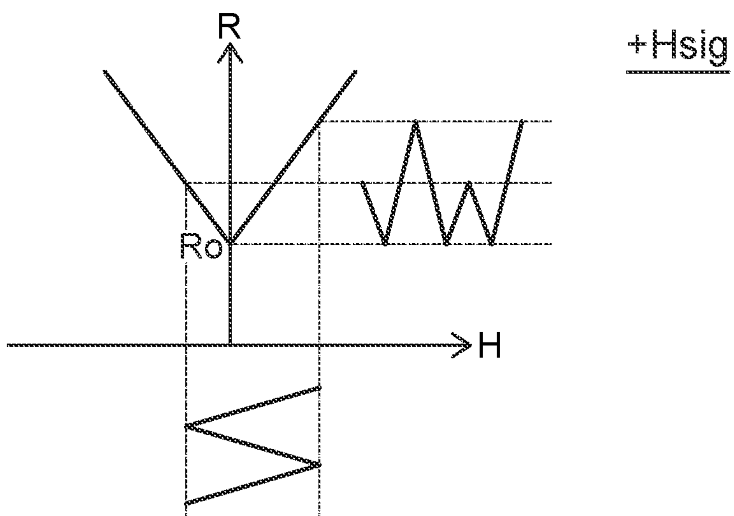


FIG. 6B

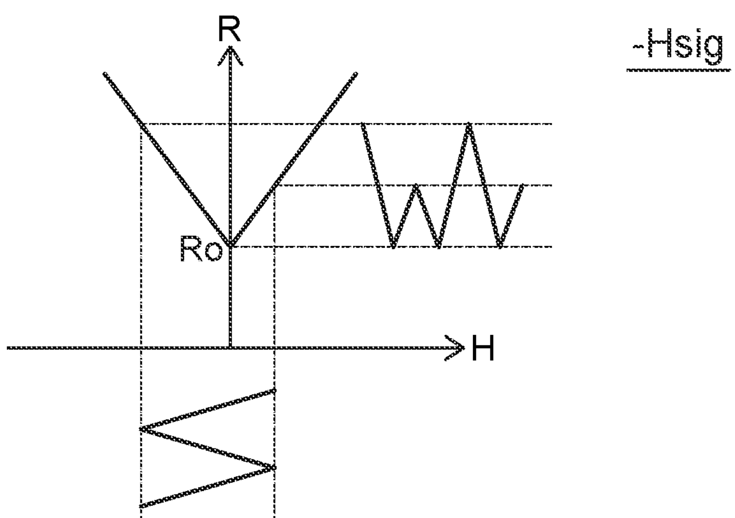
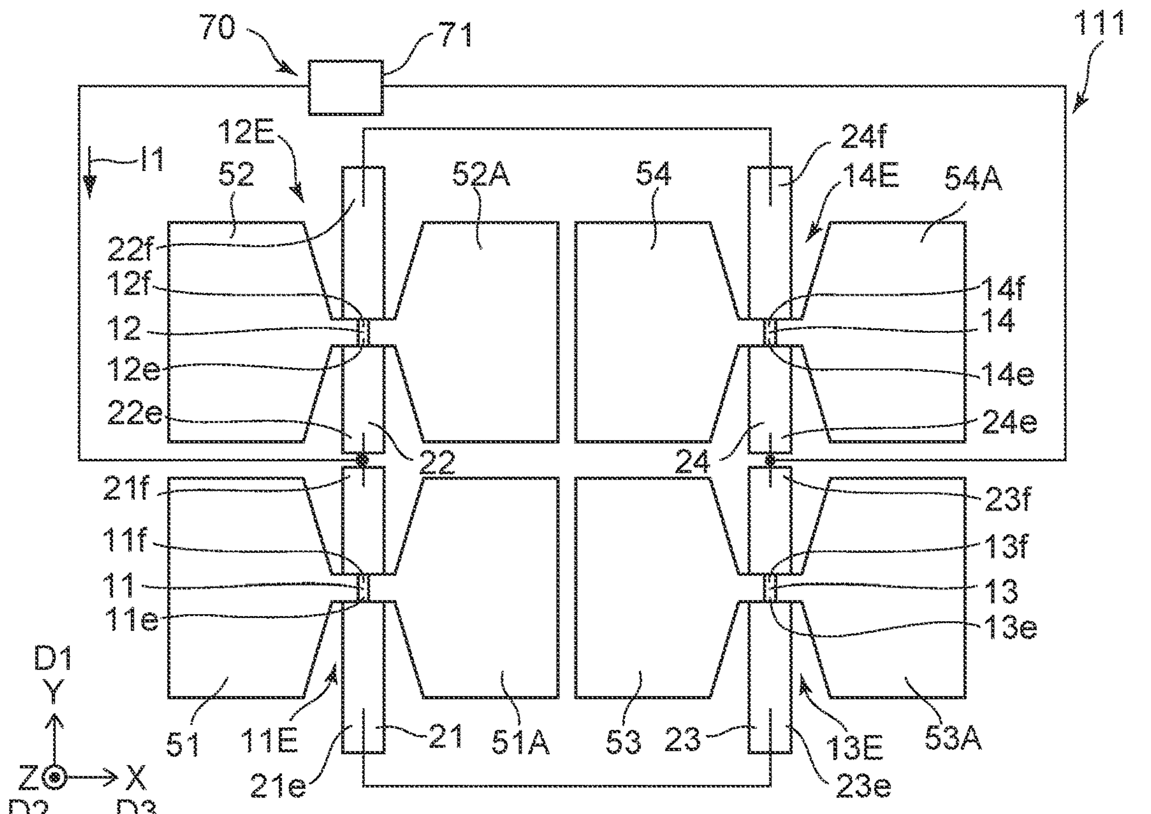


FIG. 6C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14e
24e
21f
11f
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11e
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21e
51A
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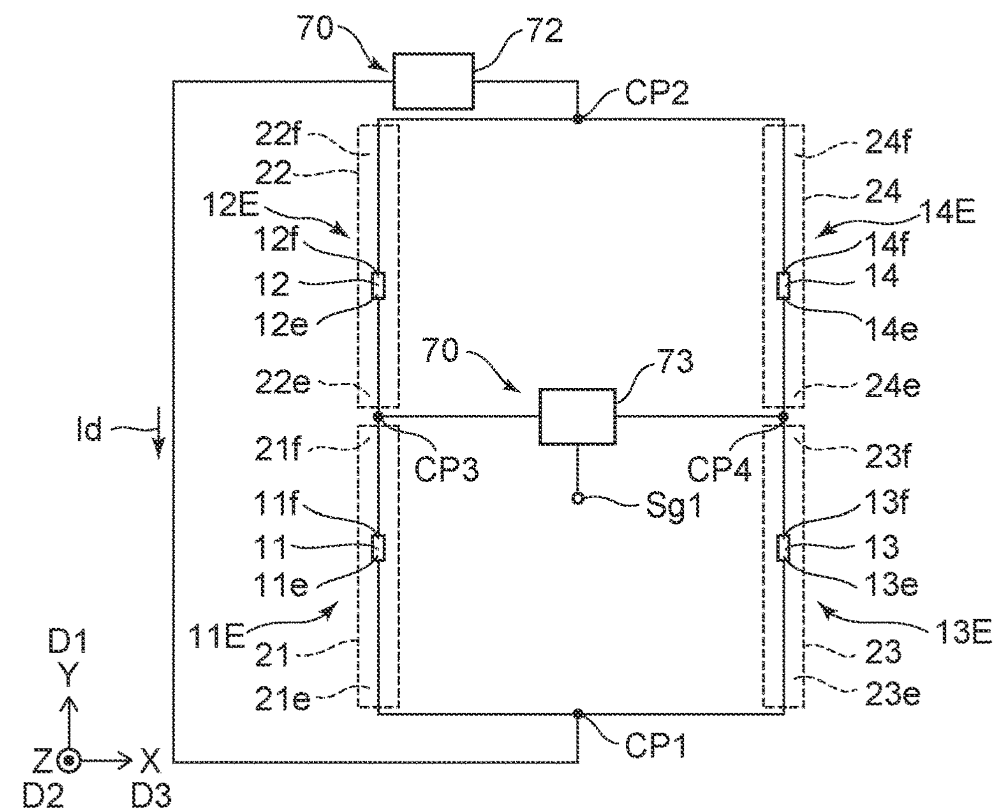
D2
D3

FIG. 7A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11E
21
21e
24f
24
14E
14f
14
14e
24e
CP4
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13E
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23e
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D1
Y
Z
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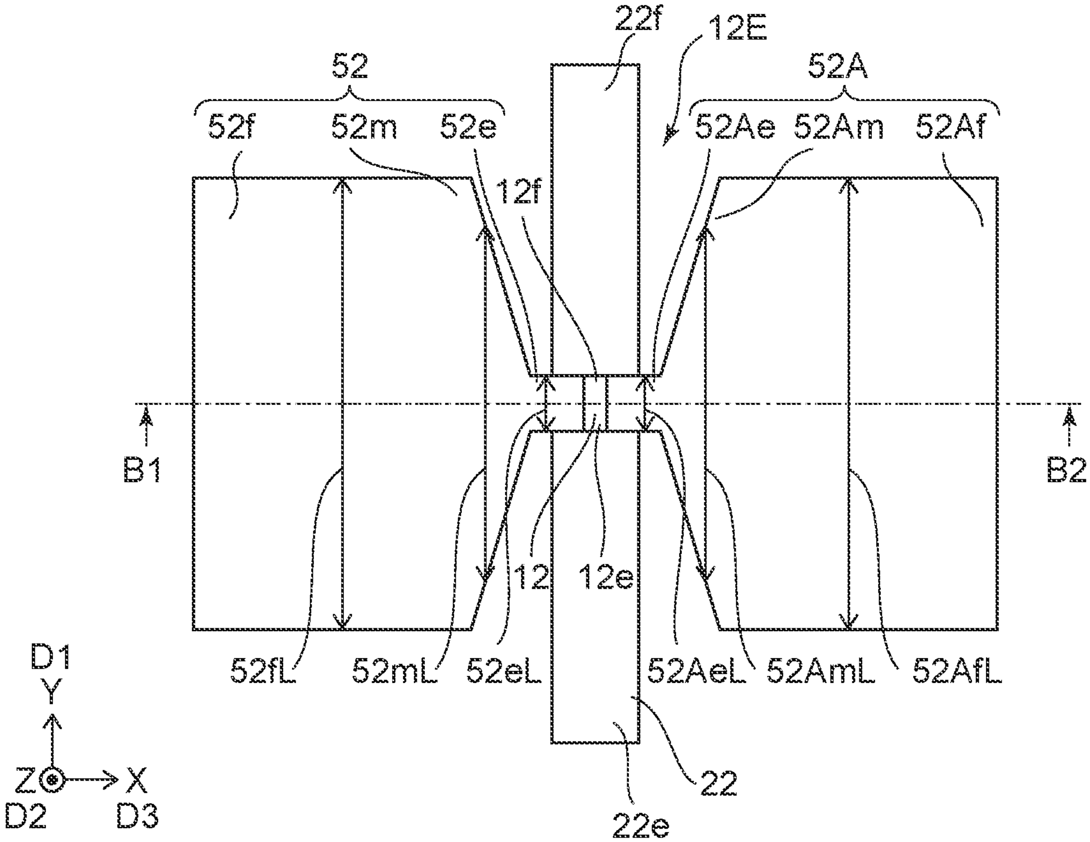
D2
D3

FIG. 7B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X
D2
D3
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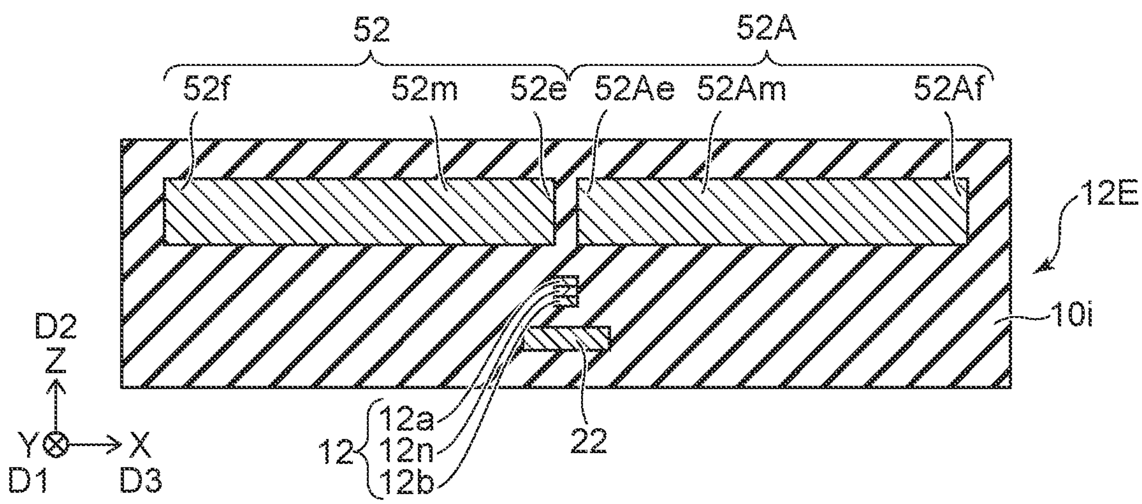
22e

FIG. 8A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12b
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FIG. 8B

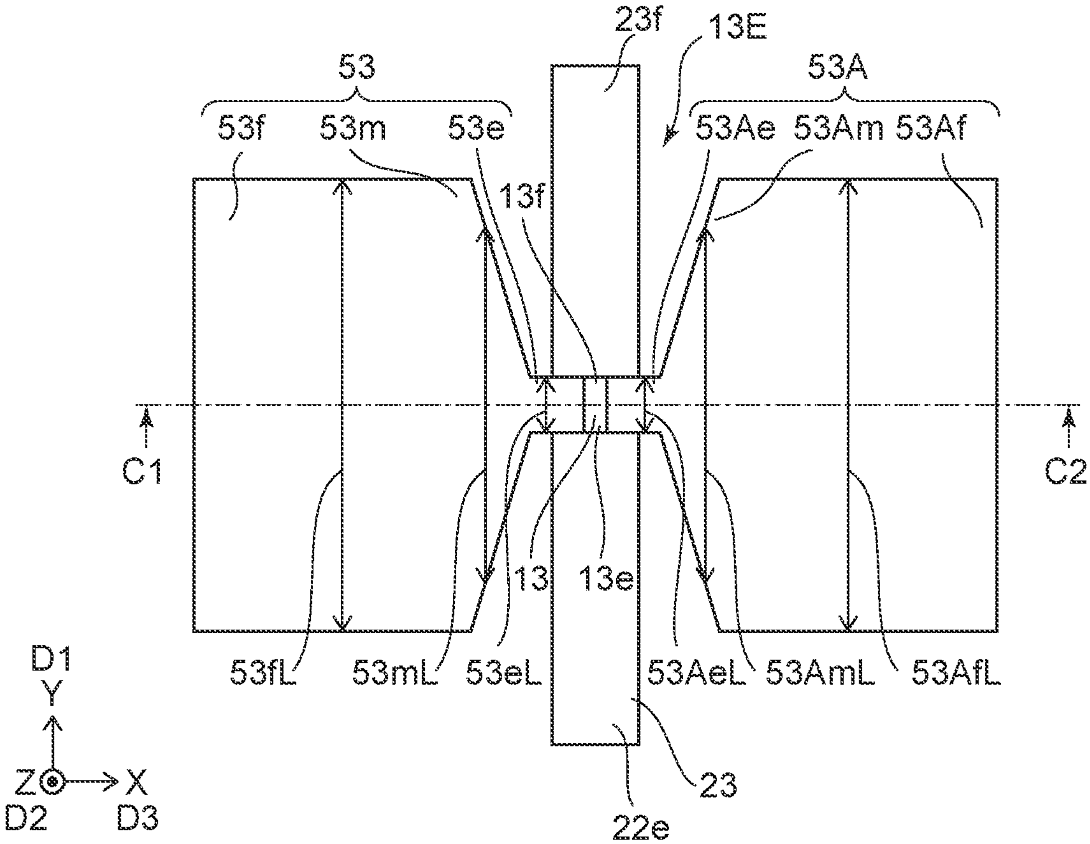
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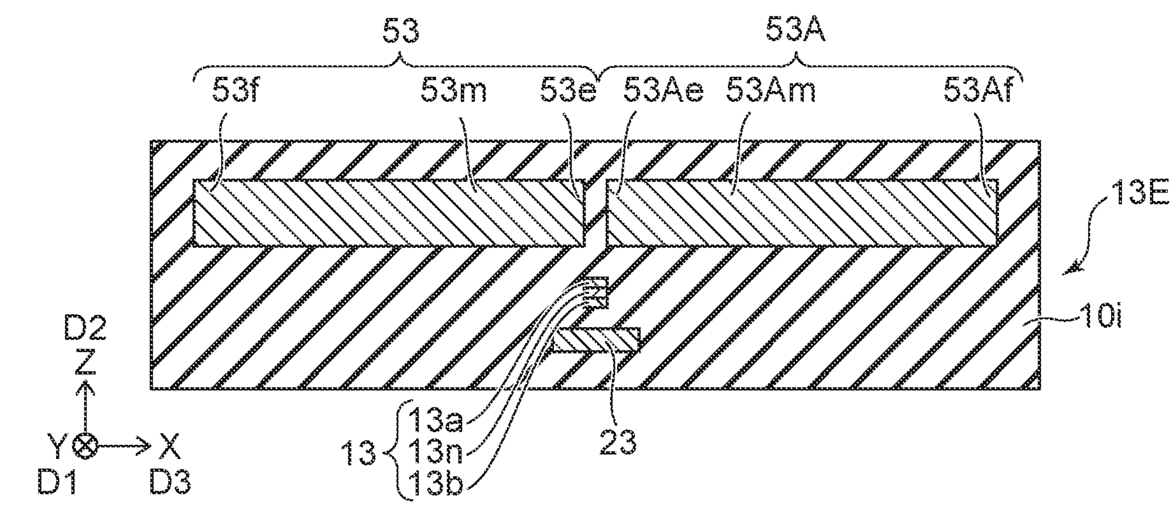
FIG. 9A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13b
23

FIG. 9B

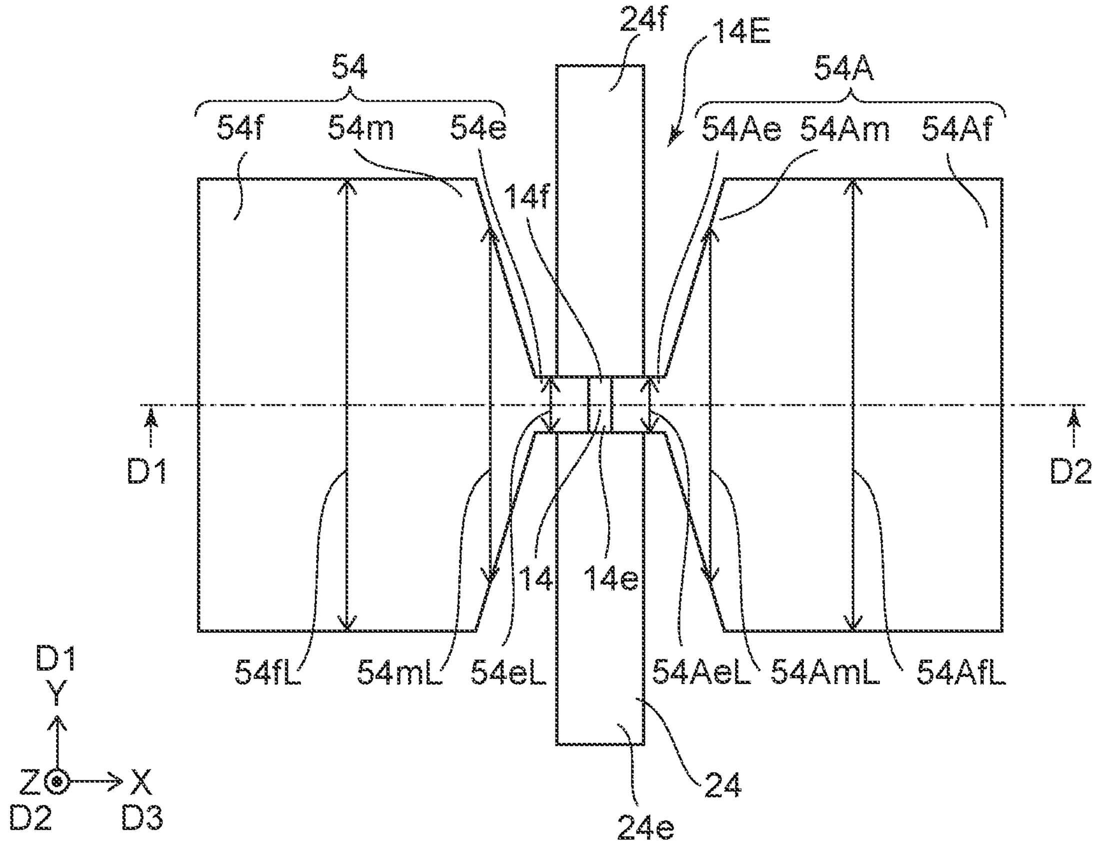


FIG. 10A

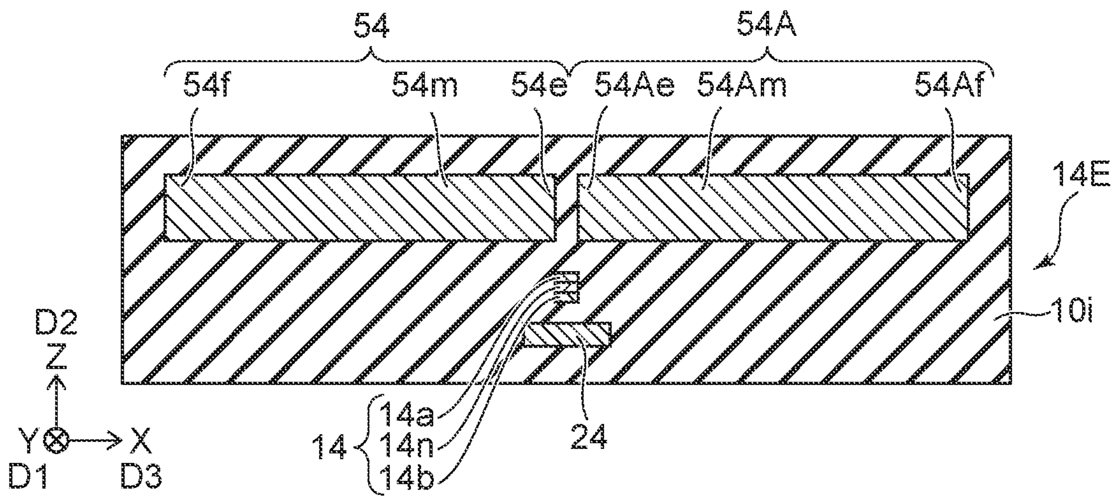


FIG. 10B

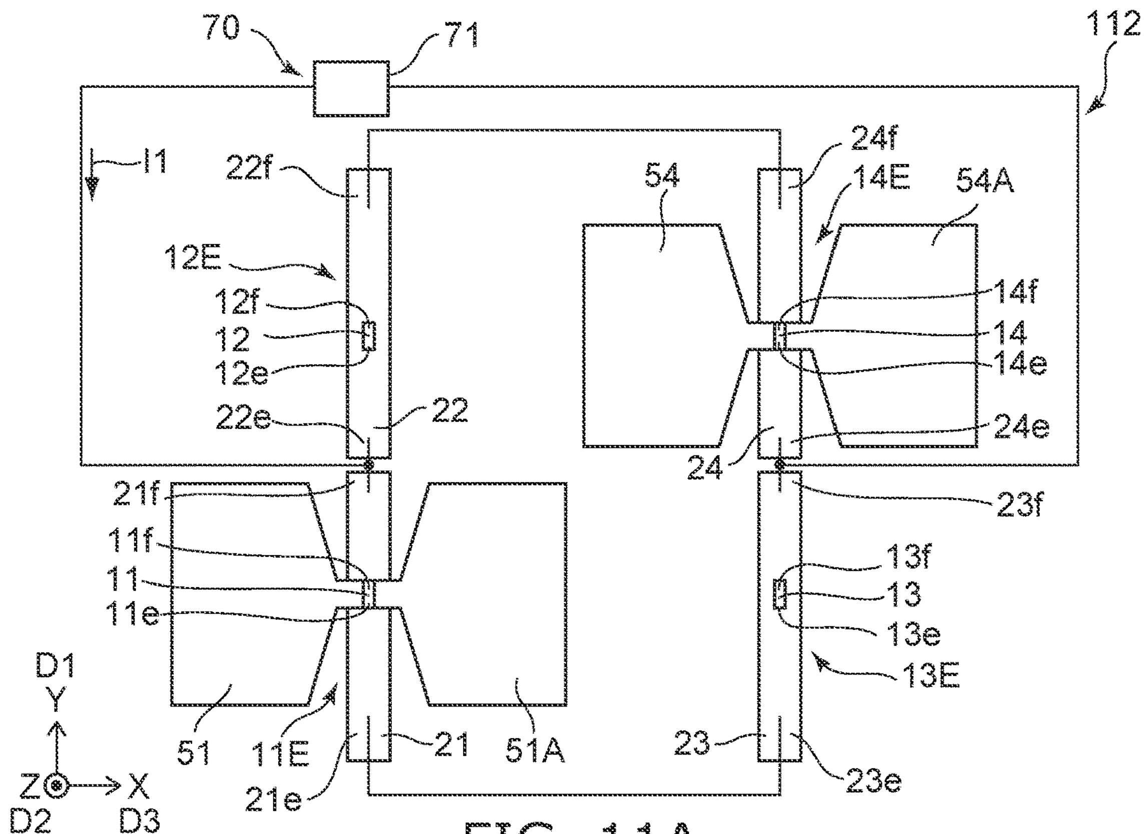


FIG. 11A

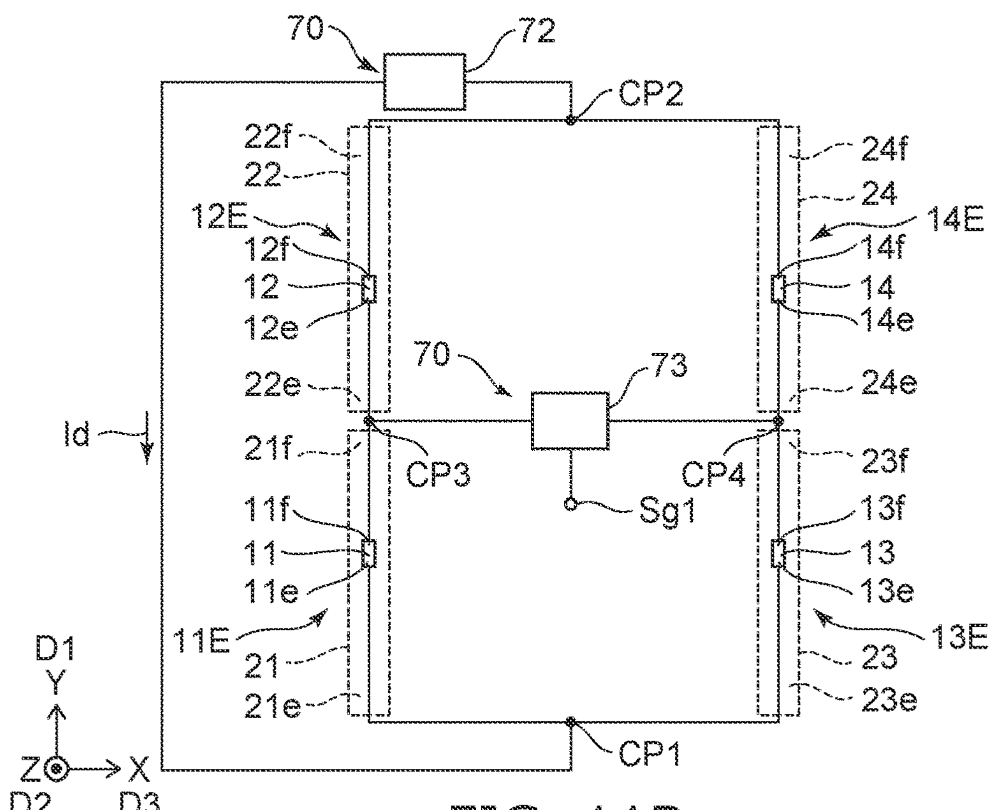
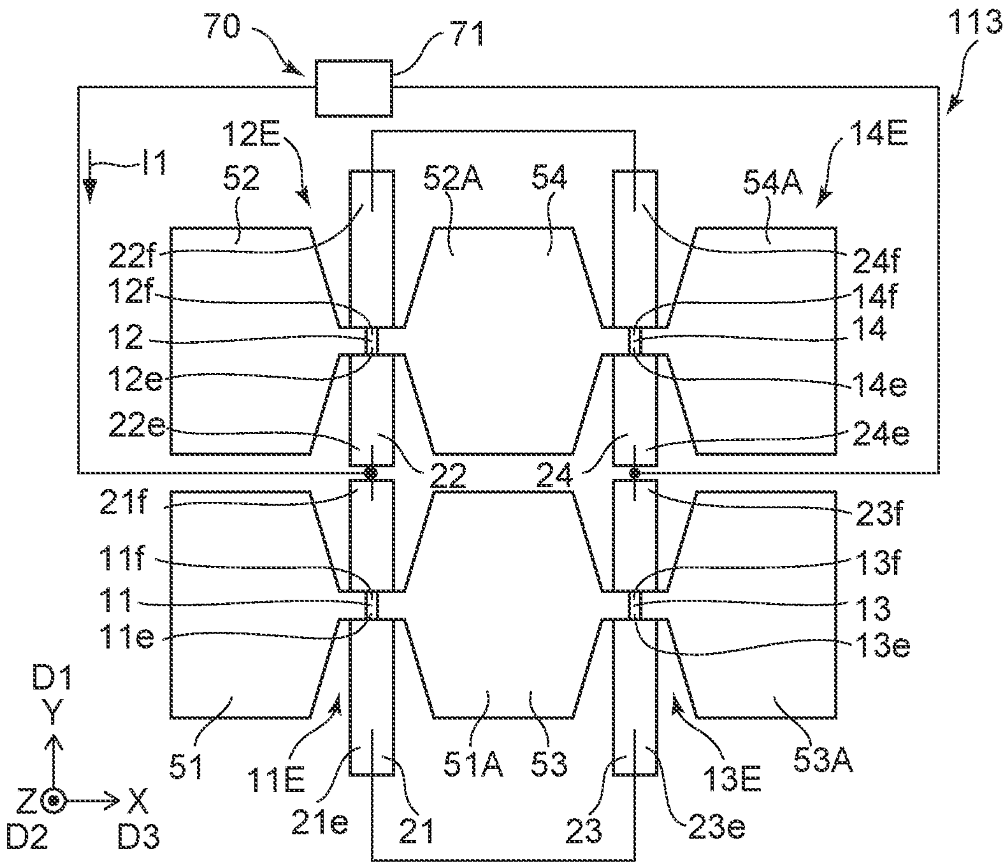


FIG. 11B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13f
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11e
13e
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FIG. 12

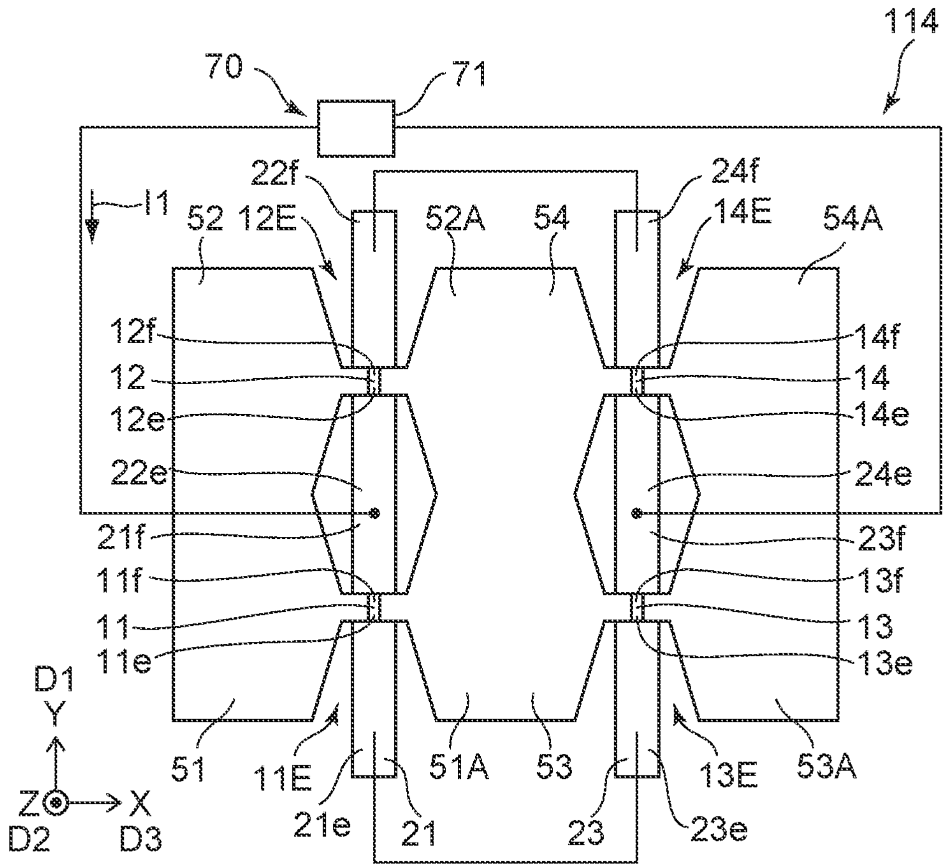
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FIG. 13

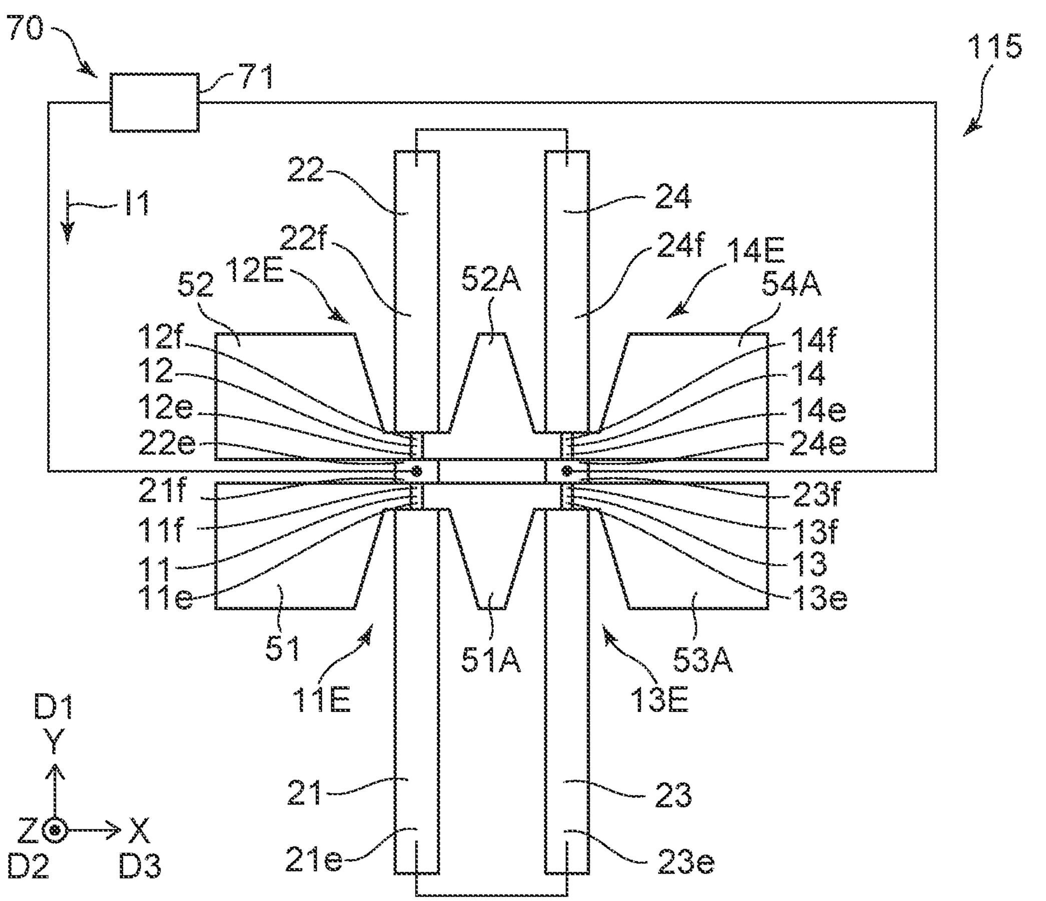
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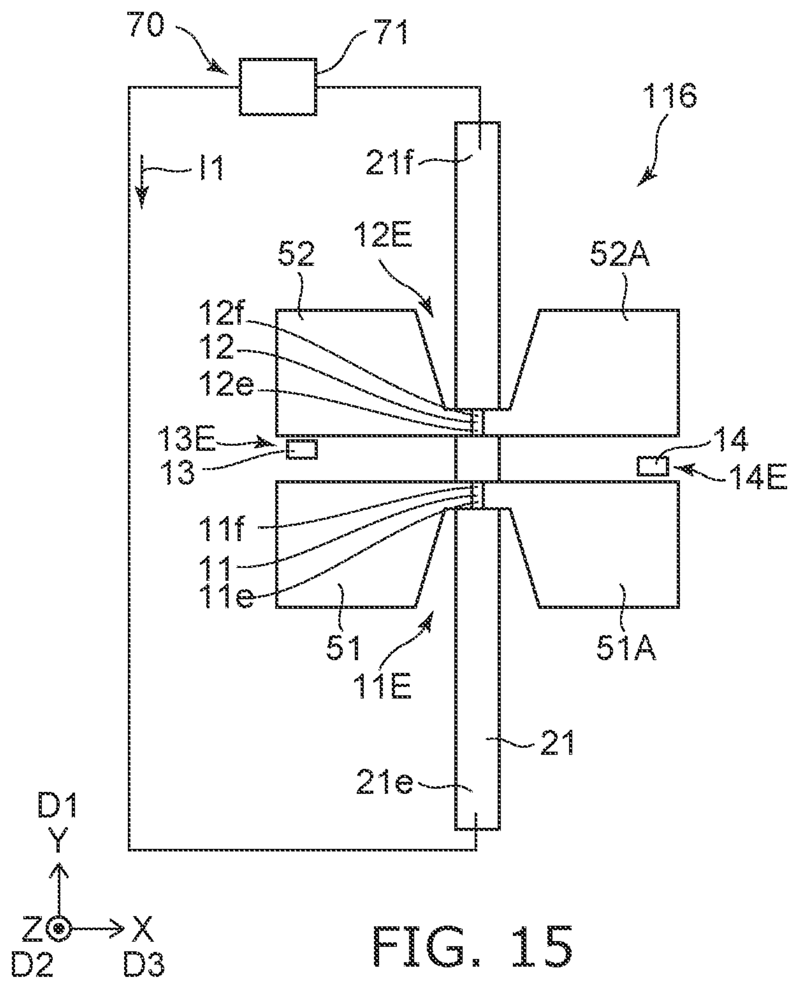
FIG. 14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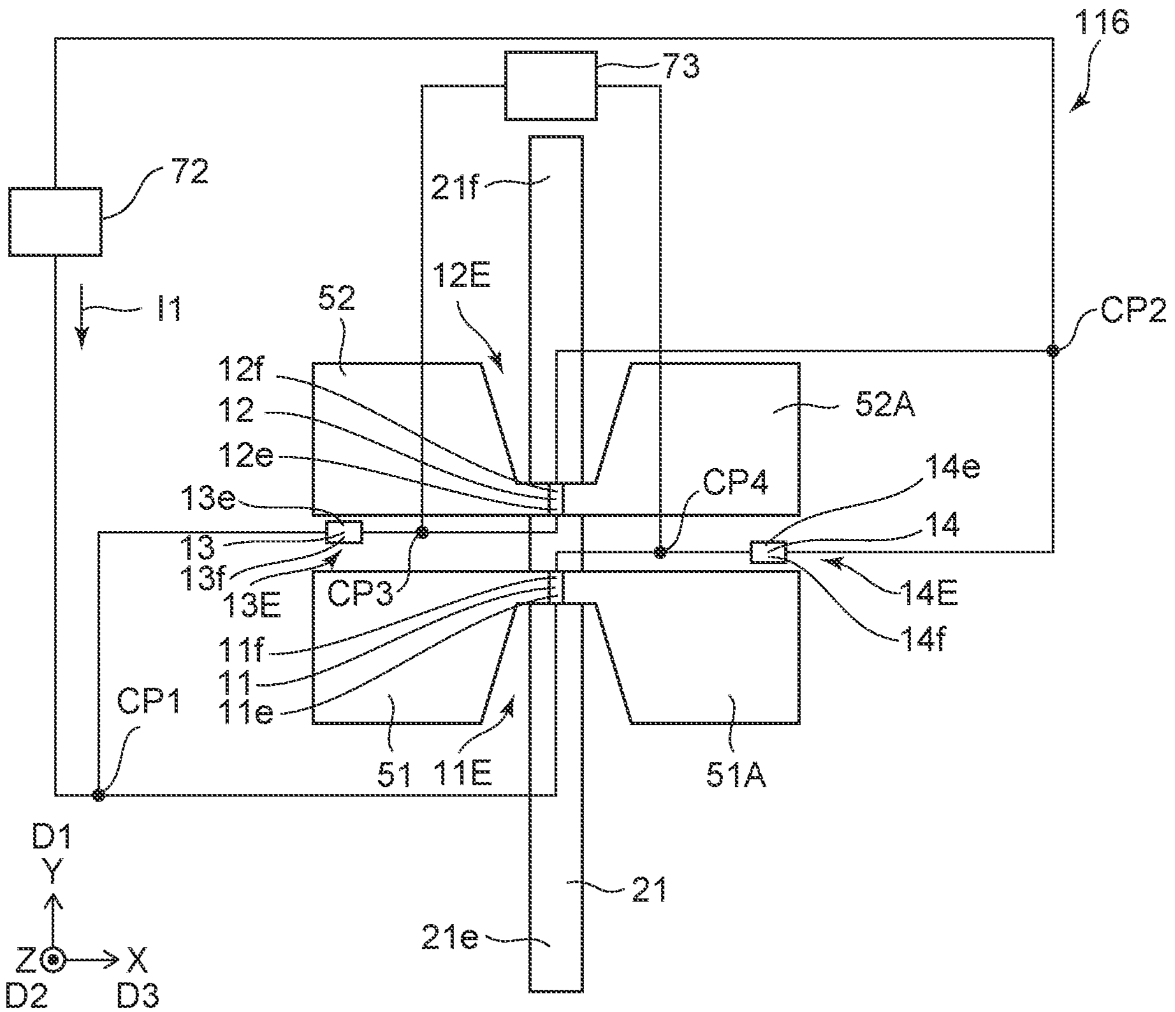
D2
D3

FIG. 15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13f
CP3
14E
13E
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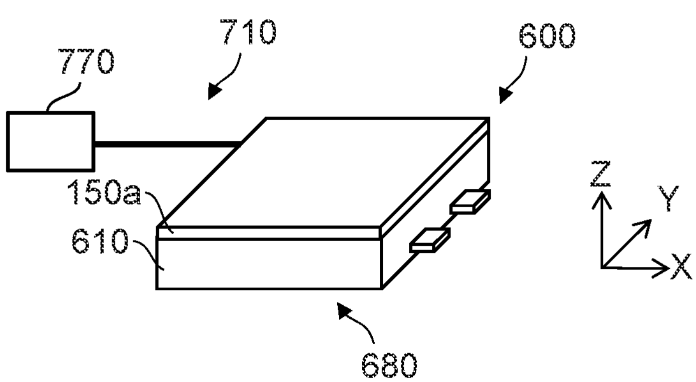
D2
D3

FIG. 16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680

FIG. 17

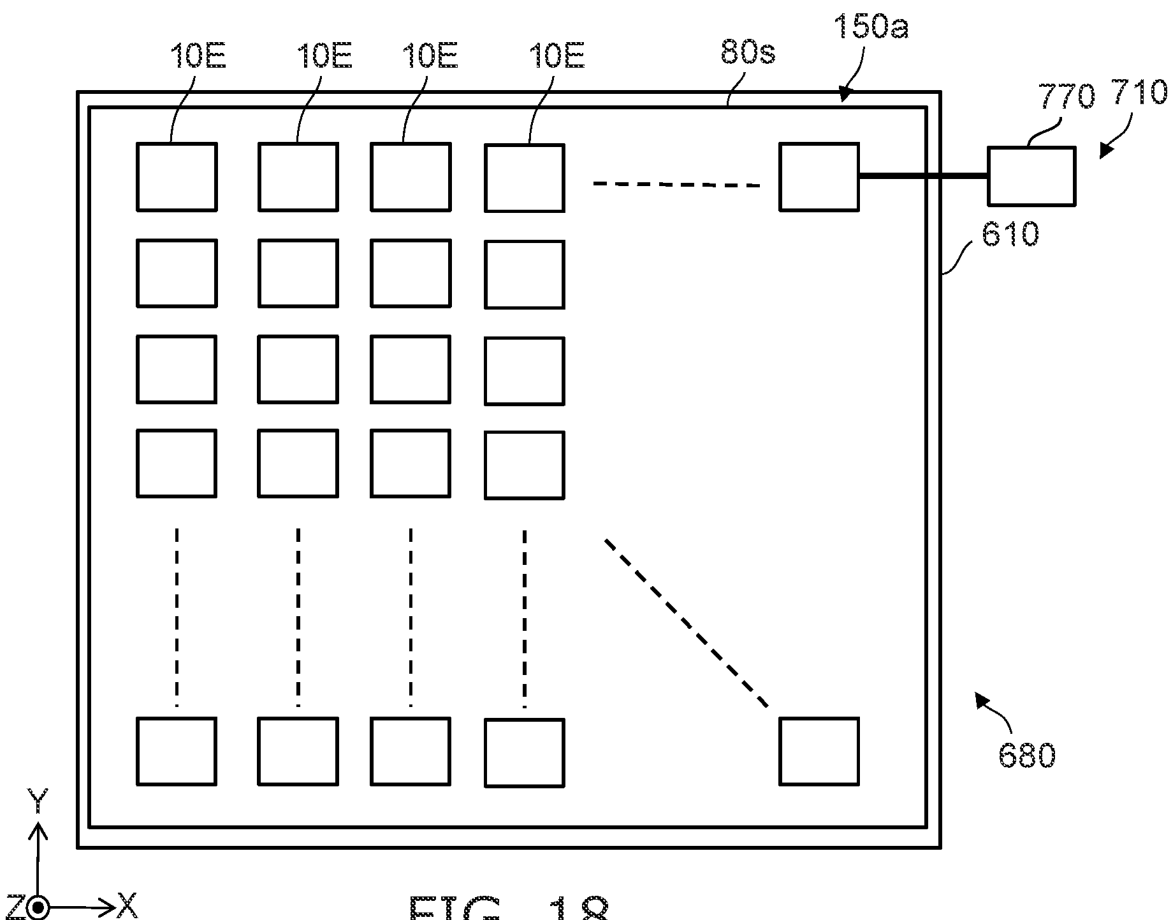
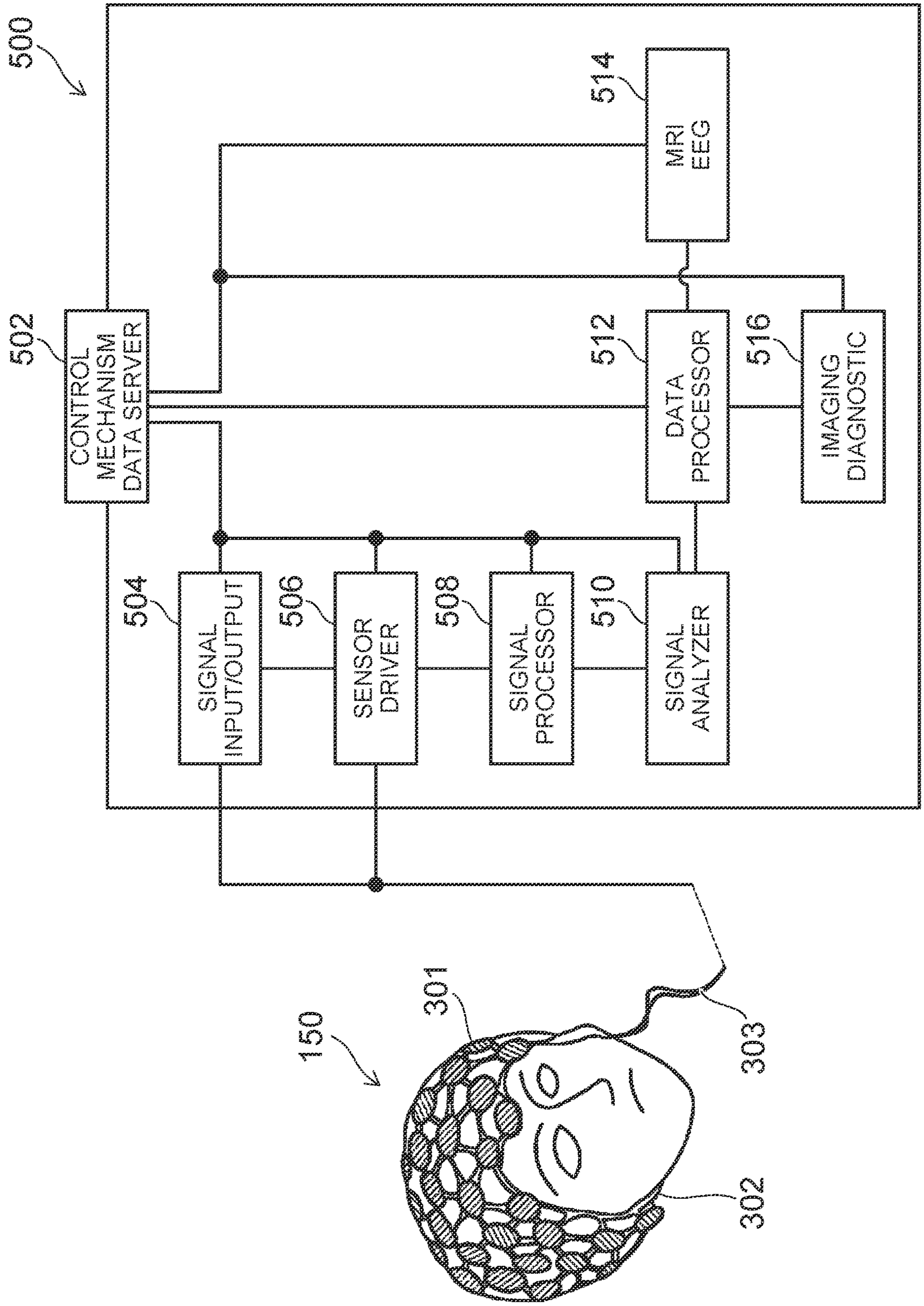


FIG. 18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SENSOR
DRIVER
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SIGNAL
PROCESSOR
510
SIGNAL
ANALYZER
150
301
302
303

FIG. 19

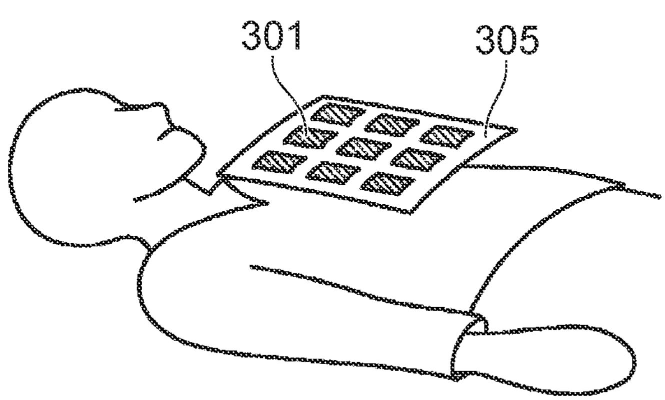

FIG. 20

MAGNETIC SENSOR AND INSPECTION DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2022-134113, filed on Aug. 25, 2022; the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein generally relate to a magnetic sensor and an inspection device.

BACKGROUND

There is a magnetic sensor using a magnetic layer. There is an inspection device using a magnetic sensor. Magnetic sensors are desired to have high detection sensitivity.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B are schematic views illustrating a magnetic sensor according to a first embodiment;

FIG. **2** is a schematic plan view illustrating a part of the magnetic sensor according to the first embodiment;

FIG. **3** is a schematic plan view illustrating a part of the magnetic sensor according to the first embodiment;

FIG. **4** is a graph illustrating characteristics of the magnetic sensor according to the first embodiment;

FIG. **5** is a graph illustrating the characteristics of the magnetic sensor according to the first embodiment;

FIGS. **6**A to **6**C are graphs illustrating characteristics of the magnetic sensor according to the first embodiment;

FIGS. **7**A and **7**B are schematic plan views illustrating the magnetic sensor according to the first embodiment;

FIGS. **8**A and **8**B are schematic views illustrating a part of the magnetic sensor according to the first embodiment;

FIGS. **9**A and **9**B are schematic views illustrating a part of the magnetic sensor according to the first embodiment;

FIGS. **10**A and **10**B are schematic views illustrating a part of the magnetic sensor according to the first embodiment;

FIGS. **11**A and **11**B are schematic plan views illustrating the magnetic sensor according to the first embodiment;

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

FIG. **13** is a schematic plan view illustrating the magnetic sensor according to the first embodiment;

FIG. **14** is a schematic plan view illustrating the magnetic sensor according to the first embodiment;

FIG. **15** is a schematic plan view illustrating the magnetic sensor according to the first embodiment;

FIG. **16** is a schematic plan view illustrating the magnetic sensor according to the first embodiment;

FIG. **17** is a schematic perspective view illustrating an inspection device according to a second embodiment;

FIG. **18** is a schematic plan view illustrating the inspection device according to the second embodiment;

FIG. **19** is a schematic diagram illustrating the sensor and the inspection device according to the embodiment; and

FIG. **20** is a schematic view illustrating the inspection device according to the embodiment.

DETAILED DESCRIPTION

According to one embodiment, a magnetic sensor includes a first element portion. The first element portion

includes a first magnetic element, a first conductive member, a first magnetic member and a first opposing magnetic member. The first magnetic element includes a first end portion and a first other end portion. A direction from the first end portion to the first other end portion is along a first direction. A second direction from the first conductive member to the first magnetic element crosses the first direction. A third direction from the first magnetic member to the first opposing magnetic member crosses a plane including the first direction and the second direction. A position of at least a part of the first magnetic element in the third direction is between a position of the first magnetic member in the third direction and a position of the first opposing magnetic member in the third direction. The first magnetic member includes a first other magnetic portion and a first magnetic portion. A direction from the first other magnetic portion to the first magnetic portion is along the third direction. A first other magnetic portion length along the first direction of the first other magnetic portion is longer than a first magnetic portion length along the first direction of the first magnetic portion. The first conductive member overlaps the first magnetic portion in the second direction. The first conductive member does not overlap the first other magnetic portion in the second direction.

Various embodiments are described below with reference to the accompanying drawings.

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

In the specification and drawings, components similar to those described previously in an antecedent drawing are marked with like reference numerals, and a detailed description is omitted as appropriate.

First Embodiment

FIGS. **1**A and **1**B are schematic views illustrating a magnetic sensor according to the first embodiment.

FIG. **1**A is a plan view. FIG. **1**B is a cross-sectional view taken along the line **A1**-**A2** of FIG. **1**A.

As shown in FIGS. **1**A and **1**B, a magnetic sensor **110** according to the embodiment includes a first element portion **11**E. The first element portion **11**E includes a first magnetic element **11**, a first conductive member **21**, a first magnetic member **51** and a first opposing magnetic member **51**A. The first magnetic element **11** includes a first end portion **11***e* and a first other end portion **11***f*. A direction from the first end portion **11***e* to the first other end portion **11***f* is along a first direction D**1**.

Let the first direction D**1** be a Y-axis direction. One direction perpendicular to the Y-axis direction is defined as a Z-axis direction. A direction perpendicular to the Y-axis direction and the Z-axis direction is defined as an X-axis direction.

As shown in FIG. **1**B, the second direction D**2** from the first conductive member **21** to the first magnetic element **11** crosses the first direction D**1**.

A third direction D**3** from the first magnetic member **51** to the first opposing magnetic member **51**A crosses a plane including the first direction D**1** and the second direction D**2**. A position of at least part of the first magnetic element **11** in the third direction D**3** is between a position of the first magnetic member **51** in the third direction D**3** and a position of the first opposing magnetic member **51**A in the third direction D**3**.

For example, a length of the first magnetic element **11** along the first direction D**1** is longer than a length of the first magnetic element **11** along the third direction D**3**. For example, a length of the first magnetic element **11** along the first direction D**1** is also longer than the length of the first magnetic element **11** along the second direction D**2**. Thereby, the magnetization of the magnetic layer included in the first magnetic element **11** is easily stabilized.

As shown in FIG. **1**A, the first magnetic member **51** includes a first other magnetic portion **51***f* and a first magnetic portion **51***e*. The direction from the first other magnetic portion **51***f* to the first magnetic portion **51***e* is along the third direction D**3**. The length (width) of the first other magnetic portion **51***f* in the first direction D**1** is defined as a first other magnetic portion length **51***f*L. The length (width) of the first magnetic portion **51***e* in the first direction D**1** is defined as a first magnetic portion length **51***e*L. The first other magnetic portion length **51***f*L is longer than the first magnetic portion length **51***e*L. The first other magnetic portion **51***f* is, for example, a wide portion. The first magnetic portion **51***e* is, for example, a narrow portion.

As shown in FIGS. **1**A and **1**B, the first conductive member **21** overlaps the first magnetic portion **51***e* in the second direction D**2**. The first conductive member **21** does not overlap the first other magnetic portion **51***f* in the second direction D**2**.

For example, the magnetic field around the first element portion **11**E is collected by the first magnetic member **51** and the first opposing magnetic member **51**A. The collected magnetic field is applied to the first magnetic element **11**. The first magnetic member **51** and the first opposing magnetic member **51**A function, for example, as an MFC (Magnetic Flux Concentrator). The magnetic field around the first element portion **11**E includes the detection target magnetic field.

As will be described later, a first current I**1** (see FIG. **1**A) including an AC component is supplied to the first conductive member **21**. A magnetic field based on the first current I**1** is also collected by the first magnetic member **51** and the first opposing magnetic member **51**A. The concentrated magnetic field based on the first current I**1** is effectively applied to the first magnetic element **11**. For example, high sensitivity is obtained. A magnetic sensor capable of detection with high sensitivity can be provided.

In the embodiment, the first conductive member **21** overlaps the first magnetic portion **51***e* and does not overlap the first other magnetic portion **51***f*. As a result, a magnetic field based on the first current I**1** is effectively applied to the first magnetic element **11**. Noise is suppressed by that the first conductive member **21** overlaps the narrow portion and does not overlap the wide portion.

As shown in FIG. **1**A, there is a portion whose width changes between the first other magnetic portion **51***f* and the first magnetic portion **51***e*. Noise increases when the first conductive member **21** overlaps the portion where the width changes. It is considered that this is caused by non-uniformity of the magnetic domains included in the magnetic layer in the portion where the width changes. It is considered that the magnetic domains are uniform in the narrow portion. Noise is suppressed by overlapping the first conductive member **21** the narrow portion. High sensitivity can be obtained while suppressing noise. A magnetic sensor capable of detection with high sensitivity can be provided.

As shown in FIG. **1**A, the first magnetic member **51** may further include a first intermediate magnetic portion **51***m*. The first intermediate magnetic portion **51***m* is between the first other magnetic portion **51***f* and the first magnetic portion **51***e* in the third direction D**3**. A length of the first intermediate magnetic portion **51***m* along the first direction D**1** is defined as a first intermediate magnetic portion length of **51***m*L. The first intermediate magnetic portion length **51***m*L is between the first other magnetic portion length **51***f*L and the first magnetic portion length **51***e*L. The first intermediate magnetic portion length **51***m*L varies in the third direction D**3**. The first intermediate magnetic portion **51***m* is a portion whose width changes.

The rate of change in the third direction D**3** of the first magnetic portion length **51***e*L is lower than the rate of change in the third direction D**3** of the first intermediate magnetic portion length **51***m*L. The rate of change of the first magnetic portion length **51***e*L in the third direction D**3** may be substantially zero. For example, the first magnetic portion length **51***e*L may be substantially constant. The first conductive member **21** does not overlap the first intermediate magnetic portion **51***m* in the second direction D**2**. Thereby, noise can be suppressed.

The rate of change in the third direction D**3** of the first other magnetic portion length **51***f*L is lower than the rate of change in the third direction D**3** of the first intermediate magnetic portion length **51***m*L. The rate of change in the third direction D**3** of the first other magnetic portion length **51***f*L may be substantially zero. For example, the first other magnetic portion length **51***f*L may be substantially constant.

In this example, the first intermediate magnetic portion **51***m* changes linearly in the third direction D**3**. The change in the third direction D**3** of the first intermediate magnetic portion **51***m* may be curved-like. The length of the first intermediate magnetic portion **51***m* along the third direction D**3** may be short. The first intermediate magnetic portion **51***m* may change sharply in the third direction D**3**.

As shown in FIG. **1**A, the first opposing magnetic member **51**A includes a first opposing other magnetic portion **51**Af and a first opposing magnetic portion **51**Ae. The direction from the first opposing magnetic portion **51**Ae to the first opposing other magnetic portion **51**Af is along the third direction D**3**. A length (width) of the first opposing other magnetic portion **51**Af in the first direction D**1** is defined as a first opposing other magnetic portion length **51**AfL. A length (width) of the first opposing magnetic portion **51**Ae in the first direction D**1** is defined as a first opposing magnetic portion length **51**AeL. The first opposing other magnetic portion length **51**AfL is longer than the first opposing magnetic portion length **51**AeL.

As shown in FIGS. **1**A and **1**B, the first conductive member **21** overlaps the first opposing magnetic portion **51**Ae in the second direction D**2**. The first conductive member **21** does not overlap the first opposing other magnetic portion **51**Af in the second direction D**2**.

As shown in FIG. **1**A, the first opposing magnetic member **51**A may further include a first opposing intermediate magnetic portion **51**Am. The first opposing intermediate magnetic portion **51**Am is located between the first opposing other magnetic portion **51**Af and the first opposing magnetic portion **51**Ae in the third direction D**3**. The length of the first opposing intermediate magnetic portion **51**Am along the first direction D**1** is defined as a first opposing intermediate magnetic portion length **51**AmL. The first opposing intermediate magnetic portion length **51**AmL is between the first opposing other magnetic portion length **51**AfL and the first opposing magnetic portion length **51**AeL. The first opposing intermediate magnetic portion length **51**AmL changes in the third direction D**3**.

The rate of change in the third direction D3 of the first opposing magnetic portion length **51**AeL is lower than the rate of change in the third direction D**3** of the first opposing intermediate magnetic portion length **51**AmL. The rate of change in the third direction D**3** of the first opposing magnetic portion length **51**AeL may be substantially 0. For example, the first opposing magnetic portion length **51**AeL may be substantially constant. The first conductive member **21** does not overlap the first opposing intermediate magnetic portion **51**Am in the second direction D**2**. Thereby, noise can be suppressed.

The first opposing magnetic portion length **51**AfL may be the same as the first magnetic portion length **51***e*L. The first opposing magnetic portion length **51**AeL may be the same as the first magnetic portion length **51***e*L. The first opposing intermediate magnetic portion length **51**AmL may be the same as the first intermediate magnetic portion length **51***m*L.

The intensity of the magnetic field based on the first current I**1** supplied to the first conductive member **21** may be higher than the intensity of the target magnetic field, for example. The magnetic field based on the first current I**1** is collected by the first magnetic member **51** and the first opposing magnetic member **51**A, and is effectively applied to the first magnetic element **11**, thereby suppressing, for example, the dynamic range of the system. High sensitivity can be obtained as a system.

As shown in FIG. **1**B, the first magnetic element **11** includes, for example, a first magnetic layer **11***a*, a first opposing magnetic layer **11***b*, and a first non-magnetic layer **11***n*. The direction from the first opposing magnetic layer **11***b* to the first magnetic layer **11***a* is along the second direction D**2**. The first non-magnetic layer **11***n* is located between the first opposing magnetic layer **11***b* and the first magnetic layer **11***a*. At least one of the first magnetic layer **11***a* and the first opposing magnetic layer **11***b* may include at least one selected from the group consisting of Fe, Co, and Ni. The first non-magnetic layer **11***n* may include, for example, at least one selected from the group consisting of Cu and Al. The first non-magnetic layer **11***n* may include, for example, an insulating material.

As shown in FIG. **1**B, an insulating member **10***i* may be provided. The insulating member **10***i* is provided, for example, around the first magnetic element **11**, the first conductive member **21**, the first magnetic member **51**, and the first opposing magnetic member **51**A.

As shown in FIG. **1**A, the first conductive member **21** may include a first conductive portion **21***e* and a first other conductive portion **21***f*. The direction from the first conductive portion **21***e* to the first other conductive portion **21***f* is along the first direction D**1**.

The distance between the first conductive portion **21***e* and the first end portion **11***e* is shorter than the distance between the first conductive portion **21***e* and the first other end portion **11***f*. The distance between the first other conductive portion **21***f* and the first other end portion **11***f* is shorter than the distance between the first other conductive portion **21***f* and the first end portion **11***e*.

As shown in FIG. **1**A, the magnetic sensor **110** may further include a circuit portion **70**. The circuit portion **70** includes a first circuit **71**. The first circuit **71** can supply a first current I**1** including an AC component to the first conductive member **21**. For example, the first circuit **71** is electrically connected to the first conductive portion **21***e* and the first other conductive portion **21***f*.

FIG. **2** is a schematic plan view illustrating a part of the magnetic sensor according to the first embodiment.

As shown in FIG. **2**, the circuit portion **70** may further includes a second circuit **72** and a third circuit **73**. The second circuit **72** supplies an element current Id or an element voltage to the first magnetic element **11**. For example, the second circuit **72** is electrically connected to the first end portion **11***e* and the first other end portion **11***f*.

The third circuit **73** is electrically connected to the first end portion **11***e* and the first other end portion **11***f*. The third circuit **73** can output a signal Sg**1** corresponding to the first electrical resistance of the first magnetic element **11**.

For example, the third circuit **73** can derive a change in the first electrical resistance based on the frequency of the AC component included in the first current I**1**. Thereby, detection with more suppressed noise can be performed. An example of the detection operation of the magnetic sensor **110** will be described later.

FIG. **3** is a schematic plan view illustrating a part of the magnetic sensor according to the first embodiment.

As shown in FIG. **3**, a length of the first magnetic portion **51***e* along the third direction D**3** is defined as a first length w**1**. The length of the first intermediate magnetic portion **51***m* along the third direction D**3** is defined as a second length w**2**. A length of the first other magnetic portion **51***f* along the third direction D**3** is defined as a third length w**3**.

For example, the first length w**1** may be shorter than the third length w**3**. For example, the second length w**2** may be shorter than the third length w**3**.

FIG. **4** is a graph illustrating characteristics of the magnetic sensor according to the first embodiment.

The horizontal axis of FIG. **4** is a first ratio RR**1**. The first ratio RR**1** is a ratio of the sum of the first length w**1** and the second length w**2** to the third length w**3**. The first ratio RR**1** is (w**1**+w**2**)/w**3**. The vertical axis of FIG. **4** is a gain G**1**. The gain G**1** is normalized to 1 for the case in which the first magnetic portion **51***e* and the first intermediate magnetic portion **51***m* are not provided and the entire first magnetic member **51** is the first other magnetic portion **51***f*. In this example, the overall length (w**1**+w**2**+w**3**) and the second length w**2** of the first magnetic member **51** are made constant, and the first length w**1** and the third length w**3** are changed.

As shown in FIG. **4**, when the first ratio RR**1** is less than 1, the gain G**1** exceeds 1. In the embodiment, the first ratio RR**1** is preferably less than 1. The first ratio RR**1** is preferably 0.5 or less. Thereby, a higher gain G**1** is obtained.

An example of a change in electrical resistance in a magnetic element will be described below.

FIG. **5** is a graph illustrating the characteristics of the magnetic sensor according to the first embodiment.

The horizontal axis of FIG. **5** shows the intensity of the external magnetic field Hex applied to the first magnetic element **11**. The vertical axis represents the electrical resistance Rx of the first magnetic element **11**. FIG. **5** corresponds to the R-H characteristic (resistance-magnetic field characteristic).

As shown in FIG. **5**, the electrical resistance Rx has a characteristic of an even function with respect to the magnetic field (external magnetic field Hex, for example, a magnetic field in the X-axis direction) applied to the first magnetic element **11**. For example, the electrical resistance Rx is a first value R**1** when the first magnetic field Hex**1** is applied to the first magnetic element **11**. The electrical resistance Rx is a second value R**2** when the second magnetic field Hex**2** is applied to the first magnetic element **11**. The electrical resistance Rx is a third value R**3** when the third magnetic field Hex3 is applied to the first magnetic element **11**. The absolute value of the first magnetic field Hex1 is smaller than the absolute value of the second magnetic field Hex2 and smaller than the absolute value of the third magnetic field Hex3. For example, the first magnetic field Hex1 is substantially zero. The direction of the second magnetic field Hex2 is opposite to the direction of the third magnetic field Hex3. The first value R1 is smaller than the second value R2 and smaller than the third value R3.

An example in which the first current I1 is an alternating current and does not substantially include a direct current component will be described below. The first current I1 (alternating current) is supplied to the first conductive member **21**. An alternating magnetic field by the alternating current is applied to the first magnetic element **11**. An example of a change in the electrical resistance Rx in such condition will be described.

FIGS. **6**A to **6**C are graphs illustrating characteristics of the magnetic sensor according to the first embodiment.

FIG. **6**A shows characteristics when a signal magnetic field Hsig (external magnetic field) applied to the first magnetic element **11** is 0. FIG. **6**B shows characteristics when the signal magnetic field Hsig is positive. FIG. **6**C shows characteristics when the signal magnetic field Hsig is negative. These figures show the relationship between the magnetic field H and the resistance R (corresponding to the electrical resistance Rx).

As shown in FIG. **6**A, when the signal magnetic field Hsig is 0, the resistance R shows a characteristic symmetrical with respect to the positive and negative magnetic field H. When the AC magnetic field Hac is zero, the resistance R is a low resistance Ro. For example, the magnetization of the magnetization free layer rotates substantially similarly with respect to the positive and negative magnetic fields H. Thus, for example, a symmetrical resistance increasing characteristic is obtained. The variation of the resistance R with respect to the AC magnetic field Hac becomes the same in positive and negative polarity. The period of change of the resistance R is ½ times the period of the alternating magnetic field Hac. The change in resistance R has substantially no frequency component of the alternating magnetic field Hac.

As shown in FIG. **6**B, when the positive signal magnetic field Hsig is applied, the characteristic of the resistance R shifts toward the positive magnetic field H. In the AC magnetic field Hac on the positive side, the resistance R increases. In the negative AC magnetic field Hac, the resistance R becomes small.

As shown in FIG. **6**C, when the negative signal magnetic field Hsig is applied, the characteristic of the resistance R shifts toward the negative magnetic field H. In the positive AC magnetic field Hac, the resistance R decreases. In the negative AC magnetic field Hac, the resistance R increases.

When the signal magnetic field Hsig of a predetermined magnitude is applied, variations of resistances R different from each other with respect to the positive and negative of the AC magnetic field Hac occur. The period of variation of the resistance R with respect to the positive and negative of the alternating magnetic field Hac is ½ of the period of the alternating magnetic field Hac. In response to the signal magnetic field Hsig, an output voltage of an AC frequency component having the same period as that of the AC magnetic field Hac is generated.

The above characteristics are obtained when the signal magnetic field Hsig does not change with time. When the signal magnetic field Hsig changes with time, it becomes as follows. Let the frequency of the signal magnetic field Hsig be the signal frequency fsig. Let the frequency of the alternating magnetic field Hac be the alternating frequency fac. At this time, an output corresponding to the signal magnetic field Hsig is generated at a frequency of fac±fsig.

When the signal magnetic field Hsig changes with time, the signal frequency fsig is, for example, 1 kHz or less. On the other hand, the AC frequency fac is sufficiently higher than the signal frequency fsig. For example, the AC frequency fac is 10 times or more of the signal frequency fsig.

For example, the signal magnetic field Hsig can be detected with high accuracy by extracting the output voltage of a component (AC frequency component) having the same period (frequency) as the period (frequency) of the AC magnetic field Hac. In the magnetic sensor **110** according to the embodiment, the external magnetic field Hex (signal magnetic field Hsig) to be detected can be detected with high sensitivity by using such characteristics. In the embodiment, the external magnetic field Hex (signal magnetic field Hsig) and the alternating magnetic field Hac by the first current I1 can be efficiently applied to the first magnetic element **11**. High sensitivity can be obtained.

One of the first magnetic layer **11*a*** and the first opposing magnetic layer **11*b*** may be a magnetization free layer. The other of the first magnetic layer **11*a*** and the first opposing magnetic layer **11*b*** may be a reference layer. By changing the angle between the magnetization of these magnetic layers, the electrical resistance changes.

FIGS. **7**A and **7**B are schematic plan views illustrating the magnetic sensor according to the first embodiment.

FIGS. **8**A and **8**B are schematic views illustrating a part of the magnetic sensor according to the first embodiment.

FIG. **8**A is a plan view. FIG. **8**B is a cross-sectional view taken along the line B1-B2 of FIG. **8**A.

FIGS. **9**A and **9**B are schematic views illustrating a part of the magnetic sensor according to the first embodiment.

FIG. **9**A is a plan view. FIG. **9**B is a cross-sectional view taken along the line C1-C2 of FIG. **9**A.

FIGS. **10**A and **10**B are schematic views illustrating a part of the magnetic sensor according to the first embodiment.

FIG. **10**A is a plan view. FIG. **10**B is a cross-sectional view taken along the line D1-D2 of FIG. **10**A.

As shown in FIG. **7**A, a magnetic sensor **111** according to the embodiment further includes a second element portion **12**E. In this example, the magnetic sensor **111** further includes a third element portion **13**E and a fourth element portion **14**E.

The second element portion **12**E includes a second magnetic element **12**, a second conductive member **22**, a second magnetic member **52**, and a second opposing magnetic member **52**A. The second magnetic element **12** includes a second end portion **12*ed*** and a second other end portion **12*f***. A direction from the second end portion **12*e*** to the second other end portion **12*f*** is along the first direction D1.

As shown in FIG. **8**B, a direction from the second conductive member **22** to the second magnetic element **12** is along the second direction D2. As shown in FIG. **8**A, the second conductive member **22** includes a second conductive portion **22*e*** and a second other conductive portion **22*f***. A direction from the second conductive portion **22*e*** to the second other conductive portion **22*f*** is along the first direction D1. A distance between the second conductive portion **22*e*** and the second end portion **12*e*** is shorter than a distance between the second conductive portion **22*e*** and the second other end portion **12*f***. The distance between the second other conductive portion **22*f*** and the second other end portion **12*f*** is shorter than a distance between the second other conductive portion **22***f* and the second end portion **12***e*.

A direction from the second magnetic member **52** to the second opposing magnetic member **52**A is along the third direction D**3**. A position of at least a part of the second magnetic element **12** in the third direction D**3** is between a position of the second magnetic member **52** in the third direction D**3** and the position of the second opposing magnetic member **52**A in the third direction D**3**.

As shown in FIG. **7**B, in this example, the first other end portion **11***f* is electrically connected to the second end portion **12***e*. The first other conductive portion **21***f* is electrically connected to the second conductive portion **22***e*. The first other conductive portion **21***f* may be continuous with the second conductive portion **22***e*. The boundary between the first other conductive portion **21***f* and the second conductive portion **22***e* may be unclear or clear. One portion of one conductive member may correspond to the first conductive member **21** and another portion may correspond to the second conductive member **22**.

As shown in FIG. **9**A, the third element portion **13**E includes a third magnetic element **13**, a third conductive member **23**, a third magnetic member **53** and a third opposing magnetic member **53**A. The third magnetic element **13** includes a third end portion **13***e* and a third other end portion **13***f*. A direction from the third end portion **13***e* to the third other end portion **13***f* is along the first direction D**1**.

As shown in FIG. **9**B, a direction from the third conductive member **23** to the third magnetic element **13** is along the second direction D**2**.

As shown in FIG. **9**A, the third conductive member **23** includes a third conductive portion **23***e* and a third other conductive portion **23***f*. A direction from the third conductive portion **23***e* to the third other conductive portion **23***f* is along the first direction D**1**. A distance between the third conductive portion **23***e* and the third end portion **13***e* is shorter than a distance between the third conductive portion **23***e* and the third other end portion **13***f*. A distance between the third other conductive portion **23***f* and the third other end portion **13***f* is shorter than a distance between the third other conductive portion **23***f* and the third end portion **13***e*.

As shown in FIGS. **9**A and **9**B, a direction from the third magnetic member **53** to the third opposing magnetic member **53**A is along the third direction D**3**. A position of at least part of the third magnetic element **13** in the third direction D**3** is between a position of the third magnetic member **53** in the third direction D**3** and a position of the third opposing magnetic member **53**A in the third direction D**3**.

As shown in FIG. **10**A, the fourth element portion **14**E includes a fourth magnetic element **14**, a fourth conductive member **24**, a fourth magnetic member **54** and a fourth opposing magnetic member **54**A. The fourth magnetic element **14** includes a fourth end portion **14***e* and a fourth other end portion **14***f*. A direction from the fourth end portion **14***e* to the fourth other end portion **14***f* is along the first direction D**1**.

As shown in FIG. **10**B, a direction from the fourth conductive member **24** to the fourth magnetic element **14** is along the second direction D**2**.

As shown in FIG. **10**A, the fourth conductive member **24** includes a fourth conductive portion **24***e* and a fourth other conductive portion **24***f*. A direction from the fourth conductive portion **24***e* to the fourth other conductive portion **24***f* is along the first direction D**1**. A distance between the fourth conductive portion **24***e* and the fourth end portion **14***e* is shorter than a distance between the fourth conductive portion **24***e* and the fourth other end portion **14***f*. A distance between the fourth other conductive portion **24***f* and the fourth other end portion **14***f* is shorter than a distance between the fourth other conductive portion **24***f* and the fourth end portion **14***e*.

As shown in FIGS. **10**A and **10**B, a direction from the fourth magnetic member **54** to the fourth opposing magnetic member **54**A is along the third direction D**3**. A position of at least part of the fourth magnetic element **14** in the third direction D**3** is between a position of the fourth magnetic member **54** in the third direction D**3** and a position of the fourth opposing magnetic member **54**A in the third direction D**3**.

As shown in FIG. **7**B, in this example, the second other end portion **12***f* is electrically connected to the fourth other end portion **14***f*. The third end portion **13***e* is electrically connected to the first end portion **11***e*. The third other end portion **13***f* is electrically connected to the fourth end portion **14***e*. The second other conductive portion **22***f* is electrically connected to the fourth other conductive portion **24***f*. The third conductive portion **23***e* is electrically connected to the first conductive portion **21***e*. The third other conductive portion **23***f* is electrically connected to the fourth conductive portion **24***e*.

The third other conductive portion **23***f* may be continuous with the fourth conductive portion **24***e*. The boundary between the third other conductive portion **23***f* and the fourth conductive portion **24***e* may be unclear or clear. One portion of one conductive member may correspond to the third conductive member **23** and another portion may correspond to the fourth conductive member **24**.

As shown in FIGS. **7**A and **7**B, the magnetic sensor **111** may include a circuit portion. The circuit portion **70** includes the first circuit **71**, the second circuit **72** and the third circuit **73**. The first circuit **71** can supply a first current I**1** including an AC component between the first other conductive portion **21***f* and the third other conductive portion **23***f*.

The second circuit **72** can supply the element current Id or the element voltage between a first connection point CP**1** of the first end portion **11***e* and the third end portion **13***e* and a second connection point CP**2** of the second other end portion **12***f* and the fourth other end portion **14***f*.

The third circuit **73** can output the signal Sg**1** corresponding to an electric signal generated between the third connection point CP**3** of the first other end portion **11***f* and the second end portion **12***e* and the fourth connection point CP**4** of the third other end portion **13***f* and the fourth end portion **14***e*. By applying the bridge circuit, detection with more suppressed noise is possible.

As shown in FIG. **8**A, the second magnetic member **52** includes a second other magnetic portion **52***f* and a second magnetic portion **52***e*. A direction from the second magnetic portion **52***e* to the second magnetic portion **52***e* is along the third direction D**3**. A second other magnetic partial length **52***f*L along the first direction D**1** of the second other magnetic portion **52***f* is longer than a second magnetic partial length **52***e*L along the first direction D**1** of the second magnetic portion **52***e*. The second conductive member **22** overlaps the second magnetic portion **52***e* in the second direction D**2**. The second conductive member **22** does not overlap the second other magnetic portion **52***f* in the second direction D**2**.

As shown in FIG. **8**A, the second magnetic member **52** may further include a second intermediate magnetic portion **52***m*. The second intermediate magnetic portion **52***m* is located between the second other magnetic portion **52***f* and the second magnetic portion **52***e* in the third direction D**3**. A length of the second intermediate magnetic portion **52***m* along the first direction D1 is defined as a second intermediate magnetic portion length 52mL. The second intermediate magnetic portion length 52mL is between the second magnetic other portion length 52fL and the second magnetic portion length 52eL.

The rate of change in the third direction D3 of the second magnetic portion length 52eL is lower than the rate of change in the third direction D3 of the second intermediate magnetic portion length 52mL. The second conductive member 22 does not overlap the second intermediate magnetic portion 52m in the second direction D2. Thereby, noise can be suppressed. The rate of change in the third direction D3 of the second other magnetic portion length 52fL is lower than the rate of change in the third direction D3 of the second intermediate magnetic portion length 52mL.

As shown in FIG. 9A, for example, the third magnetic member 53 includes a third other magnetic portion 53f and a third magnetic portion 53e. A direction from the third other magnetic portion 53f to the third magnetic portion 53e is along the third direction D3. A third other magnetic portion length 53fL along the first direction D1 of the third other magnetic portion 53f is longer than a third magnetic portion length 53eL along the first direction D1 of the third magnetic portion 53e. The third conductive member 23 overlaps the third magnetic portion 53e in the second direction D2. The third conductive member 23 does not overlap the third other magnetic portion 53f in the second direction D2.

As shown in FIG. 10A, the fourth magnetic member 54 includes a fourth other magnetic portion 54f and a fourth magnetic portion 54e. A direction from the fourth other magnetic portion 54f to the fourth magnetic portion 54e is along the third direction D3. A fourth other magnetic portion length 54fL along the first direction D1 of the fourth other magnetic portion 54f is longer than a fourth magnetic portion length 54eL along the first direction D1 of the fourth magnetic portion 54e. The fourth conductive member 24 overlaps the fourth magnetic portion 54e in the second direction D2. The fourth conductive member 24 does not overlap the fourth other magnetic portion 54f in the second direction D2.

As shown in FIG. 9A, the third magnetic member 53 may further include a third intermediate magnetic portion 53m. The third intermediate magnetic portion 53m is between the third other magnetic portion 53f and the third magnetic portion 53e in the third direction D3. A length of the third intermediate magnetic portion 53m along the first direction D1 is defined as a third intermediate magnetic portion length 53mL. The third intermediate magnetic portion length 53mL is between the third other magnetic portion length 53fL and the third magnetic portion length 53eL.

The rate of change in the third direction D3 of the third magnetic portion length 53eL is lower than the rate of change in the third direction D3 of the third intermediate magnetic portion length 53mL. The third conductive member 23 does not overlap the third intermediate magnetic portion 53m in the second direction D2. Thereby, noise can be suppressed. The rate of change in the third direction D3 of the third other magnetic portion length 53fL is lower than the rate of change in the third direction D3 of the third intermediate magnetic portion length 53mL.

As shown in FIG. 10A, the fourth magnetic member 54 may further include a fourth intermediate magnetic portion 54m. The fourth intermediate magnetic portion 54m is between the fourth other magnetic portion 54f and the fourth magnetic portion 54e in the third direction D3. A length of the fourth intermediate magnetic portion 54m along the first direction D1 is defined as a fourth intermediate magnetic portion length 54mL. The fourth intermediate magnetic portion length 54mL is between the fourth other magnetic portion length 54fL and the fourth magnetic portion length 54eL.

The rate of change in the third direction D3 of the fourth magnetic portion length 54eL is lower than the rate of change in the third direction D3 of the fourth intermediate magnetic portion length 54mL. The fourth conductive member 24 does not overlap the fourth intermediate magnetic portion 54m in the second direction D2. Thereby, noise can be suppressed. The change rate in the third direction D3 of the fourth other magnetic portion length 54fL is lower than the change rate in the third direction D3 of the fourth intermediate magnetic portion length 54mL.

As shown in FIG. 8A, the second opposing magnetic member 52A includes a second opposing other magnetic portion 52Af and a second opposing magnetic portion 52Ae. A direction from the second opposing magnetic portion 52Ae to the second opposing other magnetic portion 52Af is along the third direction D3. The length (width) of the second opposing other magnetic portion 52Af in the first direction D1 is defined as a second opposing other magnetic portion length 52AfL. The length (width) of the second opposing magnetic portion 52Ae in the first direction D1 is defined as a second opposing magnetic portion length 52AeL. The second opposing magnetic portion length 52AfL is longer than the second opposing magnetic portion length 52AeL.

As shown in FIGS. 8A and 8B, the second conductive member 22 overlaps the second opposing magnetic portion 52Ae in the second direction D2. The second conductive member 22 does not overlap the second opposing other magnetic portion 52Af in the second direction D2.

As shown in FIG. 8A, the second opposing magnetic member 52A may further include a second opposing intermediate magnetic portion 52Am. The second opposing intermediate magnetic portion 52Am is between the second opposing other magnetic portion 52Af and the second opposing magnetic portion 52Ae in the third direction D3. A length of the second opposing intermediate magnetic portion 52Am along the first direction D1 is defined as a second opposing intermediate magnetic portion length 52AmL. The second opposing intermediate magnetic portion length 52AmL is between the second opposing other magnetic portion length 52AfL and the second opposing magnetic portion length 52AeL.

The rate of change in the third direction D3 of the second opposing magnetic portion length 52AeL is lower than the rate of change in the third direction D3 of the second opposing intermediate magnetic portion length 52AmL. The second conductive member 22 does not overlap the second opposing intermediate magnetic portion 52Am in the second direction D2. Thereby, noise can be suppressed.

As shown in FIG. 9A, the third opposing magnetic member 53A includes a third opposing other magnetic portion 53Af and a third opposing magnetic portion 53Ae. A direction from the third opposing magnetic portion 53Ae to the third opposing other magnetic portion 53Af is along the third direction D3. A length (width) of the third opposing other magnetic portion 53Af in the first direction D1 is defined as a third opposing magnetic portion length 53AfL. A length (width) of the third opposing magnetic portion 53Ae in the first direction D1 is defined as a third opposing magnetic portion length 53AeL. The third opposing magnetic portion length 53AfL is longer than the third opposing magnetic portion length 53AeL.

As shown in FIGS. **9**A and **9**B, the third conductive member **23** overlaps the third opposing magnetic portion **53**Ae in the second direction D**2**. The third conductive member **23** does not overlap the third opposing other magnetic portion **53**Af in the second direction D**2**.

As shown in FIG. **9**A, the third opposing magnetic member **53**A may further include a third opposing intermediate magnetic portion **53**Am. The third opposing intermediate magnetic portion **53**Am is between the third opposing other magnetic portion **53**Af and the third opposing magnetic portion **53**Ae in the third direction D**3**. A length of the third opposing intermediate magnetic portion **53**Am along the first direction D**1** is defined as a third opposing intermediate magnetic portion length **53**AmL. The third opposing intermediate magnetic portion length **53**AmL is between the third opposing other magnetic portion length **53**AfL and the third opposing magnetic portion length **53**AeL.

The rate of change in the third direction D**3** of the third opposing magnetic portion length **53**AeL is lower than the rate of change in the third direction D**3** of the third opposing intermediate magnetic portion length **53**AmL. The third conductive member **23** does not overlap the third opposing intermediate magnetic portion **53**Am in the second direction D**2**. Thereby, noise can be suppressed.

As shown in FIG. **10**A, the fourth opposing magnetic member **54**A includes a fourth opposing other magnetic portion **54**Af and a fourth opposing magnetic portion **54**Ae. A direction from the fourth opposing magnetic portion **54**Ae to the fourth opposing other magnetic portion **54**Af is along the third direction D**3**. A length (width) of the fourth opposing other magnetic portion **54**Af in the first direction D**1** is defined as a fourth opposing other magnetic portion length **54**AfL. A length (width) of the fourth opposing magnetic portion **54**Ae in the first direction D**1** is defined as a fourth opposing magnetic portion length **54**AeL. The fourth opposing other magnetic portion length **54**AfL is longer than the fourth opposing magnetic portion length **54**AeL.

As shown in FIGS. **10**A and **10**B, the fourth conductive member **24** overlaps the fourth opposing magnetic portion **54**Ae in the second direction D**2**. The fourth conductive member **24** does not overlap the fourth opposing other magnetic portion **54**Af in the second direction D**2**.

As shown in FIG. **10**A, the fourth opposing magnetic member **54**A may further include a fourth opposing intermediate magnetic portion **54**Am. The fourth opposing intermediate magnetic portion **54**Am is between the fourth opposing other magnetic portion **54**Af and the fourth opposing magnetic portion **54**Ae in the third direction D**3**. A length of the fourth opposing intermediate magnetic portion **54**Am along the first direction D**1** is defined as a fourth opposing intermediate magnetic portion length **54**AmL. The fourth opposing intermediate magnetic portion length **54**AmL is between the fourth opposing other magnetic portion length **54**AfL and the fourth opposing magnetic portion length **54**AeL.

The change rate in the third direction D**3** of the fourth opposing magnetic portion length **54**AeL is lower than the change rate in the third direction D**3** of the fourth opposing intermediate magnetic portion length **54**AmL. The fourth conductive member **24** does not overlap the fourth opposing intermediate magnetic portion **54**Am in the second direction D**2**. Thereby, noise can be suppressed.

As shown in FIG. **8**B, the second magnetic element **12** includes, for example, a second magnetic layer **12***a*, a second opposing magnetic layer **12***b* and a second non-magnetic layer **12***n*. A direction from the second opposing magnetic layer **12***b* to the second magnetic layer **12***a* is along the second direction D**2**. The second non-magnetic layer **12***n* is between the second opposing magnetic layer **12***b* and the second magnetic layer **12***a*.

As shown in FIG. **9**B, the third magnetic element **13** includes, for example, a third magnetic layer **13***a*, a third opposing magnetic layer **13***b* and a third non-magnetic layer **13***n*. A direction from the third opposing magnetic layer **13***b* to the third magnetic layer **13***a* is along the second direction D**2**. The third non-magnetic layer **13***n* is between the third opposing magnetic layer **13***b* and the third magnetic layer **13***a*.

As shown in FIG. **10**B, the fourth magnetic element **14** includes, for example, a fourth magnetic layer **14***a*, a fourth opposing magnetic layer **14***b* and a fourth non-magnetic layer **14***n*. A direction from the fourth opposing magnetic layer **14***b* to the fourth magnetic layer **14***a* is along the second direction D**2**. The fourth non-magnetic layer **14***n* is between the fourth opposing magnetic layer **14***b* and the fourth magnetic layer **14***a*.

At least one of the second magnetic layer **12***a*, the third magnetic layer **13***a*, and the fourth magnetic layer **14***a* may include the material included in the first magnetic layer **11***a*. At least one of the second opposing magnetic layer **12***b*, the third opposing magnetic layer **13***b*, and the fourth opposing magnetic layer **14***b* may include the material included in the first opposing magnetic layer **11***b*. At least one of the second non-magnetic layer **12***n*, the third non-magnetic layer **13***n*, and the fourth non-magnetic layer **14***n* may include the material included in the first non-magnetic layer **11***n*.

FIGS. **11**A and **11**B are schematic plan views illustrating the magnetic sensor according to the first embodiment.

As shown in FIG. **11**A, in a magnetic sensor **112** according to the embodiment, the second magnetic member **52** and the second opposing magnetic member **52**A may be omitted in the second element portion **12**E. In the third element portion **13**E, the third magnetic member **53** and the third opposing magnetic member **53**A may be omitted. The configuration of the magnetic sensor **112** except for the above may be the same as that of the magnetic sensor **111**. In the magnetic sensor **112**, high sensitivity can be obtained while suppressing noise.

The magnetic sensor **112** includes a first element portion **11**E, the second element portion **12**E, the third element portion **13**E and the fourth element portion **14**E. The first element portion **11**E in the magnetic sensor **112** may be the same as the first element portion **11**E in the magnetic sensor **110**.

The second element portion **12**E includes the second magnetic element **12** and the second conductive member **22**. The second magnetic element **12** includes the second end portion **12***e* and the second other end portion **12***f*. The direction from the second end portion **12***e* to the second other end portion **12***f* is along the first direction D**1**.

The direction from the second conductive member **22** to the second magnetic element **12** is along the second direction D**2**. The second conductive member **22** includes the second conductive portion **22***e* and the second other conductive portion **22***f*. The direction from the second conductive portion **22***e* to the second other conductive portion **22***f* is along the first direction D**1**. The distance between the second conductive portion **22***e* and the second end portion **12***e* is shorter than the distance between the second conductive portion **22***e* and the second other end portion **12***f*. The distance between the second other conductive portion **22***f* and the second other end portion **12***f* is shorter than the distance between the second other conductive portion **22***f* and the second end portion **12***e*.

The third element portion **13**E includes the third magnetic element **13** and the third conductive member **23**. The third magnetic element **13** includes the third end portion **13***e* and the third other end portion **13***f*. The direction from the third end portion **13***e* to the third other end portion **13***f* is along the first direction D**1**.

The direction from the third conductive member **23** to the third magnetic element **13** is along the second direction D**2**. The third conductive member **23** includes the third conductive portion **23***e* and the third other conductive portion **23***f*. The direction from the third conductive portion **23***e* to the third other conductive portion **23***f* is along the first direction D**1**. The distance between the third conductive portion **23***e* and the third end portion **13***e* is shorter than the distance between the third conductive portion **23***e* and the third other end portion **13***f*. The distance between the third other conductive portion **23***f* and the third other end portion **13***f* is shorter than the distance between the third other conductive portion **23***f* and the third end portion **13***e*.

The fourth element portion **14**E includes the fourth magnetic element **14**, the fourth conductive member **24**, the fourth magnetic member **54** and the fourth opposing magnetic member **54**A. The fourth magnetic element **14** includes the fourth end portion **14***e* and the fourth other end portion **14***f*. The direction from the fourth end portion **14***e* to the fourth other end portion **14***f* is along the first direction D**1**.

The direction from the fourth conductive member **24** to the fourth magnetic element **14** is along the second direction D**2**. The fourth conductive member **24** includes a fourth conductive portion **24***e* and a fourth other conductive portion **24***f*. The direction from the fourth conductive portion **24***e* to the fourth other conductive portion **24***f* is along the first direction D**1**. The distance between the fourth conductive portion **24***e* and the fourth end portion **14***e* is shorter than the distance between the fourth conductive portion **24***e* and the fourth other end portion **14***f*. The distance between the fourth other conductive portion **24***f* and the fourth other end portion **14***f* is shorter than the distance between the fourth other conductive portion **24***f* and the fourth end portion **14***e*.

The position of at least part of the fourth magnetic element **14** in the third direction D**3** is between the position of the fourth magnetic member **54** in the third direction D**3** and the position of the fourth opposing magnetic member **54**A in the third direction D**3**.

The first other end portion **11***f* is electrically connected to the second end portion **12***e*. The second other end portion **12***f* is electrically connected to the fourth other end portion **14***f*. The third end portion **13***e* is electrically connected to the first end portion **11***e*. The third other end portion **13***f* is electrically connected to the fourth end portion **14***e*.

The first other conductive portion **21***f* is electrically connected to the second conductive portion **22***e*. The second other conductive portion **22***f* is electrically connected to the fourth other conductive portion **24***f*. The third conductive portion **23***e* is electrically connected to the first conductive portion **21***e*. The third other conductive portion **23***f* is electrically connected to the fourth conductive portion **24***e*.

The first circuit **71** can supply the first current I**1** including an AC component between the first other conductive portion **21***f* and the third other conductive portion **23***f*.

The second circuit **72** can supply the element current Id or the element voltage between the first connection point CP**1** of the first end portion **11***e* and the third end portion **13***e* and the second connection point CP**2** of the second other end portion **12***f* and the fourth other end portion **14***f*.

The third circuit **73** can output the signal Sg**1** corresponding to the electrical signal generated between the third connection point CP**3** of the first other end portion **11***f* and the second end portion **12***e* and the fourth connection point CP**4** of the third other end portion **13***f* and the fourth end portion **14***e*.

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

As shown in FIG. **12**, in a magnetic sensor **113** according to the embodiment, the third magnetic member **53** is continuous with the first opposing magnetic member **51**A. The fourth magnetic member **54** is continuous with the second opposing magnetic member **52**A. The configuration of the magnetic sensor **113** excluding the above may be the same as the configuration of the magnetic sensor **111**. Also in the magnetic sensor **113**, high sensitivity can be obtained while suppressing noise.

FIG. **13** is a schematic plan view illustrating the magnetic sensor according to the first embodiment.

As shown in FIG. **13**, in a magnetic sensor **114** according to the embodiment, the second magnetic member **52** is continuous with the first magnetic member **51**. The second opposing magnetic member **52**A is continuous with the first opposing magnetic member **51**A. The fourth magnetic member **54** may be continuous with the third magnetic member **53**. The fourth opposing magnetic member **54**A is continuous with the third opposing magnetic member **53**A. The configuration of the magnetic sensor **114** excluding the above may be the same as the configuration of the magnetic sensor **113**. Also in the magnetic sensor **114**, high sensitivity can be obtained while suppressing noise.

FIG. **14** is a schematic plan view illustrating the magnetic sensor according to the first embodiment.

As shown in FIG. **14**, in a magnetic sensor **115** according to the embodiment, each of the first magnetic member **51**, the first opposing magnetic member **51**A, the second magnetic member **52**, the second opposing magnetic member **52**A, the third magnetic member **53**, the third opposing magnetic member **53**A, the fourth magnetic member **54**, and the fourth opposing magnetic member **54**A may be asymmetric with respect to a line along the X-axis direction. The configuration of the magnetic sensor **115** excluding the above may be the same as the configuration of the magnetic sensor **113**. Also in the magnetic sensor **115**, high sensitivity can be obtained while suppressing noise.

FIGS. **15** and **16** are schematic plan views illustrating the magnetic sensor according to the first embodiment.

As shown in FIG. **15**, a magnetic sensor **116** according to the embodiment includes the first element portion **11**E, the second element portion **12**E, the third element portion **13**E and the fourth element portion **14**E. The first element portion **11**E in the magnetic sensor **116** may be the same as the first element portion **11**E in the magnetic sensor **110** or the magnetic sensor

In the magnetic sensor **116**, the second element portion **12**E includes the second magnetic element **12**, the second magnetic member **52** and the second opposing magnetic member **52**A. The second magnetic element **12** includes the second end portion **12***e* and the second other end portion **12***f*. The direction from the second end portion **12***e* to the second other end portion **12***f* is along the first direction D**1**.

The direction from a part of the first conductive member **21** to the second magnetic element **12** is along the second direction D**2**. The part of the first conductive member **21** overlaps the second magnetic element **12** in the second direction D**2**.

The position of at least part of the second magnetic element **12** in the third direction D**3** is between the position of the second magnetic member **52** in the third direction D**3** and the position of the second opposing magnetic member **52**A in the third direction D**3**.

The third element portion **13**E includes the third magnetic element **13**. The third magnetic element **13** includes the third end portion **13***e* and the third other end portion **13***f*. The fourth element portion **14**E includes the fourth magnetic element **14**. The fourth magnetic element **14** includes the fourth end portion **14***e* and the fourth other end portion **14***f*.

As shown in FIG. **16**, in the magnetic sensor **116**, the first end portion **11***e* is electrically connected to the third end portion **13***e*. The first other end portion **11***f* is electrically connected to the fourth end portion **14***e*. The third other end portion **13***f* is electrically connected to the second end portion **12***e*. The second other end portion **12***f* is electrically connected to the fourth other end portion **14***f*.

The third magnetic element **13** and the fourth magnetic element **14** do not overlap the first magnetic member **51**, the first opposing magnetic member **51**A, the second magnetic member **52** and the second opposing magnetic member **52**A in the second direction D**2**.

In this example, the position of the third magnetic element **13** in the first direction D**1** is between the position of the first magnetic member **51** in the first direction D**1** and the position of the second magnetic member **52** in the first direction D**1**. The position of the fourth magnetic element **14** in the first direction D**1** is between the position of the first opposing magnetic member **51**A in the first direction D**1** and the position of the second opposing magnetic member **52**A in the first direction D**1**.

As shown in FIG. **15**, the first circuit **71** can supply the first current I**1** including an AC component between the first conductive portion **21***e* and the first other conductive portion **21***f*.

As shown in FIG. **16**, the second circuit **72** can supply the element current Id or the element voltage between the first connection point CP**1** of the first end portion **11***e* and the third end portion **13***e* and the second connection point of the second other end portion **12***f* and the fourth other end portion **14***f*.

The third circuit **73** can output signal Sg**1** corresponding to the electrical signal generated between the third connection point CP**3** of the third other end portion **13***f* and the second end portion **12***e* and the fourth connection point CP**4** of the first other end portion **11***f* and the fourth end portion **14***e*.

Second Embodiment

The second embodiment relates to an inspection device. As will be described later, the inspection device may include a diagnostic device.

FIG. **17** is a schematic perspective view illustrating an inspection device according to a second embodiment.

As shown in FIG. **17**, an inspection device **710** according to the embodiment includes a sensor **150***a* (magnetic sensor) and a processor **770**. The sensor **150***a* may be the sensor according to the first embodiment and a modification thereof. The processor **770** processes an output signal obtained from the sensor **150***a*. The processor **770** may compare the signal obtained from the sensor **150***a* with the reference value. The processor **770** can output the inspection result based on the processing result.

For example, the inspection device **710** inspects an inspection object **680**. The inspection object **680** is, for example, an electronic device (including a semiconductor circuit or the like). The inspection object **680** may be, for example, a battery **610** or the like.

For example, the sensor **150***a* according to the embodiment may be used together with the battery **610**. For example, a battery system **600** includes the battery **610** and the sensor **150***a*. The sensor **150***a* can detect the magnetic field generated by the current flowing through the battery **610**.

FIG. **18** is a schematic plan view illustrating the inspection device according to the second embodiment.

As shown in FIG. **18**, the sensor **150***a* includes, for example, multiple sensors according to the embodiment. In this example, the sensor **150***a* includes multiple sensors (the element portion **10**U such as the sensor **110**, etc.). The multiple sensors are arranged along, for example, two directions (for example, the X-axis direction and the Y-axis direction). The multiple magnetic sensors **110** are provided, for example, on a substrate.

The sensor **150***a* can detect the magnetic field generated by the current flowing through the inspection object **680** (for example, the battery **610** may be used). For example, when the battery **610** approaches an abnormal state, an abnormal current may start to flow through the battery **610**. By detecting the abnormal current with the sensor **150***a*, it is possible to know the change in the state of the battery **610**. For example, in a state where the sensor **150***a* is placed close to the battery **610**, the entire battery **610** can be inspected in a short time by moving the sensor array in two directions. The sensor **150***a* may be used for inspection of the battery **610** in manufacturing process of the battery **610**.

The sensor according to the embodiment can be applied to, for example, the inspection device **710** such as a diagnostic device.

FIG. **19** is a schematic diagram illustrating the sensor and the inspection device according to the embodiment.

As shown in FIG. **19**, a diagnostic apparatus **500**, which is an example of the inspection device **710**, includes a sensor **150**. The sensor **150** includes the sensors described with respect to the first embodiment and modifications thereof.

In the diagnostic apparatus **500**, the sensor **150** is, for example, a magnetoencephalograph. The magnetoencephalograph detects the magnetic field generated by the cranial nerves. When the sensor **150** is used in a magnetoencephalograph, the size of the magnetic element included in the sensor **150** is, for example, not less than 1 mm and less than 10 mm. This size is, for example, the length including an MFC.

As shown in FIG. **19**, the sensor **150** (magnetoencephalogram) is attached to, for example, the head of a human body. The sensor **150** (magnetoencephalogram) includes a sensor part **301**. The sensor **150** (magnetoencephalogram) may include multiple sensor parts **301**. The number of the multiple sensor parts **301** is, for example, about 100 (for example, not less than 50 and not more than 150). The multiple sensor parts **301** are provided on a flexible base body **302**.

The sensor **150** may include, for example, a circuit such as differential detection. The sensor **150** may include a sensor other than the sensor (for example, a potential terminal or an acceleration sensor).

A size of the sensor **150** is smaller than a size of a conventional SQUID sensor. Therefore, it is easy to install the multiple sensor parts **301**. Installation of the multiple sensor parts **301** and other circuits is easy. The coexistence of the multiple sensor parts **301** and other sensors is easy.

The base body **302** may include an elastic body such as a silicone resin. For example, the multiple sensor parts **301** are provided to be connected to the base body **302**. The base body **302** can be in close contact with the head, for example.

The input/output code **303** of the sensor part **301** is connected to a sensor driver **506** and a signal input/output **504** of the diagnostic apparatus **500**. The magnetic field measurement is performed in the sensor part **301** based on the electric power from the sensor driver **506** and the control signal from the signal input/output **504**. The result is input to the signal input/output **504**. The signal obtained by the signal input/output **504** is supplied to a signal processor **508**. The signal processor **508** performs processing such as noise removal, filtering, amplification, and signal calculation. The signal processed by the signal processor **508** is supplied to a signal analyzer **510**. The signal analyzer **510** extracts, for example, a specific signal for magnetoencephalography measurement. In the signal analyzer **510**, for example, signal analysis for matching signal phases is performed.

The output of the signal analyzer **510** (data for which signal analysis has been completed) is supplied to a data processor **512**. The data processor **512** performs data analysis. In this data analysis, for example, image data such as MRI (Magnetic Resonance Imaging) can be incorporated. In this data analysis, for example, scalp potential information such as EEG (Electroencephalogram) can be incorporated. For example, a data part **514** such as MRI or EEG is connected to the data processor **512**. By the data analysis, for example, nerve ignition point analysis, inverse problem analysis, and the like are performed.

The result of the data analysis is supplied to, for example, an imaging diagnostic **516**. Imaging is performed in the imaging diagnostic **516**. Imaging assists in diagnosis.

The above series of operations is controlled by, for example, a control mechanism **502**. For example, necessary data such as primary signal data or metadata in the middle of data processing is stored in the data server. The data server and the control mechanism may be integrated.

The diagnostic apparatus **500** according to the embodiment includes the sensor **150** and the processor that processes an output signal obtained from the sensor **150**. This processor includes, for example, at least one of a signal processor **508** or a data processor **512**. The processor includes, for example, a computer.

In the sensor **150** shown in FIG. **19**, the sensor part **301** is installed on the head of the human body. The sensor part **301** may be installed on the chest of the human body. This enables magnetocardiography measurement. For example, the sensor part **301** may be installed on the abdomen of a pregnant woman.

This makes it possible to perform a fetal heartbeat test.

The sensor device including the subject is preferably installed in a shield room. Thereby, for example, the influence of geomagnetism or magnetic noise can be suppressed.

For example, a mechanism for locally shielding the measurement site of the human body or the sensor part **301** may be provided. For example, the sensor part **301** may be provided with a shield mechanism. For example, effective shielding may be performed in the signal analysis or the data processing.

In embodiments, the base body **302** may be flexible and may be substantially non-flexible. In the example shown in FIG. **19**, the base body **302** is a continuous film processed into a hat shape. The base body **302** may be in a net shape. Thereby, for example, good wearability can be obtained. For example, the adhesion of the base body **302** to the human body is improved. The base body **302** may be helmet-shaped and may be rigid.

FIG. **20** is a schematic view illustrating the inspection device according to the embodiment.

In the example shown in FIG. **20**, the sensor part **301** is provided on a flat plate-shaped hard base body **305**.

In the example shown in FIG. **20**, the input/output of the signal obtained from the sensor part **301** is the same as the input/output described with respect to FIG. **19**. In the example shown in FIG. **20**, the processing of the signal obtained from the sensor part **301** is the same as the processing described with respect to FIG. **19**.

There is a reference example of using a SQUID (Superconducting Quantum Interference Device) sensor as a device for measuring a weak magnetic field such as a magnetic field generated from a living body. In this reference example, since superconductivity is used, the device is large and the power consumption is also large. The burden on the measurement target (patient) is heavy.

According to the embodiment, the device can be downsized. Power consumption can be suppressed. The burden on the measurement object (patient) can be reduced. According to the embodiment, the SN ratio of magnetic field detection can be improved. Sensitivity can be improved.

The embodiments may include the following configurations (for example, technical proposals).

(Configuration 1)

A magnetic sensor, comprising:

a first element portion including a first magnetic element, a first conductive member, a first magnetic member and a first opposing magnetic member,

the first magnetic element including a first end portion and a first other end portion, a direction from the first end portion to the first other end portion being along a first direction,

a second direction from the first conductive member to the first magnetic element crossing the first direction,

a third direction from the first magnetic member to the first opposing magnetic member crossing a plane including the first direction and the second direction,

a position of at least a part of the first magnetic element in the third direction being between a position of the first magnetic member in the third direction and a position of the first opposing magnetic member in the third direction,

the first magnetic member including a first other magnetic portion and a first magnetic portion, a direction from the first other magnetic portion to the first magnetic portion being along the third direction, a first other magnetic portion length along the first direction of the first other magnetic portion being longer than a first magnetic portion length along the first direction of the first magnetic portion, and

the first conductive member overlapping the first magnetic portion in the second direction, and the first conductive member not overlapping the first other magnetic portion in the second direction.

(Configuration 2)

The sensor according to Configuration 1, wherein

the first magnetic member further includes a first intermediate magnetic portion,

the first intermediate magnetic portion is between the first other magnetic portion and the first magnetic portion in the third direction,

a first intermediate magnetic portion length along the first direction of the first intermediate magnetic portion is between the first other magnetic portion length and the first magnetic portion length,

the first intermediate magnetic portion length varies in the third direction,

a rate of change in the third direction of the first magnetic portion length is lower than a rate of change in the third direction of the first intermediate magnetic portion length in the third direction, and

the first conductive member does not overlap the first intermediate magnetic portion in the second direction.

(Configuration 3)

The sensor according to Configuration 2, wherein the first magnetic portion length is substantially constant.

(Configuration 4)

The sensor according to Configuration 2 or 3, wherein

a first ratio is less than 1,

the first ratio being a ratio of a sum of a length of the first magnetic portion along the third direction and a length of the first intermediate magnetic portion along the third direction to a length of the first other magnetic portion along the third direction.

(Configuration 5)

The sensor according to Configuration 4, wherein the first ratio is 0.5 or less.

(Configuration 6)

The sensor according to any one of Configurations 1 to 5, wherein

the first conductive member includes a first conductive portion and a first other conductive portion,

a direction from the first conductive portion to the first other conductive portion is along the first direction,

a distance between the first conductive portion and the first end portion is shorter than a distance between the first conductive portion and the first other end portion, and

a distance between the first other conductive portion and the first other end portion is shorter than the distance between the first other conductive portion and the first end portion.

(Configuration 7)

The sensor according to Configuration 6, further comprising a circuit portion including a first circuit,

the first circuit being configured to supply a first current including an AC component to the first conductive member.

(Configuration 8)

The sensor according to Configuration 7, wherein

the circuit portion further includes a second circuit and a third circuit,

the second circuit is configured to supply an element current or an element voltage to the first magnetic element, and

the third circuit is configured to output a signal corresponding to a first electrical resistance of the first magnetic element.

(Configuration 9)

The sensor according to Configuration 6, further comprising a second element unit,

the second element portion including a second magnetic element, a second conductive member, a second magnetic member and a second opposing magnetic member,

the second magnetic element including a second end portion and a second other end portion, a direction from the second end portion to the second other end portion being along the first direction,

a direction from the second conductive member to the second magnetic element being along the second direction,

the second conductive member including a second conductive portion and a second other conductive portion,

a direction from the second conductive portion to the second other conductive portion being along the first direction,

a distance between the second conductive portion and the second end portion being shorter than a distance between the second conductive portion and the second other end portion,

a distance between the second other conductive portion and the second other end portion being shorter than a distance between the second other conductive portion and the second end portion,

a position of at least a part of the second magnetic element in the third direction being between a position of the second magnetic member in the third direction and a position of the second opposing magnetic member in the third direction,

the first other end portion being electrically connected to the second end portion, and

the first other conductive portion being electrically connected to the second conductive portion.

(Configuration 10)

The sensor according to Configuration 9, wherein

the second magnetic member includes a second other magnetic portion and a second magnetic portion,

a direction from the second other magnetic portion to the second magnetic portion is along the third direction,

a second other magnetic portion length along the first direction of the second other magnetic portion is longer than a second magnetic portion length along the first direction of the second magnetic portion,

the second conductive member overlaps the second magnetic portion in the second direction, and

the second conductive member does not overlap the second other magnetic portion in the second direction.

(Configuration 11)

The sensor according to Configuration 9 or 10, wherein

the second magnetic member is continuous with the first magnetic member, and

the second opposing magnetic member is continuous with the first opposing magnetic member.

(Configuration 12)

The sensor according to Configuration 9, further comprising a third element portion and a fourth element portion,

the third element portion including a third magnetic element, a third conductive member, a third magnetic member and a third opposing magnetic member,

the third magnetic element including a third end portion and a third other end portion, a direction from the third end portion to the third other end portion being along the first direction,

a direction from the third conductive member to the third magnetic element being along the second direction,

the third conductive member including a third conductive portion and a third other conductive portion,

a direction from the third conductive portion to the third other conductive portion being along the first direction,

a distance between the third conductive portion and the third end portion being shorter than a distance between the third conductive portion and the third other end portion, a distance between the third other conductive portion and the third other end portion being shorter than a distance between the third other conductive portion and the third end portion,

a position of at least a part of the third magnetic element in the third direction being between a position of the third magnetic member in the third direction and a position of the third opposing magnetic member in the third direction,

the fourth element portion including a fourth magnetic element, a fourth conductive member, a fourth magnetic member and a fourth opposing magnetic member,

the fourth magnetic element including a fourth end portion and a fourth other end portion, a direction from the fourth end portion to the fourth other end portion being along the first direction,

a direction from the fourth conductive member to the fourth magnetic element being along the second direction,

the fourth conductive member including a fourth conductive portion and a fourth other conductive portion,

a direction from the fourth conductive portion to the fourth other conductive portion being along the first direction,

a distance between the fourth conductive portion and the fourth end portion being shorter than a distance between the fourth conductive portion and the fourth other end portion,

a distance between the fourth other conductive portion and the fourth other end portion being shorter than the distance between the fourth other conductive portion and the fourth end portion,

a position of at least a part of the fourth magnetic element in the third direction being between the position of the fourth magnetic member in the third direction and a position of the fourth opposing magnetic member in the third direction,

the second other end portion being electrically connected to the fourth other end portion,

the third end portion being electrically connected to the first end portion,

the third other end portion being electrically connected to the fourth end portion,

the second other conductive portion being electrically connected to the fourth other conductive portion,

the third conductive portion being electrically connected to the first conductive portion, and

the third conductive portion being electrically connected to the fourth conductive portion.

(Configuration 13)

The sensor according to Configuration 12, further comprising a circuit portion,

the circuit portion including a first circuit, a second circuit and a third circuit,

the first circuit being configured to supply a first current including an AC component between the first other conductive portion and the third other conductive portion,

the second circuit being configured to supply an element current or an element voltage between a first connection point of the first end portion and the third end portion and a second connection point between the second other end portion and the fourth other end portion, and

the third circuit being configured to output a signal corresponding to an electrical signal generated between a third connection point of the first other end portion and the second end portion and a fourth connection point of the third other end portion and the fourth end portion.

(Configuration 14)

The sensor according to Configuration 13, wherein

the third magnetic member includes a third other magnetic portion and a third magnetic portion, a direction from the third other magnetic portion to the third magnetic portion is along the third direction, a third magnetic portion length of the third magnetic portion along the first direction is longer than a third magnetic portion length of the third magnetic portion along the first direction,

the third conductive member overlaps the third magnetic portion in the second direction,

the third conductive member does not overlap the third other magnetic portion in the second direction,

the fourth magnetic member includes a fourth other magnetic portion and a fourth magnetic portion, a direction from the fourth other magnetic portion to the fourth magnetic portion is along the third direction, a fourth other magnetic portion length along the first direction of the fourth other magnetic portion is longer than a fourth magnetic portion length along the first direction of the fourth magnetic portion,

the fourth conductive member overlaps the fourth magnetic portion in the second direction, and

the fourth conductive member does not overlap the fourth other magnetic portion in the second direction.

(Configuration 15)

The sensor according to any one of Configurations 12 to 14, wherein

the third magnetic member is continuous with the first opposing magnetic member, and

the fourth magnetic member is continuous with the second opposing magnetic member.

(Configuration 16)

The sensor according to Configuration 6, further comprising a second element portion, a third element portion, and a fourth element portion,

the second element portion including a second magnetic element and a second conductive member,

the second magnetic element including a second end portion and a second other end portion, a direction from the second end portion to the second other end portion being along the first direction,

a direction from the second conductive member to the second magnetic element being along the second direction,

the second conductive member including a second conductive portion and a second other conductive portion,

a direction from the second conductive portion to the second other conductive portion being along the first direction,

a distance between the second conductive portion and the second end portion being shorter than a distance between the second conductive portion and the second other end portion,

a distance between the second other conductive portion and the second other end portion being shorter than the distance between the second other conductive portion and the second end portion,

the third element portion including a third magnetic element and a third conductive member, the third magnetic element including a third end portion and a third other end portion, ae direction from the third end portion to the third other end portion being along the first direction,

a direction from the third conductive member to the third magnetic element being along the second direction,

the third conductive member including a third conductive portion and a third other conductive portion,

a direction from the third conductive portion to the third other conductive portion being along the first direction,

a distance between the third conductive portion and the third end portion being shorter than a distance between the third conductive portion and the third other end portion,

a distance between the third other conductive portion and the third other end portion being shorter than a distance between the third other conductive portion and the third end portion,

the fourth element portion including a fourth magnetic element, a fourth conductive member, a fourth magnetic member and a fourth opposing magnetic member,

the fourth magnetic element including a fourth end portion and a fourth other end portion, a direction from the fourth end portion to the fourth other end portion being along the first direction,

a direction from the fourth conductive member to the fourth magnetic element being along the second direction,

the fourth conductive member including a fourth conductive portion and a fourth other conductive portion,

a direction from the fourth conductive portion to the fourth other conductive portion being along the first direction,

a distance between the fourth conductive portion and the fourth end portion being shorter than the distance between the fourth conductive portion and the fourth other end portion,

a distance between the fourth other conductive portion and the fourth other end portion being shorter than the distance between the fourth other conductive portion and the fourth end portion,

a position of at least a part of the fourth magnetic element in the third direction being between a position of the fourth magnetic member in the third direction and a position of the fourth opposing magnetic member in the third direction,

the first other end portion being electrically connected to the second end portion,

the first other conductive portion being electrically connected to the second conductive portion,

the second other end portion being electrically connected to the fourth other end portion,

the third end portion being electrically connected to the first end portion,

the third other end portion being electrically connected to the fourth end portion,

the second other conductive portion being electrically connected to the fourth other conductive portion,

the third conductive portion being electrically connected to the first conductive portion, and

the third conductive portion being electrically connected to the fourth conductive portion.

(Configuration 17)

The sensor according to Configuration 16, further comprising a circuit portion,

the circuit portion including a first circuit, a second circuit and a third circuit,

the first circuit being configured to supply a first current including an AC component between the first other conductive portion and the third other conductive portion,

the second circuit being configured to supply an element current or an element voltage between a first connection point of the first end portion and the third end portion and a second connection point of the second other end portion and the fourth other end portion, and

the third circuit being configured to output a signal corresponding to an electrical signal generated between a third connection point of the first other end portion and the second end portion and a fourth connection point of the third other end portion and the fourth end portion.

(Configuration 18)

The sensor according to Configuration 6, further comprising a second element portion, a third element portion, and a fourth element portion,

the second element portion including a second magnetic element, a second magnetic member and a second opposing magnetic member,

the second magnetic element including a second end portion and a second other end portion, a direction from the second end portion to the second other end portion being along the first direction,

a direction from the portion of the first conductive member to the second magnetic element being along the second direction,

a position of at least a part of the second magnetic element in the third direction being between a position of the second magnetic member in the third direction and a position of the second opposing magnetic member in the third direction,

the third element unit including a third magnetic element,

the third magnetic element including a third end portion and a third other end portion,

the fourth element portion including a fourth magnetic element,

the fourth magnetic element including a fourth end portion and a fourth other end portion,

the first end portion being electrically connected to the third end portion,

the first other end portion being electrically connected to the fourth end portion,

the third other end portion being electrically connected to the second end portion,

the second other end portion being electrically connected to the fourth other end portion, and

the third magnetic element and the fourth magnetic element not overlapping the first magnetic member, the first opposing magnetic member, the second magnetic member, and the second opposing magnetic member in the second direction.

(Configuration 19)

The sensor according to Configuration 18, further comprising a circuit portion,

the circuit portion including a first circuit, a second circuit and a third circuit,

the first circuit being configured to supply a first current including an AC component between the first conductive portion and the first other conductive portion,

the second circuit being configured to supply an element current or an element voltage between a first connection point of the first end portion and the third end portion and a second connection point of the second other end portion and the fourth other end portion, and the third circuit being configured to output a signal corresponding to an electrical signal generated between a third connection point of the third other end portion and the second end portion and a fourth connection point of the first other end portion and the fourth end portion.

(Configuration 20)

An inspection device, comprising:

the magnetic sensor according to any one of Configurations 1 to 19; and

a processor configured to process an output signal obtained from the magnetic sensor.

According to the embodiment, it is possible to provide a magnetic sensor and an inspection device capable of improving the characteristics.

In the present specification, "perpendicular" and "parallel" include not only strict perpendicularity and strict parallelism, but also variations in the manufacturing process, for example, and may be substantially perpendicular and substantially parallel.

Hereinabove, exemplary embodiments of the invention are described with reference to specific examples. However, the embodiments of the invention are 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 magnetic sensors such as element portions, magnetic elements, magnetic layers, non-magnetic layers, conductive members, conductive layers circuit, etc., from known art. Such practice is included in the scope of the invention to the extent that similar effects thereto are obtained.

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

Moreover, all magnetic sensors and all inspection devices practicable by an appropriate design modification by one skilled in the art based on the magnetic sensors and the inspection devices described above as embodiments of the invention also are within the scope of the invention to the extent that the purport 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 magnetic sensor, comprising:

a first element portion including a first magnetic element, a first conductive member, a first magnetic member and a first opposing magnetic member,

the first magnetic element extending along a first direction, a length of the first magnetic element along the first direction being longer than a length of the first magnetic element along a third direction crossing the first direction,

the first magnetic element including a first end portion and a first other end portion, a direction from the first end portion to the first other end portion being along the first direction,

a second direction from the first conductive member to the first magnetic element crossing a plane including the first direction and the third direction,

a direction from the first magnetic member to the first opposing magnetic member being along the third direction,

a position of at least a part of the first magnetic element in the third direction being between a position of the first magnetic member in the third direction and a position of the first opposing magnetic member in the third direction,

the first magnetic member including a first other magnetic portion and a first magnetic portion, a direction from the first other magnetic portion to the first magnetic portion being along the third direction, a first other magnetic portion length along the first direction of the first other magnetic portion being longer than a first magnetic portion length along the first direction of the first magnetic portion, and

the first conductive member overlapping the first magnetic portion in the second direction, and the first conductive member not overlapping the first other magnetic portion in the second direction.

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

the first magnetic member further includes a first intermediate magnetic portion,

the first intermediate magnetic portion is between the first other magnetic portion and the first magnetic portion in the third direction,

a first intermediate magnetic portion length along the first direction of the first intermediate magnetic portion is between the first other magnetic portion length and the first magnetic portion length,

the first intermediate magnetic portion length varies in the third direction,

a rate of change in the third direction of the first magnetic portion length is lower than a rate of change in the third direction of the first intermediate magnetic portion length in the third direction, and

the first conductive member does not overlap the first intermediate magnetic portion in the second direction.

3. The sensor according to claim **2**, wherein the first magnetic portion length is substantially constant.

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

a first ratio is less than 1,

the first ratio being a ratio of a sum of a length of the first magnetic portion along the third direction and a length of the first intermediate magnetic portion along the third direction to a length of the first other magnetic portion along the third direction.

5. The sensor according to claim **4**, wherein the first ratio is 0.5 or less.

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

the first conductive member includes a first conductive portion and a first other conductive portion,

a direction from the first conductive portion to the first other conductive portion is along the first direction,

a distance between the first conductive portion and the first end portion is shorter than a distance between the first conductive portion and the first other end portion, and a distance between the first other conductive portion and the first other end portion is shorter than the distance between the first other conductive portion and the first end portion.

7. The sensor according to claim **6**, further comprising a circuit portion including a first circuit,

the first circuit being configured to supply a first current including an AC component to the first conductive member.

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

the circuit portion further includes a second circuit and a third circuit,

the second circuit is configured to supply an element current or an element voltage to the first magnetic element, and

the third circuit is configured to output a signal corresponding to a first electrical resistance of the first magnetic element.

9. The sensor according to claim **6**, further comprising a second element portion,

the second element portion including a second magnetic element, a second conductive member, a second magnetic member and a second opposing magnetic member,

the second magnetic element including a second end portion and a second other end portion, a direction from the second end portion to the second other end portion being along the first direction,

a direction from the second conductive member to the second magnetic element being along the second direction,

the second conductive member including a second conductive portion and a second other conductive portion,

a direction from the second conductive portion to the second other conductive portion being along the first direction,

a distance between the second conductive portion and the second end portion being shorter than a distance between the second conductive portion and the second other end portion,

a distance between the second other conductive portion and the second other end portion being shorter than a distance between the second other conductive portion and the second end portion,

a position of at least a part of the second magnetic element in the third direction being between a position of the second magnetic member in the third direction and a position of the second opposing magnetic member in the third direction,

the first other end portion being electrically connected to the second end portion, and

the first other conductive portion being electrically connected to the second conductive portion.

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

the second magnetic member includes a second other magnetic portion and a second magnetic portion,

a direction from the second other magnetic portion to the second magnetic portion is along the third direction,

a second other magnetic portion length along the first direction of the second other magnetic portion is longer than a second magnetic portion length along the first direction of the second magnetic portion,

the second conductive member overlaps the second magnetic portion in the second direction, and

the second conductive member does not overlap the second other magnetic portion in the second direction.

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

the second magnetic member is continuous with the first magnetic member, and

the second opposing magnetic member is continuous with the first opposing magnetic member.

12. The sensor according to claim **9**, further comprising a third element portion and a fourth element portion,

the third element portion including a third magnetic element, a third conductive member, a third magnetic member and a third opposing magnetic member,

the third magnetic element including a third end portion and a third other end portion, a direction from the third end portion to the third other end portion being along the first direction,

a direction from the third conductive member to the third magnetic element being along the second direction,

the third conductive member including a third conductive portion and a third other conductive portion,

a direction from the third conductive portion to the third other conductive portion being along the first direction,

a distance between the third conductive portion and the third end portion being shorter than a distance between the third conductive portion and the third other end portion,

a distance between the third other conductive portion and the third other end portion being shorter than a distance between the third other conductive portion and the third end portion,

a position of at least a part of the third magnetic element in the third direction being between a position of the third magnetic member in the third direction and a position of the third opposing magnetic member in the third direction,

the fourth element portion including a fourth magnetic element, a fourth conductive member, a fourth magnetic member and a fourth opposing magnetic member,

the fourth magnetic element including a fourth end portion and a fourth other end portion, a direction from the fourth end portion to the fourth other end portion being along the first direction,

a direction from the fourth conductive member to the fourth magnetic element being along the second direction,

the fourth conductive member including a fourth conductive portion and a fourth other conductive portion,

a direction from the fourth conductive portion to the fourth other conductive portion being along the first direction,

a distance between the fourth conductive portion and the fourth end portion being shorter than a distance between the fourth conductive portion and the fourth other end portion,

a distance between the fourth other conductive portion and the fourth other end portion being shorter than the distance between the fourth other conductive portion and the fourth end portion,

a position of at least a part of the fourth magnetic element in the third direction being between the position of the fourth magnetic member in the third direction and a position of the fourth opposing magnetic member in the third direction,

the second other end portion being electrically connected to the fourth other end portion,

the third end portion being electrically connected to the first end portion,

the third other end portion being electrically connected to the fourth end portion, the second other conductive portion being electrically connected to the fourth other conductive portion,

the third conductive portion being electrically connected to the first conductive portion, and

the third conductive portion being electrically connected to the fourth conductive portion.

13. The sensor according to claim **12**, further comprising a circuit portion,

the circuit portion including a first circuit, a second circuit and a third circuit,

the first circuit being configured to supply a first current including an AC component between the first other conductive portion and the third other conductive portion,

the second circuit being configured to supply an element current or an element voltage between a first connection point of the first end portion and the third end portion and a second connection point between the second other end portion and the fourth other end portion, and

the third circuit being configured to output a signal corresponding to an electrical signal generated between a third connection point of the first other end portion and the second end portion and a fourth connection point of the third other end portion and the fourth end portion.

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

the third magnetic member includes a third other magnetic portion and a third magnetic portion, a direction from the third other magnetic portion to the third magnetic portion is along the third direction, a third magnetic portion length of the third magnetic portion along the first direction is longer than a third magnetic portion length of the third magnetic portion along the first direction,

the third conductive member overlaps the third magnetic portion in the second direction,

the third conductive member does not overlap the third other magnetic portion in the second direction,

the fourth magnetic member includes a fourth other magnetic portion and a fourth magnetic portion, a direction from the fourth other magnetic portion to the fourth magnetic portion is along the third direction, a fourth other magnetic portion length along the first direction of the fourth other magnetic portion is longer than a fourth magnetic portion length along the first direction of the fourth magnetic portion,

the fourth conductive member overlaps the fourth magnetic portion in the second direction, and

the fourth conductive member does not overlap the fourth other magnetic portion in the second direction.

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

the third magnetic member is continuous with the first opposing magnetic member, and

the fourth magnetic member is continuous with the second opposing magnetic member.

16. The sensor according to claim **6**, further comprising a second element portion, a third element portion, and a fourth element portion,

the second element portion including a second magnetic element and a second conductive member,

the second magnetic element including a second end portion and a second other end portion, a direction from the second end portion to the second other end portion being along the first direction,

a direction from the second conductive member to the second magnetic element being along the second direction,

the second conductive member including a second conductive portion and a second other conductive portion,

a direction from the second conductive portion to the second other conductive portion being along the first direction,

a distance between the second conductive portion and the second end portion being shorter than a distance between the second conductive portion and the second other end portion,

a distance between the second other conductive portion and the second other end portion being shorter than the distance between the second other conductive portion and the second end portion,

the third element portion including a third magnetic element and a third conductive member,

the third magnetic element including a third end portion and a third other end portion, ae direction from the third end portion to the third other end portion being along the first direction,

a direction from the third conductive member to the third magnetic element being along the second direction,

the third conductive member including a third conductive portion and a third other conductive portion,

a direction from the third conductive portion to the third other conductive portion being along the first direction,

a distance between the third conductive portion and the third end portion being shorter than a distance between the third conductive portion and the third other end portion,

a distance between the third other conductive portion and the third other end portion being shorter than a distance between the third other conductive portion and the third end portion,

the fourth element portion including a fourth magnetic element, a fourth conductive member, a fourth magnetic member and a fourth opposing magnetic member,

the fourth magnetic element including a fourth end portion and a fourth other end portion, a direction from the fourth end portion to the fourth other end portion being along the first direction,

a direction from the fourth conductive member to the fourth magnetic element being along the second direction,

the fourth conductive member including a fourth conductive portion and a fourth other conductive portion,

a direction from the fourth conductive portion to the fourth other conductive portion being along the first direction,

a distance between the fourth conductive portion and the fourth end portion being shorter than the distance between the fourth conductive portion and the fourth other end portion,

a distance between the fourth other conductive portion and the fourth other end portion being shorter than the distance between the fourth other conductive portion and the fourth end portion,

a position of at least a part of the fourth magnetic element in the third direction being between a position of the fourth magnetic member in the third direction and a position of the fourth opposing magnetic member in the third direction,

the first other end portion being electrically connected to the second end portion, the first other conductive portion being electrically connected to the second conductive portion,

the second other end portion being electrically connected to the fourth other end portion,

the third end portion being electrically connected to the first end portion,

the third other end portion being electrically connected to the fourth end portion,

the second other conductive portion being electrically connected to the fourth other conductive portion,

the third conductive portion being electrically connected to the first conductive portion, and

the third conductive portion being electrically connected to the fourth conductive portion.

17. The sensor according to claim **16**, further comprising a circuit portion,

the circuit portion including a first circuit, a second circuit and a third circuit,

the first circuit being configured to supply a first current including an AC component between the first other conductive portion and the third other conductive portion,

the second circuit being configured to supply an element current or an element voltage between a first connection point of the first end portion and the third end portion and a second connection point of the second other end portion and the fourth other end portion, and

the third circuit being configured to output a signal corresponding to an electrical signal generated between a third connection point of the first other end portion and the second end portion and a fourth connection point of the third other end portion and the fourth end portion.

18. The sensor according to claim **6**, further comprising a second element portion, a third element portion, and a fourth element portion,

the second element portion including a second magnetic element, a second magnetic member and a second opposing magnetic member,

the second magnetic element including a second end portion and a second other end portion, a direction from the second end portion to the second other end portion being along the first direction,

a direction from the portion of the first conductive member to the second magnetic element being along the second direction,

a position of at least a part of the second magnetic element in the third direction being between a position of the second magnetic member in the third direction and a position of the second opposing magnetic member in the third direction,

the third element unit including a third magnetic element,

the third magnetic element including a third end portion and a third other end portion,

the fourth element portion including a fourth magnetic element,

the fourth magnetic element including a fourth end portion and a fourth other end portion,

the first end portion being electrically connected to the third end portion,

the first other end portion being electrically connected to the fourth end portion,

the third other end portion being electrically connected to the second end portion,

the second other end portion being electrically connected to the fourth other end portion, and

the third magnetic element and the fourth magnetic element not overlapping the first magnetic member, the first opposing magnetic member, the second magnetic member, and the second opposing magnetic member in the second direction.

19. The sensor according to claim **18**, further comprising a circuit portion,

the circuit portion including a first circuit, a second circuit and a third circuit,

the first circuit being configured to supply a first current including an AC component between the first conductive portion and the first other conductive portion,

the second circuit being configured to supply an element current or an element voltage between a first connection point of the first end portion and the third end portion and a second connection point of the second other end portion and the fourth other end portion, and

the third circuit being configured to output a signal corresponding to an electrical signal generated between a third connection point of the third other end portion and the second end portion and a fourth connection point of the first other end portion and the fourth end portion.

20. An inspection device, comprising:

the magnetic sensor according to claim **1**; and

a processor configured to process an output signal obtained from the magnetic sensor.

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