US012387748B2

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

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(45) **Date of Patent: Aug. 12, 2025**

(54) **MAGNETIC HEAD WITH MULTILAYER CONFIGURATION BETWEEN MAGNETIC POLES AND MAGNETIC RECORDING DEVICE**

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(21) Appl. No.: **18/358,677**

(22) Filed: **Jul. 25, 2023**

(65) **Prior Publication Data**

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US 2024/0233755 A9 Jul. 11, 2024

(30) **Foreign Application Priority Data**

Oct. 20, 2022 (JP) 2022-168539

(51) **Int. Cl.**
G11B 5/235 (2006.01)
G11B 5/127 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G11B 5/235*** (2013.01); ***G11B 5/1278*** (2013.01); ***G11B 5/3116*** (2013.01); ***G11B 5/314*** (2013.01);
(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

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Primary Examiner — Craig A. Renner
(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson & Bear, LLP

(57) **ABSTRACT**

According to one embodiment, a magnetic head includes first and second magnetic poles, a conductive part, an element part, and first to fourth terminals. The conductive part is electrically insulated from the first and second magnetic poles. The first and second terminals are electrically connected to the conductive part. The element part is provided between the first and second magnetic poles and electrically connected to the first and second magnetic poles. The element part is conductive. The third terminal is electrically connected to the first magnetic pole. The fourth
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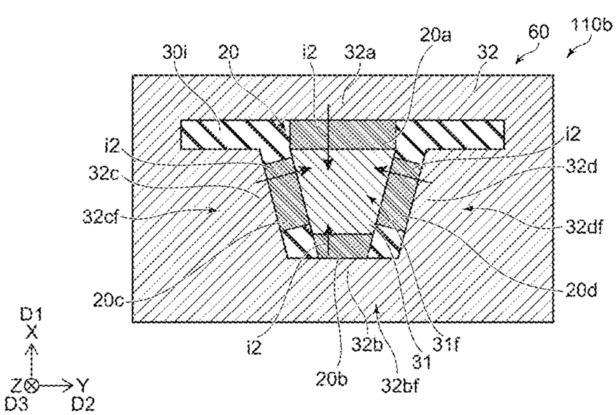

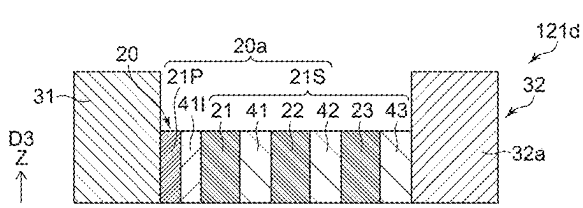

terminal is electrically connected to the second magnetic pole. A first magnetic pole temperature in a first state is higher than a second magnetic pole temperature of the second magnetic pole in the first state. A first current is supplied between the first and second terminals in the first state.

21 Claims, 15 Drawing Sheets

(51) **Int. Cl.**
G11B 5/31 (2006.01)
G11B 5/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/3146*** (2013.01); ***G11B 5/315*** (2013.01); *G11B 2005/0024* (2013.01)

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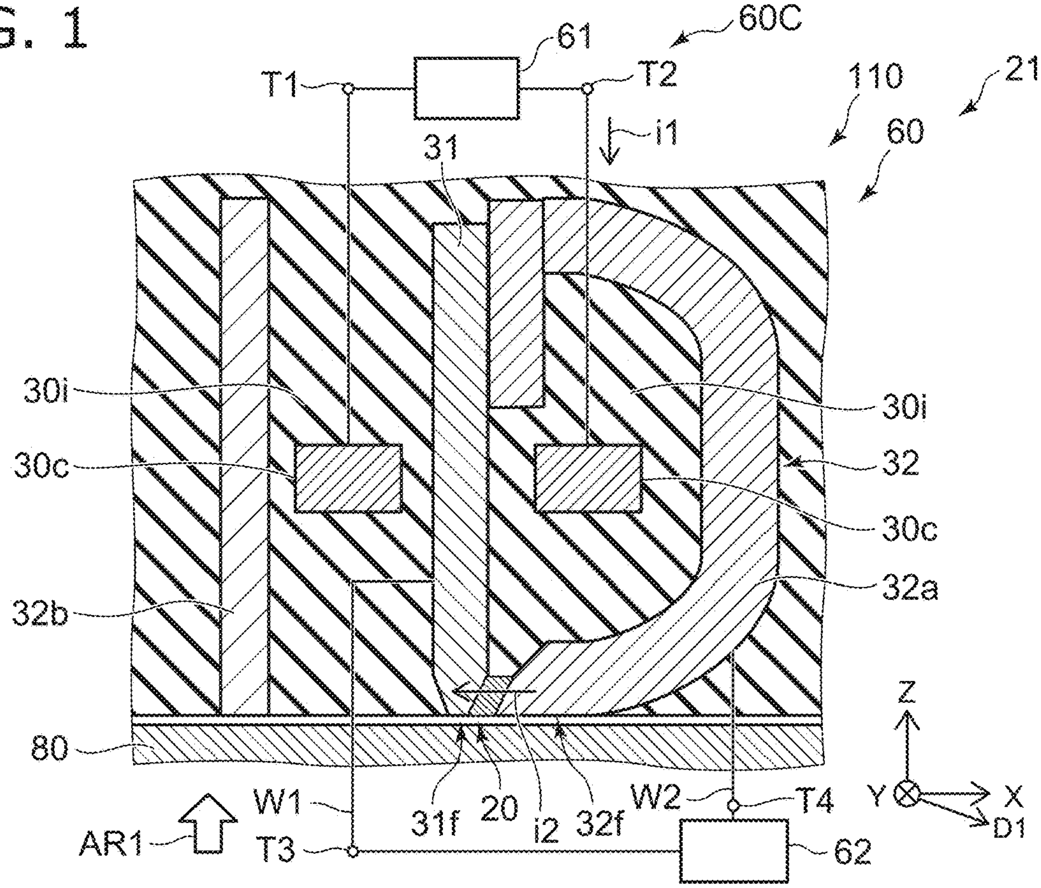
FIG. 1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T4
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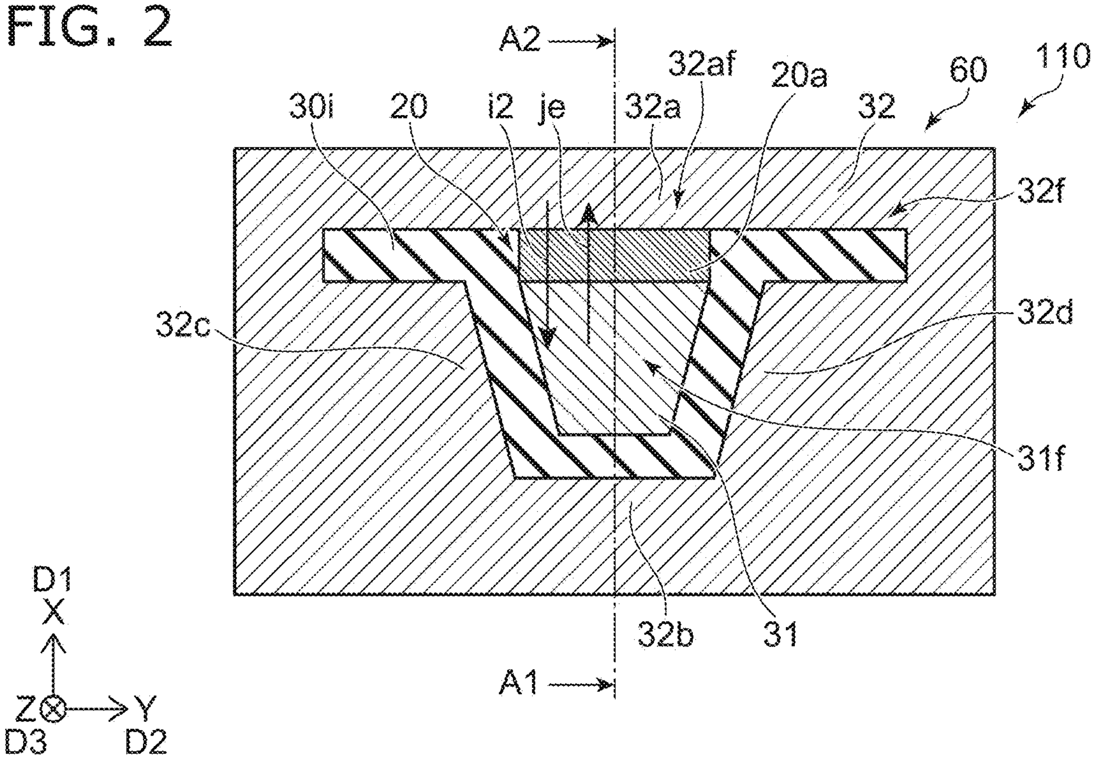
T3
62

FIG. 2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D3
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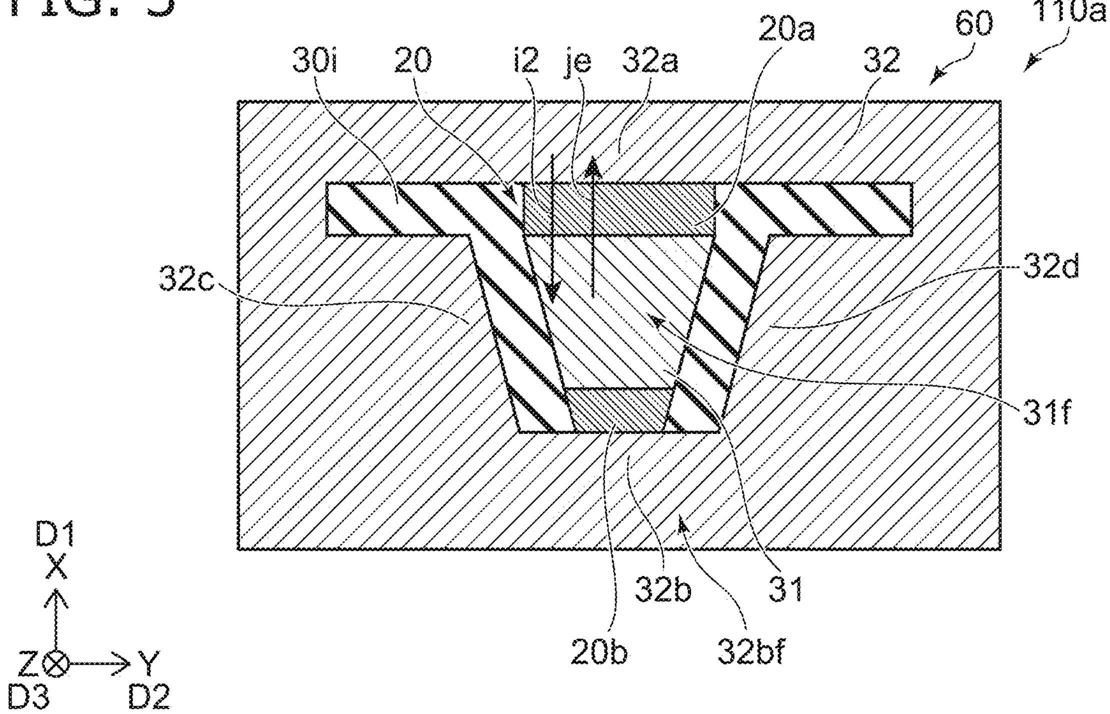
FIG. 3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Y
D3
D2

FIG. 4

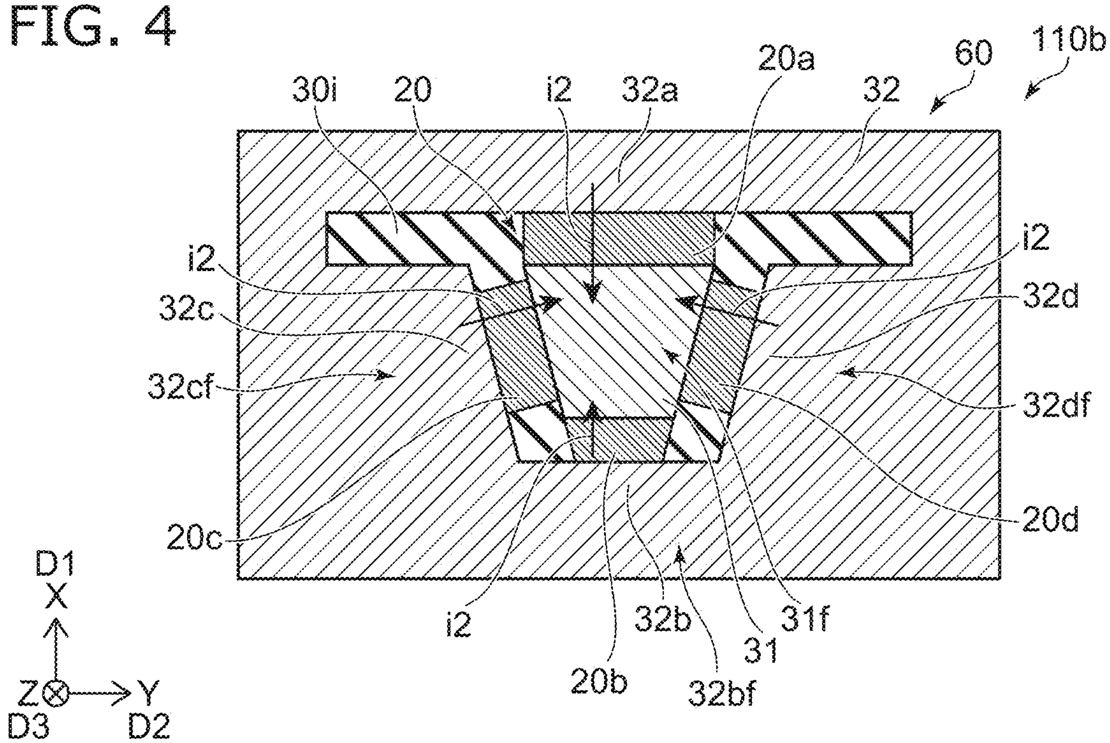
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FIG. 5A

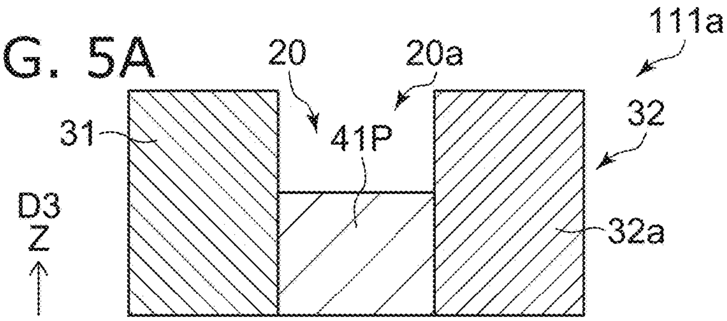


FIG. 5B

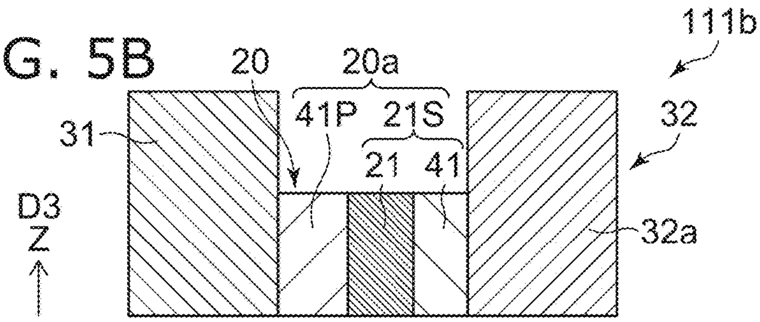


FIG. 5C

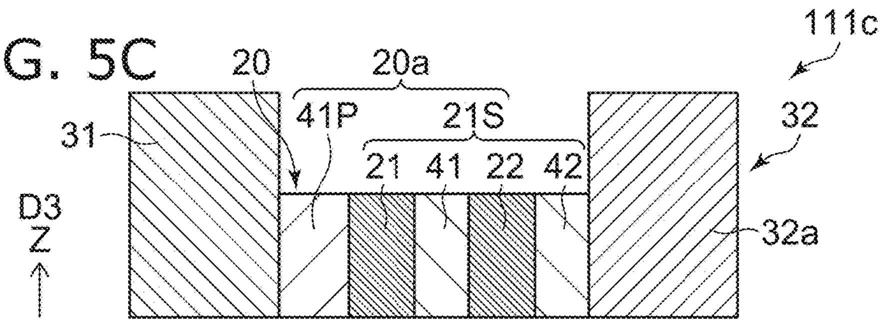


FIG. 5D

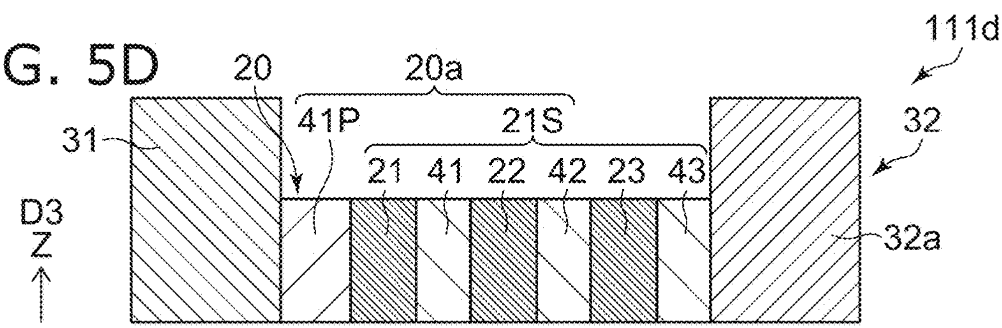


FIG. 5E

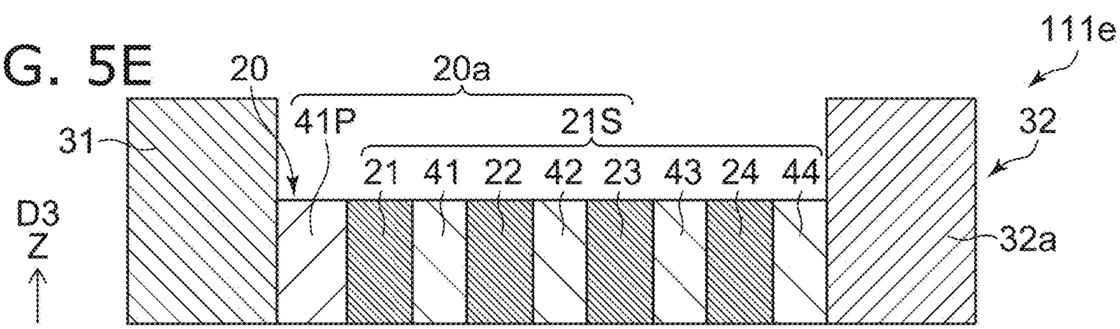


FIG. 6A

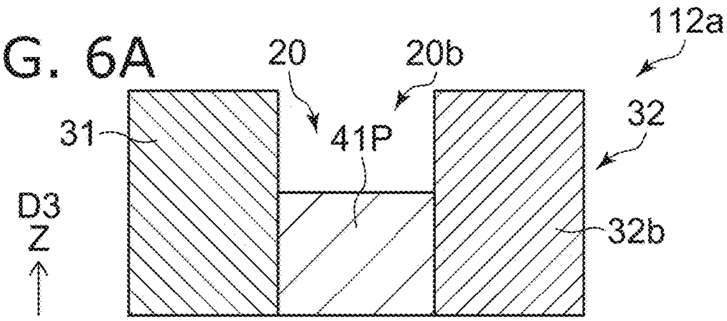


FIG. 6B

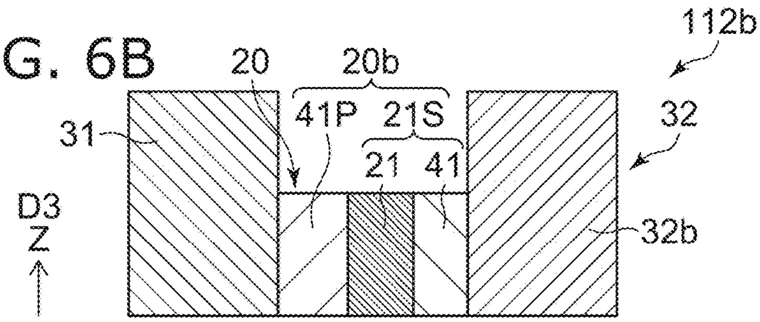


FIG. 6C

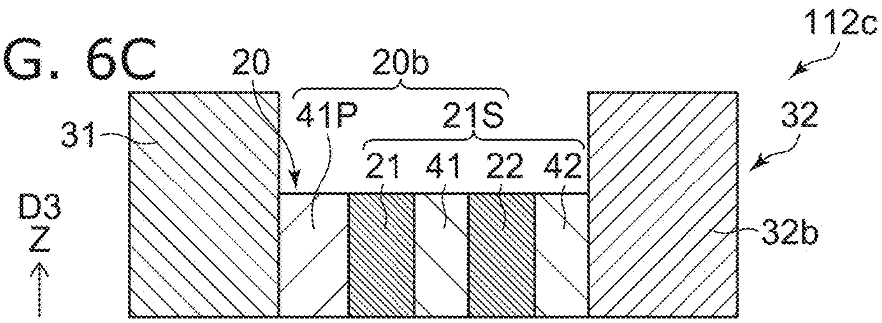
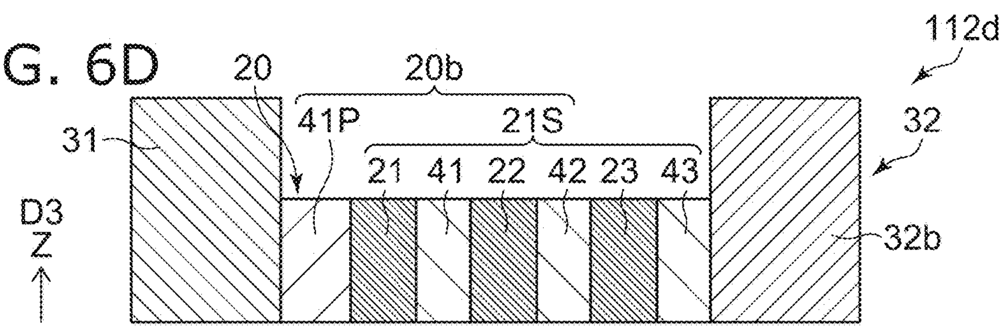


FIG. 6D



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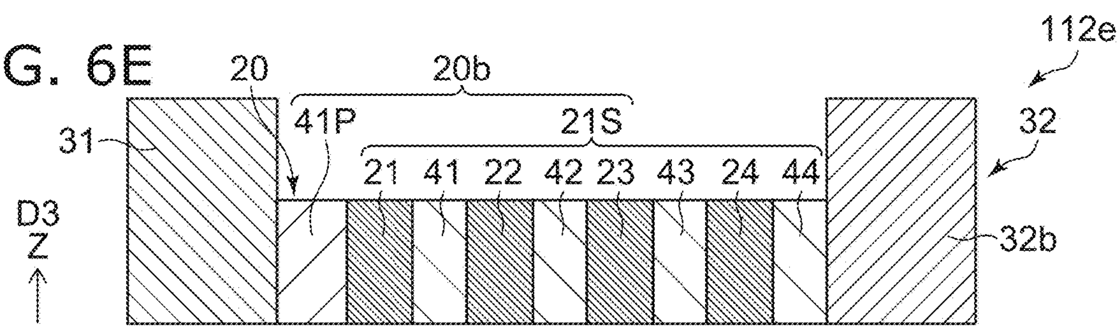


FIG. 7A

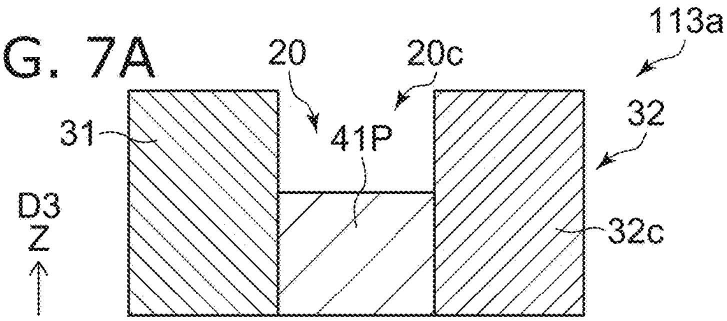


FIG. 7B

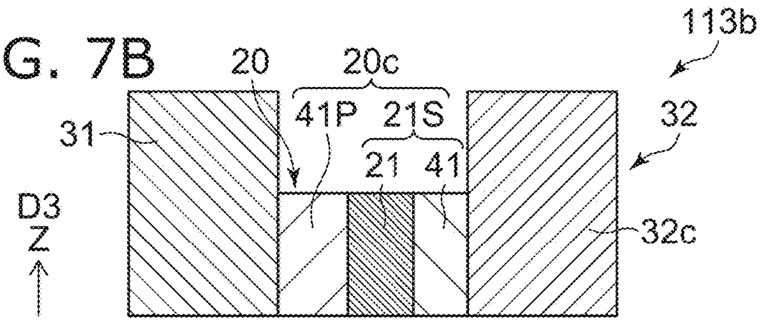


FIG. 7C

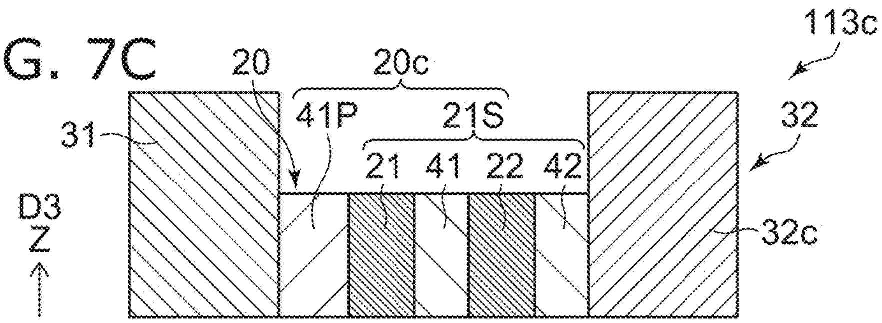
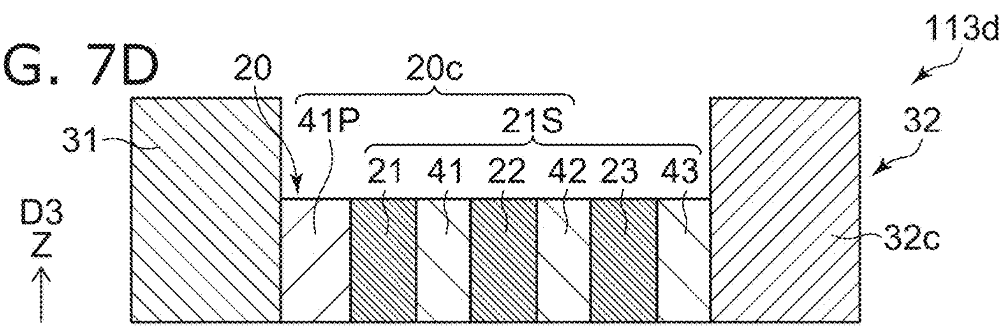


FIG. 7D



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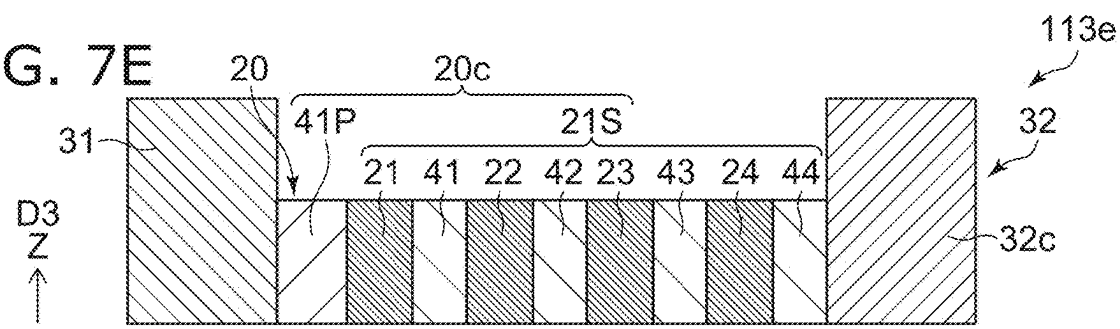
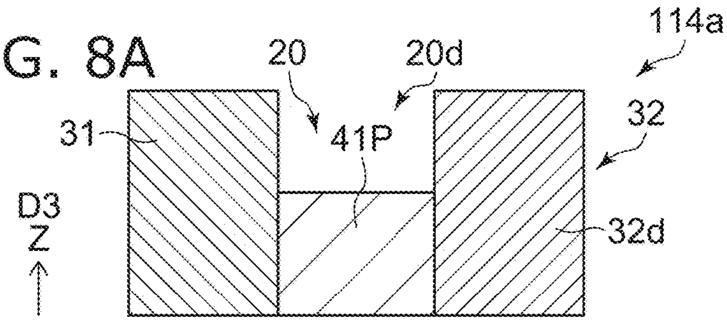


FIG. 8A



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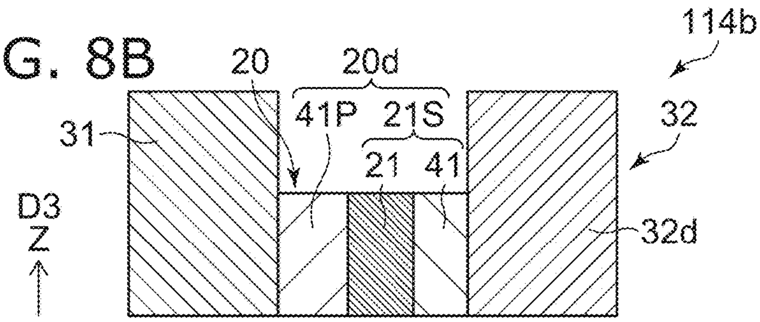

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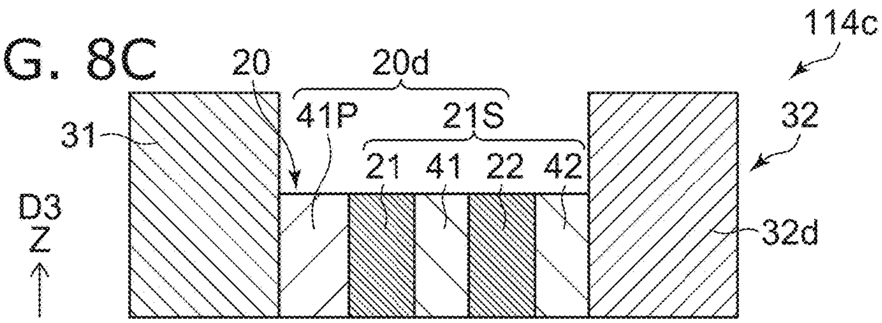

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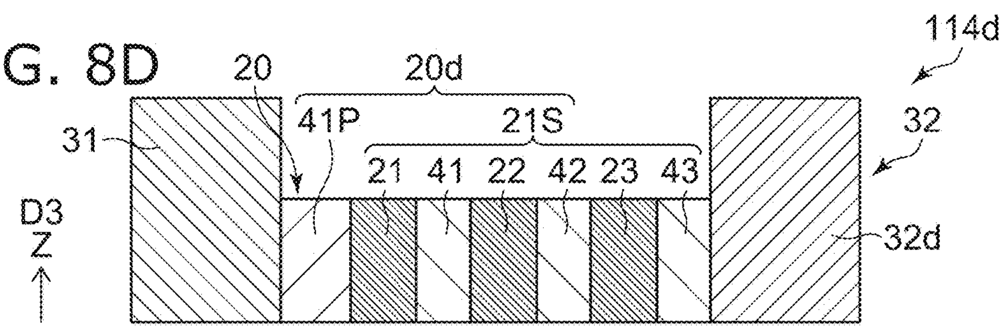

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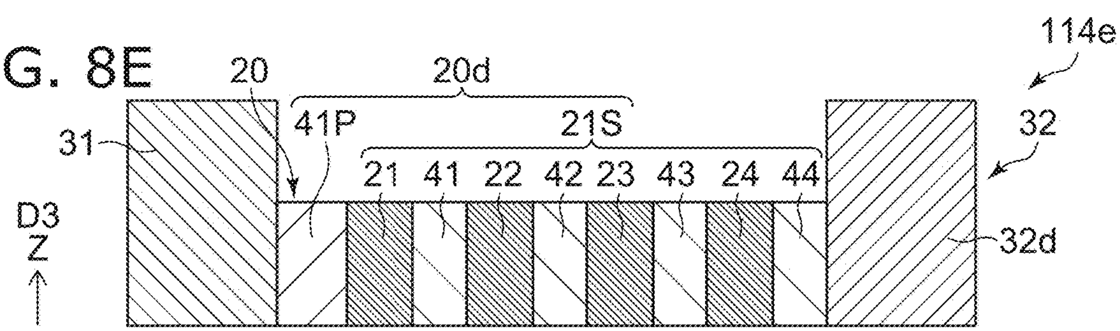
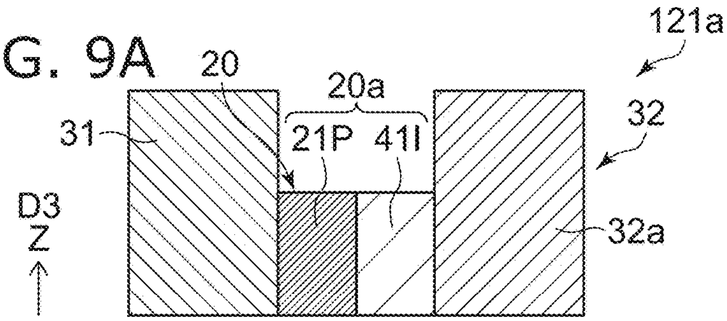


FIG. 9A



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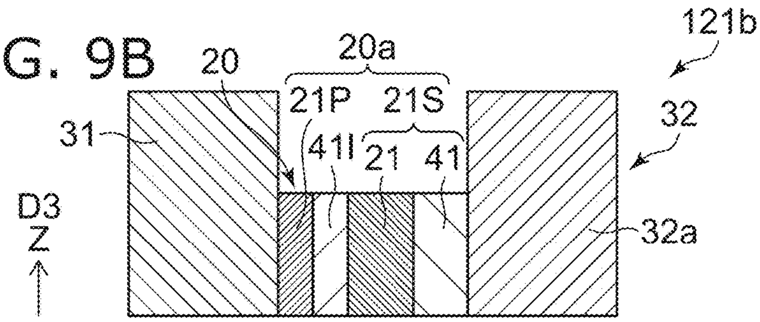
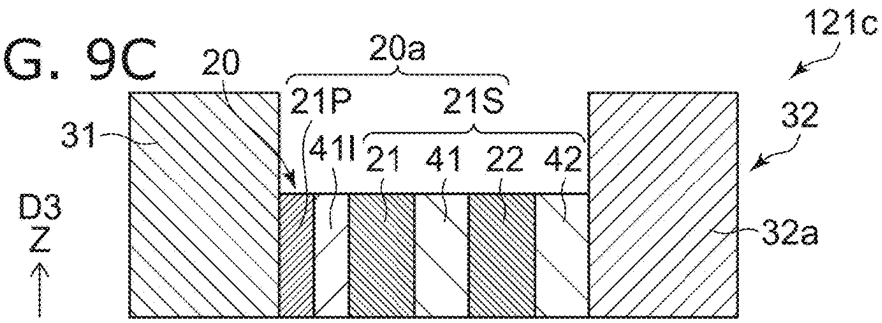


FIG. 9C



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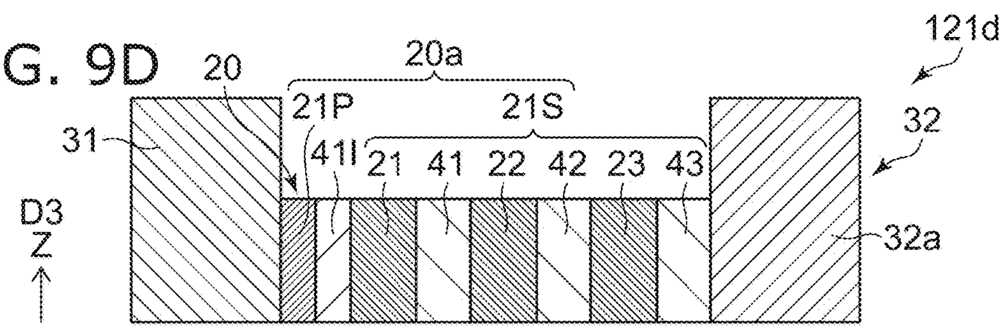

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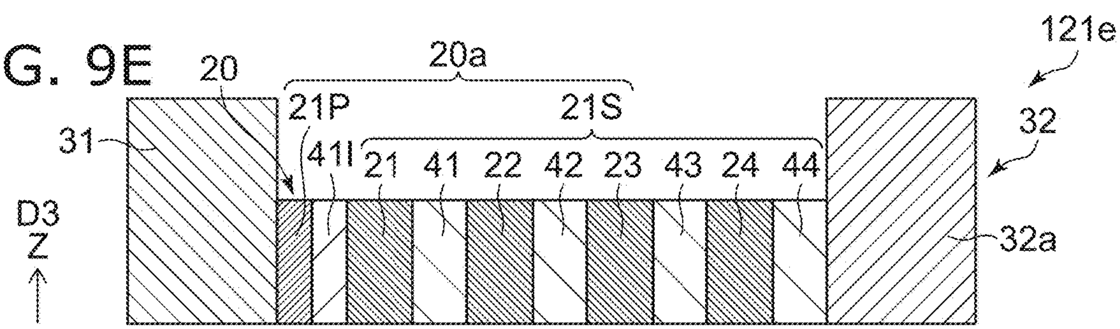

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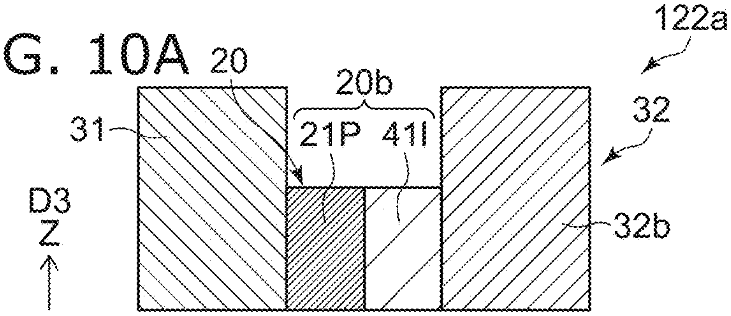

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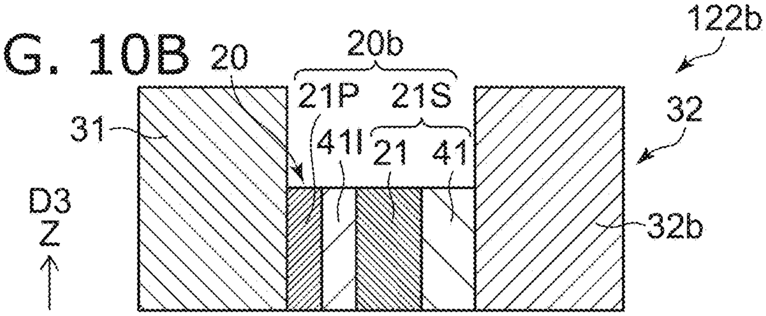

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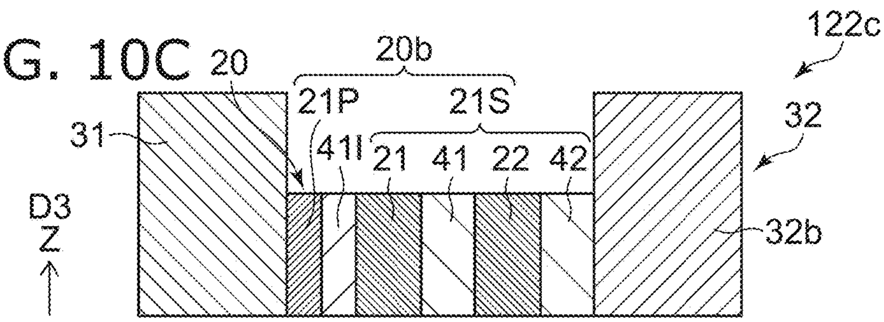

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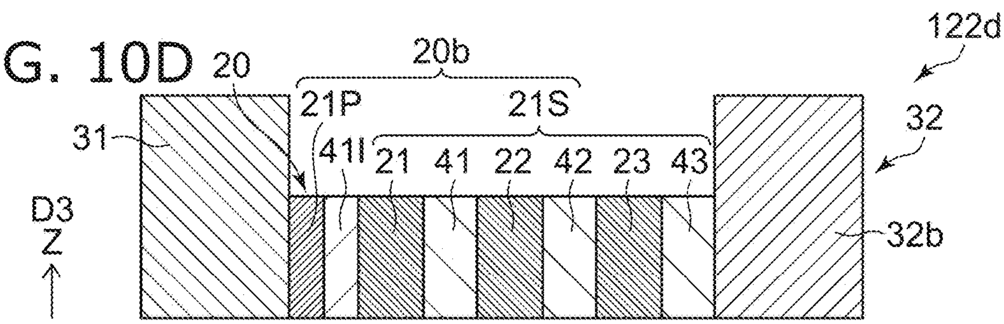

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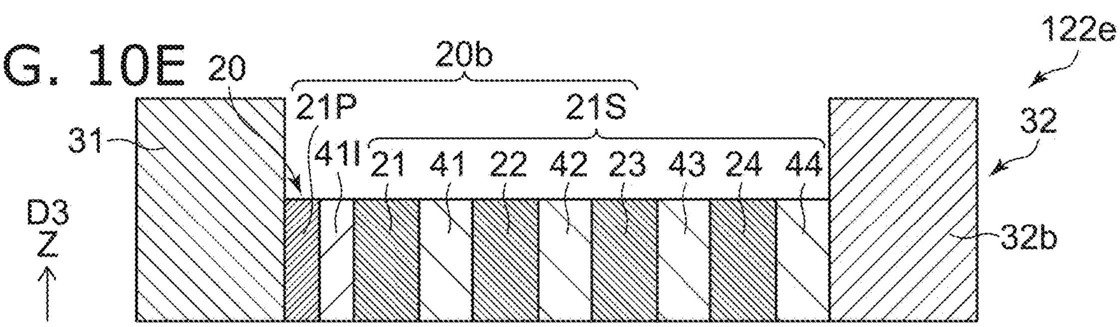
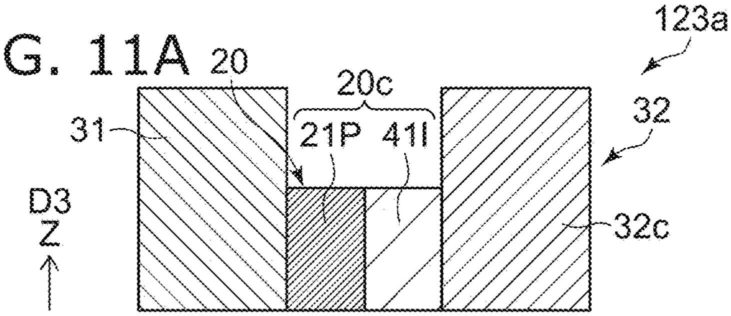


FIG. 11A



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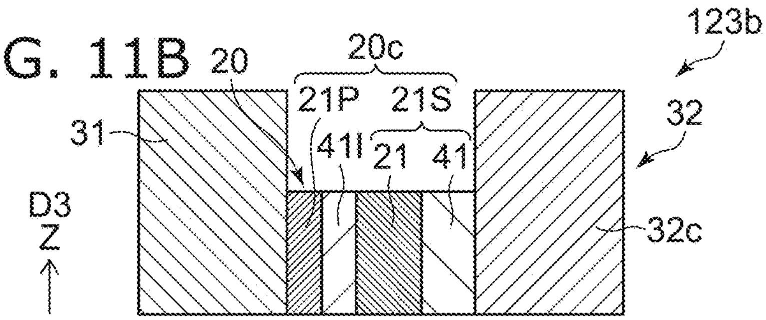

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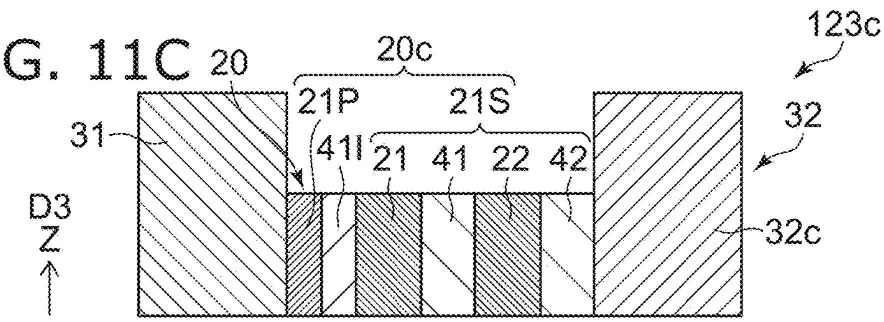


FIG. 11D

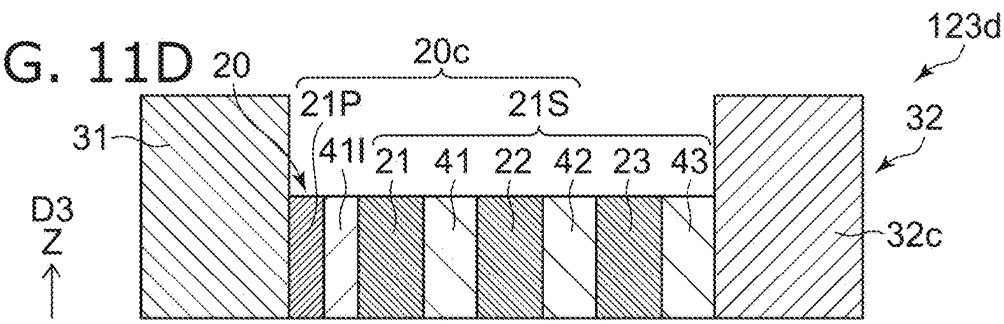


FIG. 11E

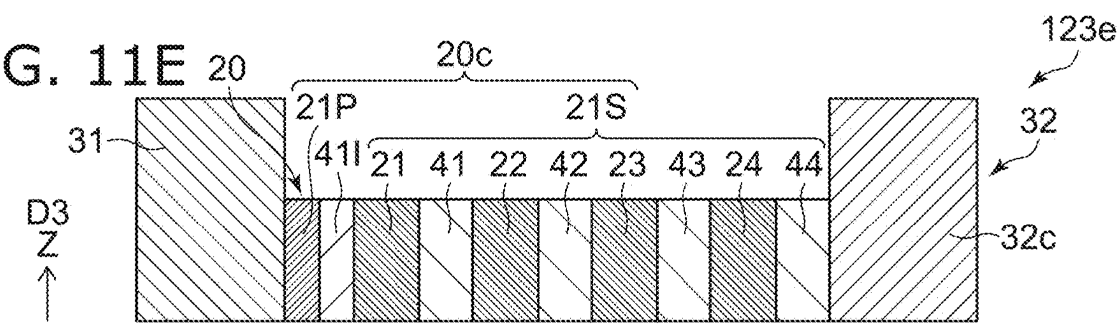
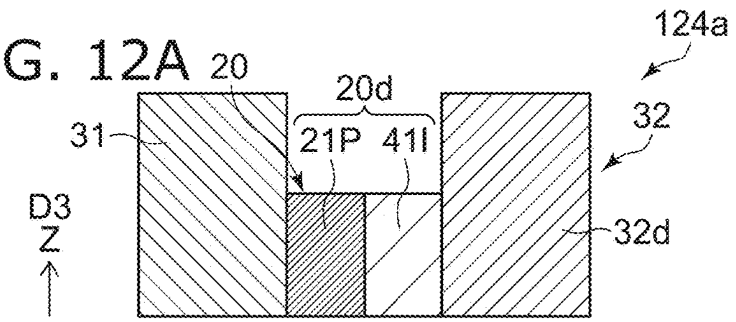


FIG. 12A



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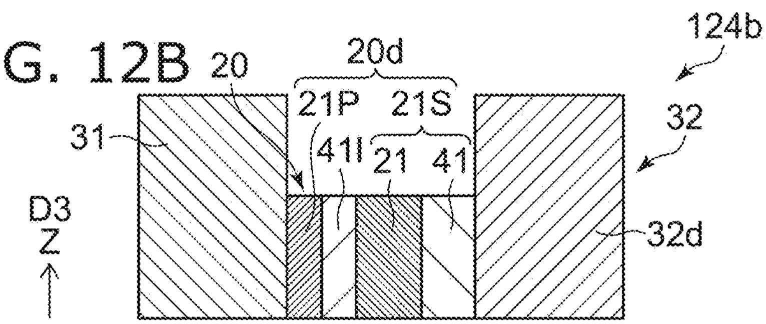


FIG. 12C

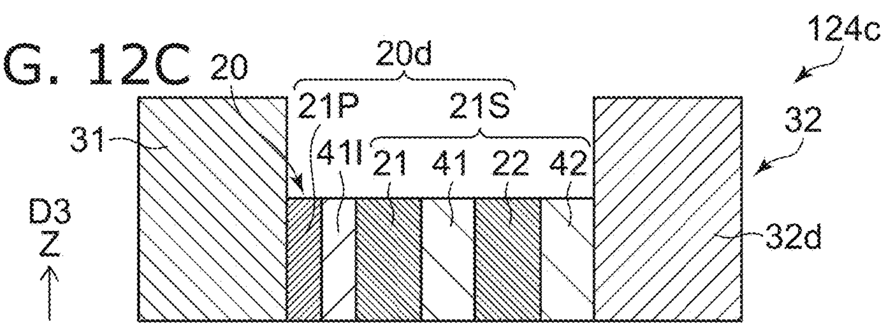


FIG. 12D

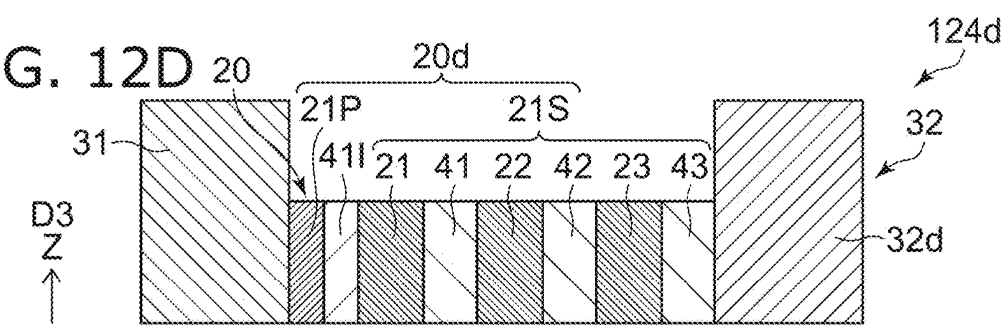


FIG. 12E

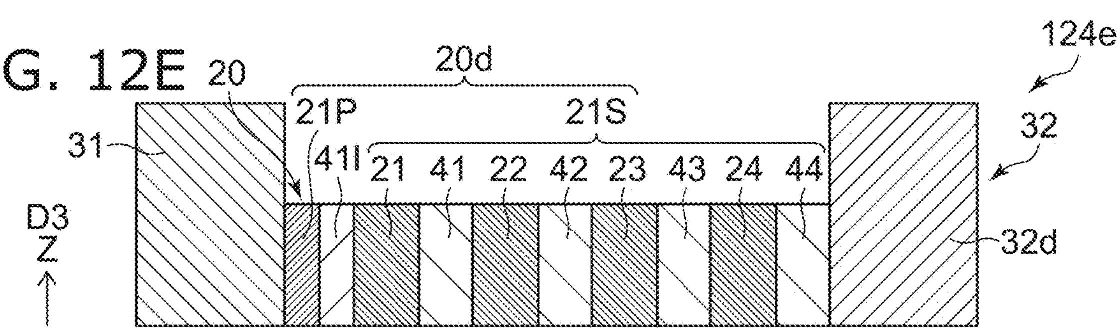
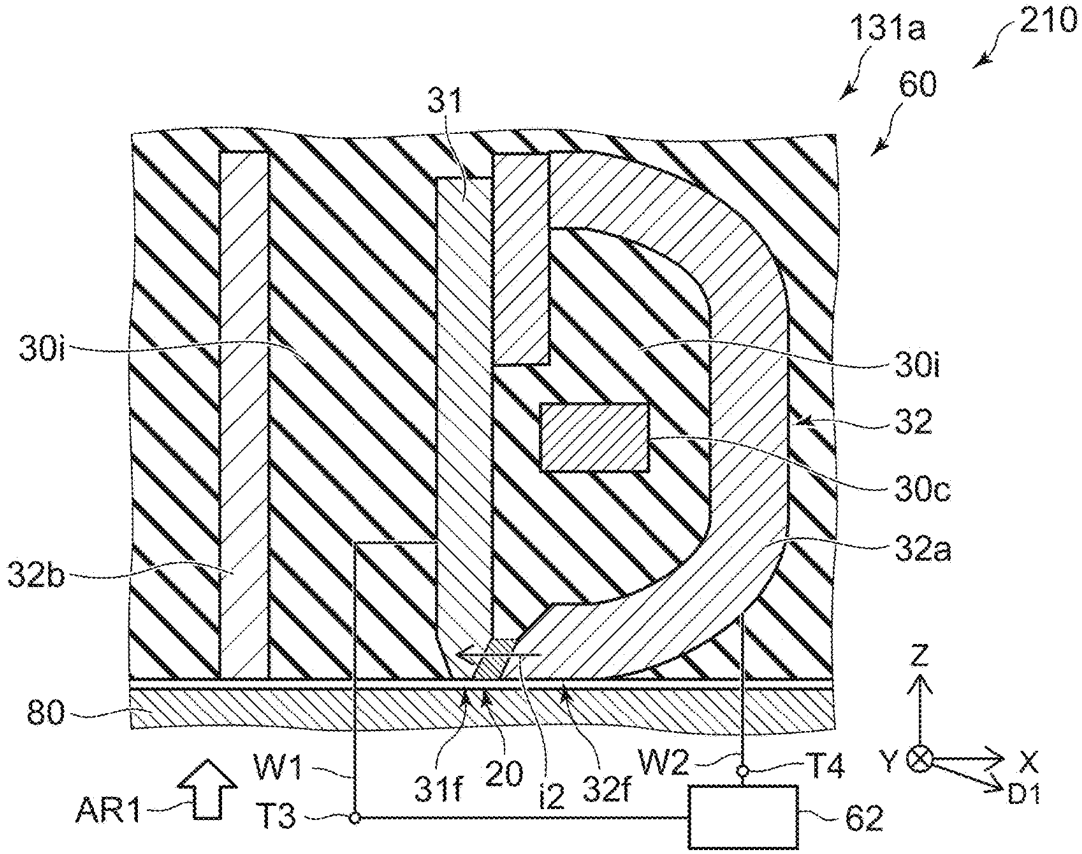


FIG. 13



131a
210
60
31
30i
30i
32
30c
32a
32b
80
W1
W2
T4
T3
AR1
31f
20
i2
32f
62
Z
Y
X
D1

FIG. 14

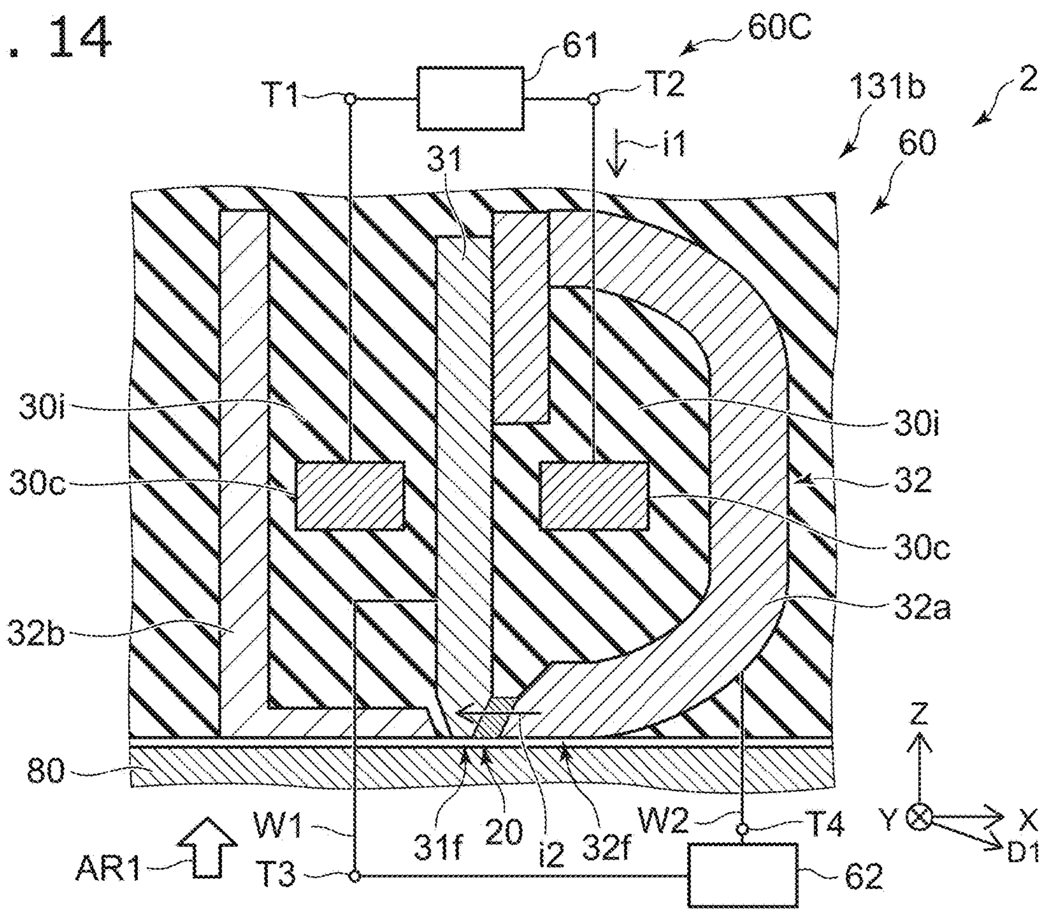

60C
61
T1
T2
131b
210
i1
31
60
30i
30i
30c
32
30c
32a
32b
Z
80
W1
20
W2
T4
Y
X
AR1
31f
i2
32f
D1
T3
62

FIG. 15

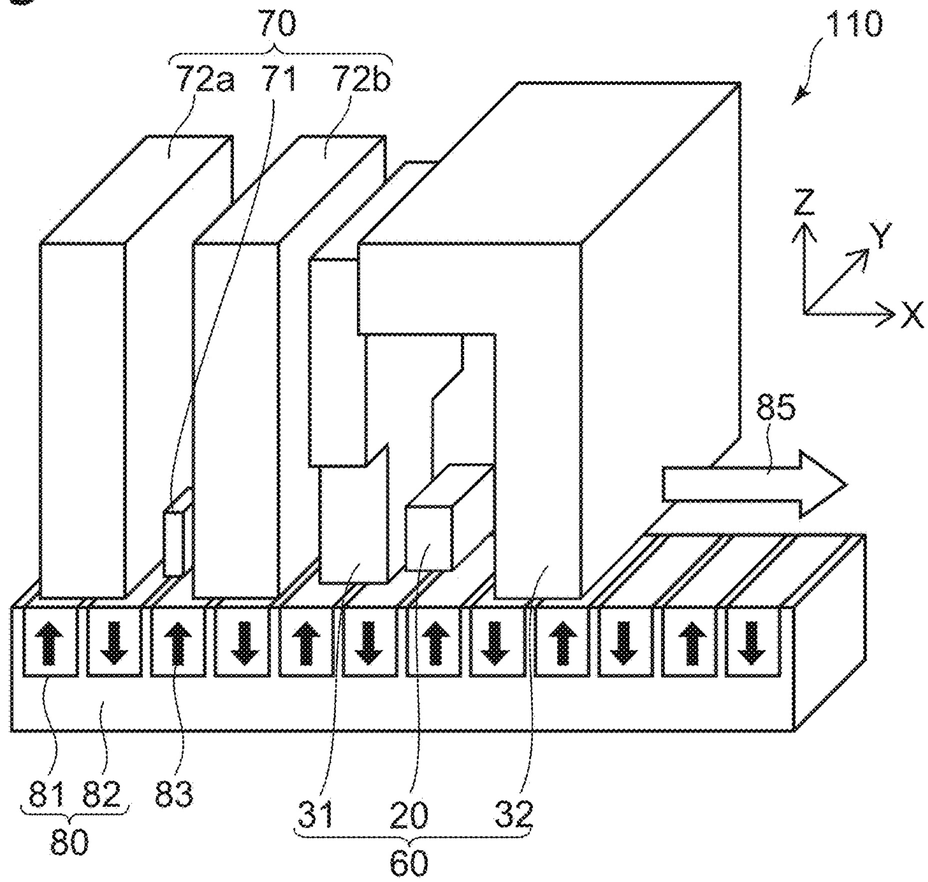
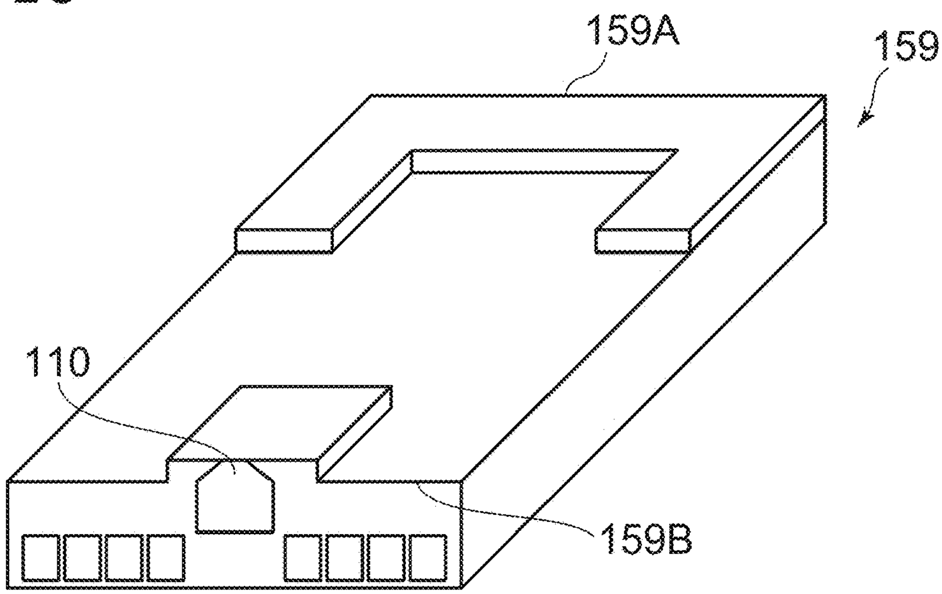


FIG. 16



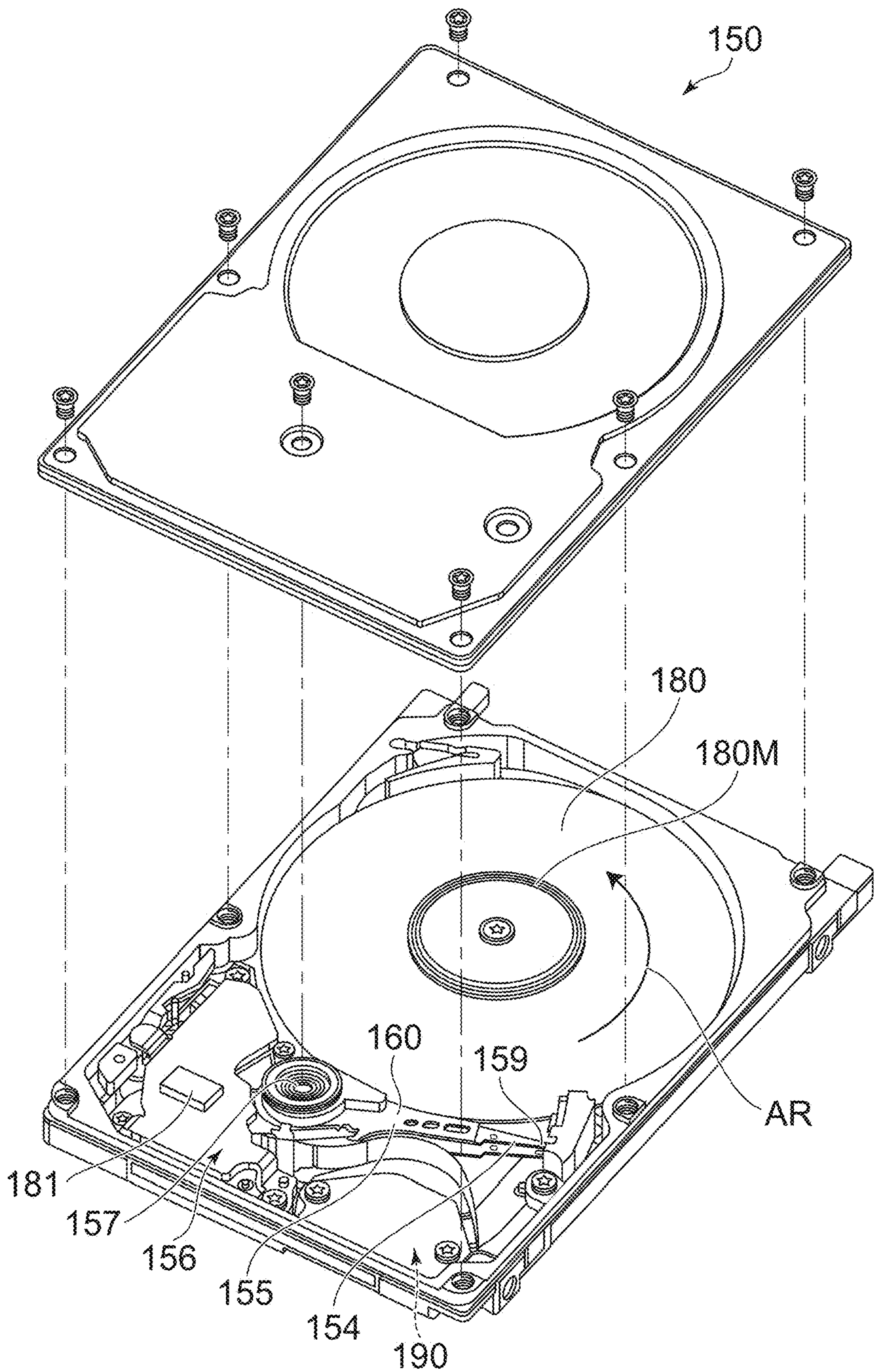


FIG. 17

FIG. 18A

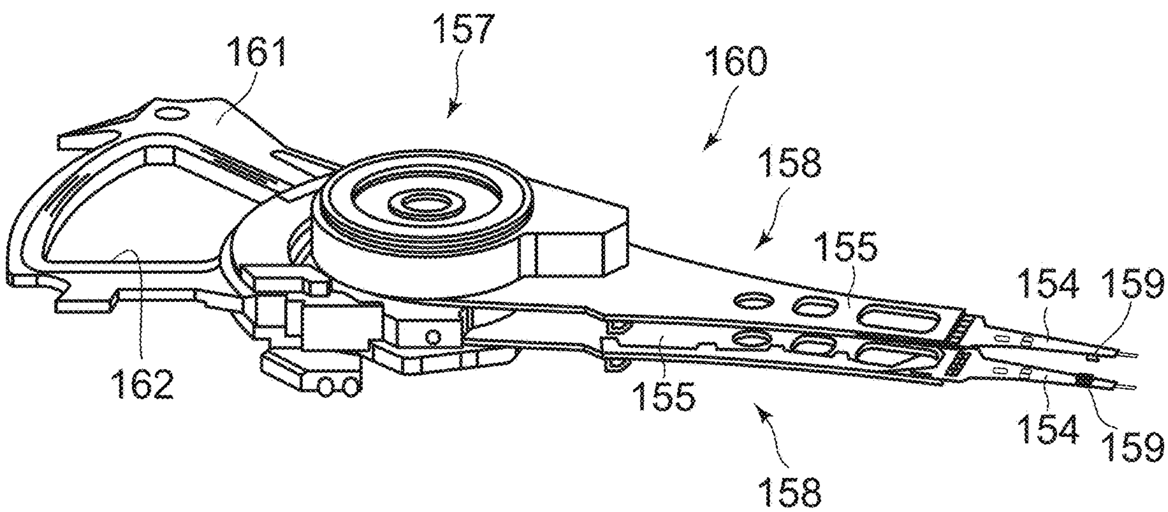
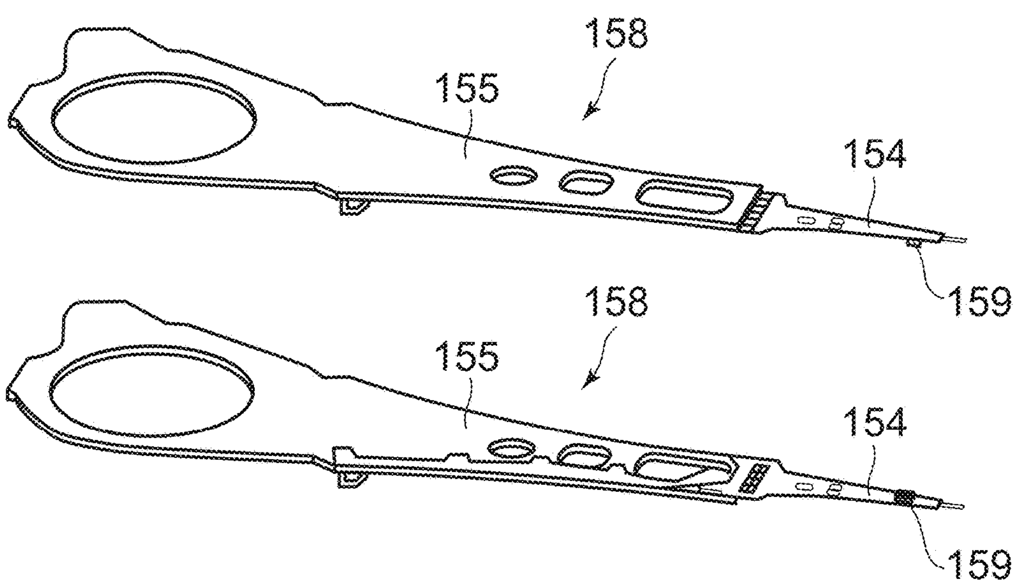


FIG. 18B



MAGNETIC HEAD WITH MULTILAYER CONFIGURATION BETWEEN MAGNETIC POLES AND MAGNETIC RECORDING DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2022-168539, filed on Oct. 20, 2022; the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a magnetic head and a magnetic recording device.

BACKGROUND

Information is recorded on a magnetic recording medium such as an HDD (Hard Disk Drive) using a magnetic head. It is desired to improve the characteristics of the magnetic head.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic cross-sectional view illustrating a magnetic head according to a first embodiment;

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

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

FIG. **4** is a schematic plan view illustrating a magnetic head according to the first embodiment;

FIGS. **5**A to **5**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment;

FIGS. **6**A to **6**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment;

FIGS. **7**A to **7**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment;

FIGS. **8**A to **8**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment;

FIGS. **9**A to **9**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment;

FIGS. **10**A to **10**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment;

FIGS. **11**A to **11**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment;

FIGS. **12**A to **12**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment;

FIG. **13** is a schematic cross-sectional view illustrating a magnetic head according to the first embodiment;

FIG. **14** is a schematic cross-sectional view illustrating a magnetic head according to the first embodiment;

FIG. **15** is a schematic perspective view illustrating a magnetic recording device according to a second embodiment;

FIG. **16** is a schematic perspective view illustrating a part of the magnetic recording device according to the embodiment;

FIG. **17** is a schematic perspective view illustrating the magnetic recording device according to the second embodiment; and

FIGS. **18**A and **18**B are schematic perspective views illustrating a part of the magnetic recording device according to the second embodiment.

DETAILED DESCRIPTION

According to one embodiment, a magnetic head includes a first magnetic pole, a second magnetic pole, a conductive part, an element part, a first terminal, a second terminal, a third terminal, and a fourth terminal. The conductive part is electrically insulated from the first magnetic pole and the second magnetic pole. The first terminal and the second terminal are electrically connected to the conductive part. The element part is provided between the first magnetic pole and the second magnetic pole and is electrically connected to the first magnetic pole and the second magnetic pole. The element part is conductive. The third terminal is electrically connected to the first magnetic pole. The fourth terminal is electrically connected to the second magnetic pole. A first magnetic pole temperature of the first magnetic pole in a first state is higher than a second magnetic pole temperature of the second magnetic pole in the first state. A first current is supplied between the first terminal and the second terminal in the first state.

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 or illustrated in an antecedent drawing are marked with like reference numerals, and a detailed description is omitted as appropriate.

First Embodiment

FIG. **1** is a schematic cross-sectional view illustrating a magnetic head according to a first embodiment.

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

FIG. **2** is a plan view viewed in an arrow AR**1** of FIG. **1**. FIG. **1** is an **A1**-**A2** line cross-sectional view of FIG. **2**.

A magnetic head **110** according to the embodiment is included in a magnetic recording device **210**. As shown in FIG. **1**, the magnetic recording device **210** may include, for example, the magnetic head **110**, a magnetic recording medium **80**, and a controller **60**C. A recording operation is performed in the magnetic head **110**. In the recording operation, information is recorded on the magnetic recording medium **80** using the magnetic head **110**. A reproducing operation may be performed in the magnetic head **110**.

The magnetic head **110** includes a first magnetic pole **31**, a second magnetic pole **32**, a conductive part **30***c* and an element part **20**. The magnetic head **110** may include a first terminal T**1**, a second terminal T**2**, a third terminal T**3**, and a fourth terminal T**4**.

The second magnetic pole **32** includes, for example, a first region **32***a*. The second magnetic pole **32** may include a second region **32***b*, and so on.

For example, the first magnetic pole **31** and the second magnetic pole **32** form a magnetic circuit. The first magnetic pole **31** is, for example, a main magnetic pole. The first region **32***a* of the second magnetic pole **32** is, for example, a trailing shield. The second region **32***b* is, for example, a leading shield.

As shown in FIG. **1**, a direction from the magnetic recording medium **80** to the magnetic head **110** is defined as a Z-axis direction. One direction perpendicular to the Z-axis direction is defined as an X-axis direction. A direction perpendicular to the Z-axis direction and the X-axis direction is defined as a Y-axis direction. The Z-axis direction corresponds to, for example, a height direction. The X-axis direction corresponds to, for example, a down-track direction. The Y-axis direction corresponds to, for example, a cross-track direction. The magnetic recording medium **80** and the magnetic head **110** move relatively along the down-track direction. A recording magnetic field generated by the magnetic head **110** is applied to a desired position on the magnetic recording medium **80**. Magnetization at a desired position of the magnetic recording medium **80** is controlled in a direction corresponding to the recording magnetic field. Information is thus recorded on the magnetic recording medium **80**.

As shown in FIG. **1**, the first magnetic pole **31** includes a first magnetic pole face **31***f*. The first magnetic pole face **31***f* faces the magnetic recording medium **80**, for example. The first magnetic pole face **31***f* is, for example, an ABS (Air Bearing Surface). The first magnetic pole face **31***f* is substantially along the X-Y plane, for example.

A first direction D**1** from the first magnetic pole **31** to the first region **32***a* is along the X-axis direction. As shown in FIG. **1**, the first magnetic pole **31** includes a surface facing the first region **32***a*. The first region **32***a* includes a surface facing the first magnetic pole **31**. These planes may be inclined with respect to the Z-axis direction.

The conductive part **30***c* is electrically insulated from the first magnetic pole **31** and the second magnetic pole **32**. For example, insulating members **30***i* are provided between the first magnetic pole **31** and the conductive part **30***c* and between the second magnetic pole **32** and the conductive part **30***c*. In one example, the conductive part **30***c* may be a recording coil.

The first terminal T**1** and the second terminal T**2** are electrically connected to the conductive part **30***c*. For example, the first terminal T**1** is electrically connected to a part (e.g., one end) of the conductive part **30***c*. The second terminal T**2** is electrically connected to another part (for example, the other end) of the conductive part **30***c*. A first current i**1** can be supplied between the first terminal T**1** and the second terminal T**2**.

When the recording coil is used as the conductive part **30***c*, the first current i**1** may be a recording current. In the embodiment, the conductive part **30***c* may be provided separately from the recording coil. An example in which the recording coil is used as the conductive part **30***c* will be described below.

For example, the recording coil is supplied with the recording current corresponding to information to be recorded. A magnetic field (recording magnetic field) is generated from the first magnetic pole **31** by the recording current. Information is recorded on the magnetic recording medium **80** by the recording magnetic field.

As shown in FIG. **2**, the element part **20** is conductive. As shown in FIGS. **1** and **2**, the element part **20** is provided between the first magnetic pole **31** and the second magnetic pole **32**. The element part **20** is electrically connected to the first magnetic pole **31** and the second magnetic pole **32**.

For example, the element part **20** includes a first region element **20***a*. The first region element **20***a* is electrically conductive. The first region element **20***a* is provided between the first magnetic pole **31** and the first region **32***a*. The first region element **20***a* is electrically connected to the first magnetic pole **31** and the first region **32***a*.

As shown in FIG. **1**, the third terminal T**3** is electrically connected to the first magnetic pole **31**. The fourth terminal T**4** is electrically connected to the second magnetic pole **32**. For example, the third terminal T**3** is electrically connected to the first magnetic pole **31** by a first wiring W**1**. The fourth terminal T**4** is electrically connected to the second magnetic pole **32** by a second wiring W**2**.

In the embodiment, a first state may be provided. In the first state, the first current i**1** is supplied between the first terminal T**1** and the second terminal T**2**. The temperature of the first magnetic pole **31** in the first state (first magnetic pole temperature) is higher than the temperature of the second magnetic pole **32** in the first state (second magnetic pole temperature). For example, the temperature of the first magnetic pole **31** (first magnetic pole temperature) in the first state is higher than the temperature of the first region **32***a* in the first state.

For example, the temperature of the first magnetic pole **31** rises due to Joule heat due to the first current i**1** supplied to the conductive part **30***c*. As a result, the temperature of the first magnetic pole **31** in the first state becomes higher than the temperature of the second magnetic pole **32** (for example, the first region **32***a*) in the first state. The temperature difference causes, for example, a thermoelectric effect. As a result, for example, a potential difference is generated between the first magnetic pole **31** and the second magnetic pole **32** (first region **32***a*). By using the potential difference based on the temperature difference, for example, power consumption can be suppressed. For example, it is easy to obtain the element part **20** being stable.

As will be described later, an element current i**2** is supplied to the element part **20** (e.g., the first region device **20***a*). Thereby, a magnetic field is generated from the element part **20**. At least one of the orientation and magnitude of the recording magnetic field generated from the first magnetic pole **31**, for example, is appropriately controlled by this magnetic field. This enables efficient recording operation.

Alternatively, an alternating magnetic field is generated from the element part **20** by supplying the element current i**2** to the element part **20**. The alternating magnetic field is, for example, a high frequency magnetic field. The application of the alternating magnetic field to the magnetic recording medium **80** assists the recording on the magnetic recording medium **80**. For example, MAMR (Microwave Assisted Magnetic Recording) can be performed.

In the embodiment, as described above, the first current i**1** supplied to the conductive part **30***c* causes a temperature difference. By using the potential difference based on the temperature difference, the voltage of the externally supplied element current i**2** can be lowered. Thereby, the electric power supplied to the element part **20** can be suppressed. For example, thermal deterioration of the element part **20** can be suppressed. For example, it becomes easier to obtain stable characteristics in the element part **20**. For example, the element part **20** having a long life can be obtained. For example, the element current i2 can be increased while maintaining high reliability. For example, high recording density can be obtained. According to the embodiment, for example, a magnetic head whose characteristics can be improved can be obtained.

When the temperature of the first magnetic pole **31** is higher than the temperature of the second magnetic pole **32**, the potential of the first magnetic pole **31** tends to be higher than the potential of the second magnetic pole **32**. It is considered that this is due to the thermoelectric effect at the element part **20**, a first interface between the element part **20** and the first magnetic pole **31**, and a second interface between the element part **20** and the second magnetic pole **32** (for example, the first region **32***a*). For example, the sum of the Seebeck coefficient at the element part **20**, the Seebeck coefficient at the first interface, and the Seebeck coefficient at the second interface may be positive.

In the embodiment, the above temperature difference is obtained in the first state in which the first current i**1** is supplied between the first terminal T**1** and the second terminal T**2**. In this first state, no current (element current i**2**) may be supplied between the third terminal T**3** and the fourth terminal T**4**. The temperature difference may occur in the first state in which the element current i**2** does not flow through the element part **20**.

As described above, the magnetic head **110** performs the recording operation (first operation). In the first operation, the first current i**1** (for example, recording current) is supplied between the first terminal T**1** and the second terminal T**2**. In the recording operation (first operation), the element current i**2** is supplied between the third terminal T**3** and the fourth terminal T**4**. As a result, at least one of the orientation and magnitude of the recording magnetic field is appropriately controlled. Alternatively, MAMR is performed.

The orientation of the device current i**2** is, for example, the orientation from the fourth terminal T**4** to the third terminal T**3**. The element current i**2** flows through the element part **20**, for example, in the orientation from the second magnetic pole **32** to the first magnetic pole **31** (see FIG. **2**). An electron flow je flows through the element part **20**, for example, in the orientation from the first magnetic pole **31** to the second magnetic pole **32** (see FIG. **2**). For example, the element current i**2** flows through the first region element **20***a* in the orientation from the first region **32***a* to the first magnetic pole **31**, for example. The electron current je flows through the first region element **20***a*, for example, in the orientation from the first magnetic pole **31** to the first region **32***a*.

In the first operation (for example, recording operation), the magnetic field (recording magnetic field) is generated from the first magnetic pole **31** corresponding to the first current i**1**. The orientation of the magnetic field generated from the first magnetic pole **31** changes according to the orientation of the first current i**1**. In the first operation, information corresponding to the orientation of the first current i**1** is recorded on the magnetic recording medium **80**.

For example, the potential of the second magnetic pole **32** is higher than the potential of the first magnetic pole **31** when the element current i**2** is supplied. When the temperature of the first magnetic pole **31** is higher than the temperature of the second magnetic pole **33**, the potential of the first magnetic pole **31** tends to be higher than the potential of the second magnetic pole **32**, for example, due to the temperature difference. This makes it possible to reduce the absolute value of the difference between the potential of the second magnetic pole **32** and the potential of the first magnetic pole **31** when the element current i**2** flows. For example, power supplied to the element part **20** can be suppressed.

In the first operation (for example, recording operation), for example, the element current i**2** flows through the first magnetic pole **31** and the second magnetic pole **32**, thereby a change in the recording magnetic field corresponding to the first current i**1** is promoted. For example, variations in changes in the recording magnetic field when the first current i**1** is changed are suppressed. For example, variations in the difference between the time when the polarity of the first current i**1** changes and the time when the polarity of the recording magnetic field changes are suppressed. For example, a stable first operation can be performed. For example, high writability can be obtained. For example, high recording density can be obtained.

As shown in FIG. **1**, a first circuit **61** and a second circuit **62** may be provided. The first circuit **61** can supply the first current i**1** between the first terminal T**1** and the second terminal T**2**. The second circuit **62** can supply the element current i**2** to the third terminal T**3** and the fourth terminal T**4**. The first circuit **61** and the second circuit **62** are included in the controller **60**C. The first circuit **61** and the second circuit **62** may be included in the magnetic recording device **210**.

As shown in FIG. **1**, the first magnetic pole **31** includes the first magnetic pole face **31***f*. The first magnetic pole face **31***f* faces the magnetic recording medium **80**. The second magnetic pole **32** includes a second magnetic pole face **32***f*. The second magnetic pole face **32***f* faces the magnetic recording medium **80**. As shown in FIG. **2**, the first magnetic pole face **31***f* is smaller than the second magnetic pole face **32***f*. For example, the volume of the first magnetic pole **31** is smaller than the volume of the second magnetic pole **32**. The temperature of the first magnetic pole **31** tends to rise. For example, a potential difference based on a temperature difference can be effectively obtained.

As shown in FIG. **2**, the first region **32***a* includes a first region face **32***af*. The first region face **32***af* faces the magnetic recording medium **80**. As shown in FIG. **2**, the first magnetic pole face **31***f* may be smaller than the first region face **32***af*.

As shown in FIG. **2**, the second magnetic pole **32** may further include a third region **32***c*. A second direction D**2** from the third region **32***c* to the first magnetic pole **31** crosses the first direction D**1** from the first magnetic pole **31** to the first region **32***a*. The second direction D**2** is, for example, the Y-axis direction. The Z-axis direction is, for example, along the third direction D**3**. The third direction D**3** crosses a plane including the first direction D**1** and the second direction D**2**.

As shown in FIG. **2**, the second magnetic pole **32** may further include a fourth region **32***d*. A direction from the third region **32***c* to the fourth region **32***d* is along the second direction D**2**. The first magnetic pole **31** is between the third region **32***c* and the fourth region **32***d* in the second direction D**2**. The third region **32***c* and the fourth region **32***d* are side shields, for example. By providing the third region **32***c* and the fourth region **32***d*, the recording magnetic field generated from the first magnetic pole **31** is controlled and applied to the magnetic recording medium **80** efficiently.

Several examples of magnetic heads according to the embodiment will be described below. In the following, description of the same configuration as that of the magnetic head **110** described above will be omitted.

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

As shown in FIG. **3**, in a magnetic head **110***a* according to the embodiment, the element part **20** includes a second region element **20***b*. As already described, the second magnetic pole **32** further includes the second region **32***b*. The first magnetic pole **31** is between the second region **32***b* and the first region **32***a*. The second region element **20***b* is electrically conductive. The second region element **20***b* is provided between the second region **32***b* and the first magnetic pole **31**.

In the magnetic head **110***a*, in the first operation (for example, recording operation), the element current i**2** oriented from the second region **32***b* to the first magnetic pole **31** flows through the second region element **20***b*.

In the magnetic head **110***a*, the first magnetic pole face **31***f* is smaller than the second magnetic pole face **32***f*. As shown in FIG. **3**, the second region **32***b* may include a second region face **32***bf*. The second region face **32***bf* faces the magnetic recording medium **80**. The first magnetic pole face **31***f* may be smaller than the second region face **32***bf*.

FIG. **4** is a schematic plan view illustrating a magnetic head according to the first embodiment.

As shown in FIG. **4**, a magnetic head **110***b* according to the embodiment includes a third region element **20***c*. As already described, the second magnetic pole **32** includes the third region **32***c*. A direction from the third region **32***c* to the first magnetic pole **31** is along the second direction D**2**. The third region element **20***c* is electrically conductive. The third region element **20***c* is provided between the third region **32***c* and the first magnetic pole **31**.

The magnetic head **110***b* may include a fourth region element **20***d*. As already described, the second magnetic pole **32** includes the fourth region **32***d*. A direction from the third region **32***c* to the fourth region **32***d* is along the second direction D**2**. The first magnetic pole **31** is between the third region **32***c* and the fourth region **32***d*. The fourth region element **20***d* is electrically conductive. The fourth region element **20***d* is provided between the first magnetic pole **31** and the fourth region **32***d*.

In the magnetic head **110***b*, in the first operation (for example, recording operation), the element current i**2** oriented from the third region **32***c* to the first magnetic pole **31** flows through the third region element **20***c*. In the first operation (for example, recording operation), the element current i**2** oriented from the fourth region **32***d* to the first magnetic pole **31** flows through the fourth region element **20***d*.

In the magnetic head **110***b*, the first magnetic pole face **31***f* is smaller than the second magnetic pole face **32***f*. As shown in FIG. **4**, the third region **32***c* may include a third region face **32***cf*. The third region face **32***cf* faces the magnetic recording medium **80**. The first magnetic pole face **31***f* may be smaller than the third region face **32***cf*. As shown in FIG. **4**, the fourth region **32***d* may include a fourth region face **32***df*. The fourth region face **32***df* faces the magnetic recording medium **80**. The first magnetic pole face **31***f* may be smaller than the fourth region face **32***df*.

In the magnetic head **110***a* and the magnetic head **110***b*, the temperature of the first magnetic pole **31** is higher than the temperature of the second magnetic pole **32** in the first state. The first potential of the first magnetic pole **31** is higher than the second potential of the second magnetic pole **32** in the first state in which the element current i**2** does not flow. For example, power supplied to the element part **20** can be suppressed. For example, thermal deterioration of the element part **20** can be suppressed. For example, a magnetic head whose characteristics can be improved can be obtained.

Several examples of the element part **20** will be described below.

FIGS. **5**A to **5**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment.

As shown in FIG. **5**A, in a magnetic head **111***a* according to the embodiment, the element part **20** (for example, the first region element **20***a*) includes a first magnetic pole side non-magnetic layer **41**P. The first magnetic pole side non-magnetic layer **41**P is in contact with the first magnetic pole **31**. The first magnetic pole side non-magnetic layer **41**P includes at least one selected from the group consisting of Ru, Ta, Ir, Rh, Pd, Pt and W (first element group).

As shown in FIG. **5**B, in a magnetic head **111***b* according to the embodiment, the element part **20** (for example, the first region element **20***a*) includes the first magnetic pole side non-magnetic layer **41**P and a first stacked body **21**S. The first magnetic pole side non-magnetic layer **41**P is between the first magnetic pole **31** and the first stacked body **21**S. In this example, the first stacked body **21**S includes a first magnetic layer **21** and a first non-magnetic layer **41**. The first magnetic layer **21** is between the first magnetic pole side non-magnetic layer **41**P and the first non-magnetic layer **41**. In this example, the first non-magnetic layer **41** includes at least one selected from the group (second element group) consisting of Cu, Au, Cr, V, Al, and Ag.

As shown in FIG. **5**C, in a magnetic head **111***c* according to the embodiment, the first stacked body **21**S further includes a second magnetic layer **22** and a second non-magnetic layer **42**. The second magnetic layer **22** is between the first magnetic layer **21** and the second non-magnetic layer **42**. The second non-magnetic layer **42** may include at least one selected from the above first element group or at least one selected from the above second element group.

As shown in FIG. **5**D, in a magnetic head **111***d* according to the embodiment, the first stacked body **21**S further includes a third magnetic layer **23** and a third non-magnetic layer **43**. The third magnetic layer **23** is between the second magnetic layer **22** and the third non-magnetic layer **43**. The third non-magnetic layer **43** may include at least one selected from the above first element group or at least one selected from the above second element group.

As shown in FIG. **5**E, in a magnetic head **111***e* according to the embodiment, the first stacked body **21**S further includes a fourth magnetic layer **24** and a fourth non-magnetic layer **44**. The fourth magnetic layer **24** is between the third magnetic layer **23** and the fourth non-magnetic layer **44**. The fourth non-magnetic layer **44** may include at least one selected from the above first element group or at least one selected from the above second element group.

At least one of the first magnetic layer **21**, the second magnetic layer **22**, the third magnetic layer **23** and the fourth magnetic layer **24** includes at least one selected from the group consisting of Fe, Co, and Ni.

FIGS. **6**A to **6**E, **7**A to **7**E, and **8**A to **8**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment.

As shown in FIGS. **6**A, **7**A, and **8**A, in a magnetic head **112***a*, a magnetic head **113***a*, and a magnetic head **114***a*, the element part **20** (for example, the second region element **20***b*, the third region element **20***c* and the fourth region element **20***d*) may include the first magnetic pole side non-magnetic layer **41**P described above.

As shown in FIGS. **6**B, **7**B, and **8**B, in a magnetic head **112***b*, a magnetic head **113***b*, and a magnetic head **114***b*, the element part **20** (for example, the second region element **20***b*, the third region element **20***c* and the fourth region element **20***d*) may include the first magnetic pole side non-magnetic layer **41**P and the first stacked body **21**S. The first stacked body **21**S includes the first magnetic layer **21** and the first non-magnetic layer **41**.

As shown in FIGS. **6**C, **7**C, and **8**C, in a magnetic head **112***c*, a magnetic head **113***c*, and a magnetic head **114***c*, in the element part **20** (for example, the second region element **20***b*, the third region element **20***c* and the fourth region element **20***d*), the first stacked body **21**S may further include the second magnetic layer **22** and the second non-magnetic layer **42**.

As shown in FIGS. **6**D, **7**D, and **8**D, in a magnetic head **112***d*, a magnetic head **113***d*, and a magnetic head **114***d*, in the element part **20** (for example, the second region element **20***b*, the third region element **20***c* and the fourth region element **20***d*), the first stacked body **21**S may further include the third magnetic layer **23** and the third non-magnetic layer **43**.

As shown in FIGS. **6**E, **7**E, and **8**E, in a magnetic head **112***e*, a magnetic head **113***e*, and a magnetic head **114***e*, in the element part **20** (for example, the second region element **20***b*, the third region element **20***c* and the fourth region element **20***d*), the first stacked body **21**S may further include the fourth magnetic layer **24** and the fourth non-magnetic layer **44**.

In the magnetic head **111***a*, the magnetic head **112***a*, the magnetic head **113***a*, and the magnetic head **114***a*, at least one of the orientation and magnitude of the recording magnetic field is appropriately controlled.

The magnetization of the first magnetic layer **21** is reversed with respect to the magnetization of the first magnetic pole **31** in the magnetic head **111***b*, the magnetic head **112***b*, the magnetic head **113***b*, and the magnetic head **114***b*. At least one of the orientation and magnitude of the recording magnetic field is appropriately controlled.

In one example of at least one of the magnetic head **111***c*, the magnetic head **112***c*, the magnetic head **113***c*, the magnetic head **114***c*, the magnetic head **111***d*, the magnetic head **112***d*, the magnetic head **113***d*, the magnetic head **114***d*, the magnetic head **111***e*, the magnetic head **112***e*, the magnetic head **113***e* and the magnetic head **114***e*, an alternating magnetic field is generated from the first stacked body **21**S. MAMR is performed. In one example, at least one of the magnetization of the first magnetic layer **21** and the magnetization of the second magnetic layer **22** is reversed with respect to the magnetization of the first magnetic pole **31**. At least one of the orientation and magnitude of the recording magnetic field is appropriately controlled. MAMR and control of the orientation and/or magnitude of the recording magnetic field may be performed.

FIGS. **9**A to **9**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment.

As shown in FIG. **9**A, in a magnetic head **121***a* according to the embodiment, the element part **20** (for example, the first region element **20***a*) includes a first magnetic pole side magnetic layer **21**P and a non-magnetic intermediate layer **411**. The first magnetic pole side magnetic layer **21**P is provided between the first magnetic pole **31** and the non-magnetic intermediate layer **411**. The non-magnetic intermediate layer **411** includes at least one selected from the group (second group) consisting of Cu, Au, Cr, V, Al, and Ag. The first magnetic pole side magnetic layer **21**P includes at least one selected from the group consisting of Fe, Co, and Ni, at least one selected from the group (third group) consisting of Cr, V, Mn, Ti and Sc. The first magnetic pole side magnetic layer **21**P has, for example, negative polarization. For example, the first magnetic pole side magnetic layer **21**P is in contact with the non-magnetic intermediate layer **411**. For example, the first magnetic pole side magnetic layer **21**P contacts the first magnetic pole **31**.

As shown in FIG. **9**B, in a magnetic head **121***b* according to the embodiment, the element part **20** (for example, the first region element **20***a*) further includes the first stacked body **21**S. The non-magnetic intermediate layer **411** is between the first magnetic pole side magnetic layer **21**P and the first stacked body **21**S. The first stacked body **21**S includes the first magnetic layer **21** and the first non-magnetic layer **41**. The first magnetic layer **21** is between the non-magnetic intermediate layer **411** and the first non-magnetic layer **41**. The first non-magnetic layer **41** may include, for example, at least one selected from the above first element group or at least one selected from the above second element group.

As shown in FIG. **9**C, in a magnetic head **121***c* according to the embodiment, the first stacked body **21**S further includes the second magnetic layer **22** and the second non-magnetic layer **42**. The second magnetic layer **22** is between the first magnetic layer **21** and the second non-magnetic layer **42**. The second non-magnetic layer **42** may include at least one selected from the above first element group or at least one selected from the above second element group.

As shown in FIG. **9**D, in a magnetic head **121***d* according to the embodiment, the first stacked body **21**S further includes the third magnetic layer **23** and the third non-magnetic layer **43**. The third magnetic layer **23** is between the second magnetic layer **22** and the third non-magnetic layer **43**. The third non-magnetic layer **43** may include at least one selected from the above first element group or at least one selected from the above second element group.

As shown in FIG. **9**E, in a magnetic head **121***e* according to the embodiment, the first stacked body **21**S further includes the fourth magnetic layer **24** and the fourth non-magnetic layer **44**. The fourth magnetic layer **24** is between the third magnetic layer **23** and the fourth non-magnetic layer **44**. The fourth non-magnetic layer **44** may include at least one selected from the above first element group or at least one selected from the above second element group.

At least one of the first magnetic layer **21**, the second magnetic layer **22**, the third magnetic layer **23** and the fourth magnetic layer **24** includes at least one selected from the group consisting of Fe, Co, and Ni.

FIGS. **10**A to **10**E, **11**A to **11**E, and **12**A to **12**E are schematic cross-sectional views illustrating magnetic heads according to the first embodiment.

As shown in FIGS. **10**A, **11**A, and **12**A, in a magnetic head **122***a*, a magnetic head **123***a*, and a magnetic head **124***a*, the element part **20** (for example, the second region element **20***b*, the third region element **20***c* and the fourth region element **20***d*) may include the first magnetic pole side magnetic layer **21**P and the non-magnetic intermediate layer **411** described above.

As shown in FIGS. **10**B, **11**B, and **12**B, in a magnetic head **122***b*, a magnetic head **123***b*, and a magnetic head **124***b*, the element part **20** (for example, the second region element **20***b*, the third region element **20***c* and the fourth region element **20***d*) may include the first magnetic pole side magnetic layer **21**P, the non-magnetic intermediate layer **411** and the first stacked body **21**S. The first stacked body **21**S includes the first magnetic layer **21** and the first non-magnetic layer **41**.

As shown in FIGS. **10**C, **11**C, and **12**C, in a magnetic head **122***c*, a magnetic head **123***c*, and a magnetic head **124***c*, in the element part **20** (for example, the second region element **20**b, the third region element **20**c and the fourth region element **20**d), the first stacked body **21**S may further include the second magnetic layer **22** and the second non-magnetic layer **42**.

As shown in FIGS. **10**D, **11**D, and **12**D, in a magnetic head **122**d, a magnetic head **123**d, and a magnetic head **124**d, in the element part **20** (for example, the second region element **20**b, the third region element **20**c and the fourth region element **20**d), the first stacked body **21**S may further include the third magnetic layer **23** and the third non-magnetic layer **43**.

As shown in FIGS. **10**E, **11**E, and **12**E, in a magnetic head **122**e, a magnetic head **123**e, and a magnetic head **124**e, in the element part **20** (for example, the second region element **20**b, the third region element **20**c and the fourth region element **20**d), the first stacked body **21**S may further include the fourth magnetic layer **24** and the fourth non-magnetic layer **44**.

In the magnetic head **121**a, the magnetic head **122**a, the magnetic head **123**a, and the magnetic head **124**a, at least one of the orientation and magnitude of the recording magnetic field is appropriately controlled.

The magnetization of the first magnetic layer **21** is reversed with respect to the magnetization of the first magnetic pole **31** in the magnetic head **121**b, the magnetic head **122**b, the magnetic head **123**b, and the magnetic head **124**b. At least one of the orientation and magnitude of the recording magnetic field is appropriately controlled.

In one example of at least one of the magnetic head **121**c, the magnetic head **122**c, the magnetic head **123**c, the magnetic head **124**c, the magnetic head **121**d, the magnetic head **122**d, the magnetic head **123**d, the magnetic head **124**d, the magnetic head **121**e, the magnetic head **122**e, the magnetic head **123**e and the magnetic head **124**e, an alternating magnetic field is generated from the first stacked body **21**S. MAMR is performed. In one example, at least one of the magnetization of the first magnetic layer **21** and the magnetization of the second magnetic layer **22** is reversed with respect to the magnetization of the first magnetic pole **31**. At least one of the orientation and magnitude of the recording magnetic field is appropriately controlled. MAMR and control of the orientation and/or magnitude of the recording magnetic field may be implemented.

In the embodiment, the first region element **20**a, the second region element **20**b, the third region element **20**c and/or the fourth region element **20**d may be provided. For example, the first region **32**a may be the leading shield and the second region **32**b may be the trailing shield. For example, the first region element **20**a and the second region element **20**b may be omitted and the third region element **20**c may be provided. In this case, the third region element **20**c may be regarded as the "first region element".

Any combination of these configurations illustrated in FIGS. **5**A to **5**E, **6**A to **6**E, **7**A to **7**E, **8**A to **8**E, and **9**A to **9**E, **10**A to **10**E, **11**A to **11**E, and **12**A to **12**E may be applied.

FIG. **13** is a schematic cross-sectional view illustrating a magnetic head according to the first embodiment.

As shown in FIG. **13**, in a magnetic head **131**a according to the embodiment, the recording coil (conductive part **30**c) is provided between the first magnetic pole **31** and the first region **32**a of the second magnetic pole **32**. The recording coil (the conductive part **30**c) need not be provided between the first magnetic pole **31** and the second region **32**b.

FIG. **14** is a schematic cross-sectional view illustrating a magnetic head according to the first embodiment.

As shown in FIG. **14**, in a magnetic head **131**b according to the embodiment, the second region **32**b of the second magnetic pole **32** may include a portion along the Z-axis direction and a portion extending along the X-Y plane. The area of the second region **32**b is likely to expand. The second region **32**b may include a portion extending along the X-Y plane and may not include a portion extending along the Z-axis direction.

Second Embodiment

In the following embodiments, the magnetic head (such as the magnetic head **110**) described in relation to the first embodiment and modifications thereof are applied. An example in which the magnetic head **110** is used will be described below.

FIG. **15** is a schematic perspective view illustrating a magnetic recording device according to a second embodiment.

As shown in FIG. **15**, the magnetic head (e.g., magnetic head **110**) according to the embodiment is used together with the magnetic recording medium **80**. In this example, the magnetic head **110** includes a recording part **60** and a reproducing part **70**. Information is recorded on the magnetic recording medium **80** by the recording part **60** of the magnetic head **110**. Information recorded on the magnetic recording medium **80** is reproduced by the reproducing part **70**.

The magnetic recording medium **80** includes, for example, a medium substrate **82** and a magnetic recording layer **81** provided on the medium substrate **82**. The magnetization **83** of the magnetic recording layer **81** is controlled by the recording part **60**.

The reproducing part **70** includes, for example, a first reproducing magnetic shield **72**a, a second reproducing magnetic shield **72**b, and a magnetic reproducing element **71**. The magnetic reproducing element **71** is provided between the first reproducing magnetic shield **72**a and the second reproducing magnetic shield **72**b. The magnetic reproducing element **71** can output a signal corresponding to the magnetization **83** of the magnetic recording layer **81**.

As shown in FIG. **15**, the magnetic recording medium **80** moves relative to the magnetic head **110** in a direction of medium movement **85**. Information corresponding to the magnetization **83** of the magnetic recording layer **81** is controlled at an arbitrary position by the magnetic head **110**. Information corresponding to the magnetization **83** of the magnetic recording layer **81** is reproduced at an arbitrary position by the magnetic head **110**.

FIG. **16** is a schematic perspective view illustrating a part of the magnetic recording device according to the embodiment.

FIG. **16** illustrates a head slider.

The magnetic head **110** is provided on the head slider **159**. The head slider **159** includes, for example, Al_2O_3/TiC or the like. The head slider **159** moves relative to the magnetic recording medium while floating or in contact with the magnetic recording medium.

The head slider **159** includes, for example, an air inflow side **159**A and an air outflow side **159**B. The magnetic head **110** is arranged on the side surface of the air outflow side **159**B of the head slider **159** or the like. As a result, the magnetic head **110** moves relative to the magnetic recording medium while flying above or in contact with the magnetic recording medium.

FIG. **17** is a schematic perspective view illustrating the magnetic recording device according to the second embodiment.

As shown in FIG. **17**, in a magnetic recording device **150** according to the embodiment, a rotary actuator is used. A recording medium disk **180** is connected to a spindle motor **180**M. The recording medium disk **180** is rotated in a direction of arrow AR by the spindle motor **180**M. The spindle motor **180**M is responsive to control signals from the drive device controller. The magnetic recording device **150** according to the embodiment may include the multiple recording medium disks **180**. The magnetic recording device **150** may include a recording medium **181**. The recording medium **181** is, for example, an SSD (Solid State Drive). A non-volatile memory such as a flash memory is used for the recording medium **181**, for example. For example, the magnetic recording device **150** may be a hybrid HDD (Hard Disk Drive).

The head slider **159** records and reproduces information to be recorded on the recording medium disk **180**. The head slider **159** is provided at an end of a thin-film suspension **154**. A magnetic head according to the embodiment is provided near the end of the head slider **159**.

While the recording medium disk **180** is rotating, the pressing pressure by the suspension **154** and the floating pressure generated at the medium facing surface (ABS) of the head slider **159** are balanced. The distance between the medium facing surface of the head slider **159** and the surface of the recording medium disk **180** is the predetermined fly height. In the embodiment, the head slider **159** may contact the recording medium disk **180**. For example, a contact sliding type may be applied.

The suspension **154** is connected to one end of an arm **155** (e.g., an actuator arm). The arm **155** includes, for example, a bobbin part or the like. The bobbin part holds a drive coil. A voice coil motor **156** is provided at the other end of the arm **155**. The voice coil motor **156** is a type of linear motor. The voice coil motor **156** includes, for example, a drive coil and a magnetic circuit. The drive coil is wound on the bobbin part of the arm **155**. The magnetic circuit includes permanent magnets and opposing yokes. The drive coil is provided between the permanent magnet and the opposing yoke. The suspension **154** includes one end and the other end. A magnetic head is provided at one end of the suspension **154**. The arm **155** is connected to the other end of the suspension **154**.

The arm **155** is held by ball bearings. Ball bearings are provided at two locations above and below a bearing part **157**. The arm **155** can be rotated and slid by the voice coil motor **156**. The magnetic head can move to any position on the recording medium disk **180**.

FIGS. **18**A and **18**B are schematic perspective views illustrating a part of the magnetic recording device according to the second embodiment.

FIG. **18**A illustrates a head stack assembly **160** included in the magnetic recording device **150**. The head stack assembly **160** includes a magnetic head assembly **158** (e.g., head gimbal assembly: HGA). FIG. **18**B illustrates the magnetic head assembly **158**.

As shown in FIG. **18**A, the head stack assembly **160** includes the bearing part **157**, the magnetic head assembly **158** and a support frame **161**. The magnetic head assembly **158** extends from the bearing part **157**. The support frame **161** extends from the bearing part **157**. A direction in which the support frame **161** extends is opposite to a direction in which the magnetic head assembly **158** extends. The support frame **161** supports a coil **162** of the voice coil motor **156**.

As shown in FIG. **18**B, the magnetic head assembly **158** includes the arm **155** extending from the bearing part **157** and the suspension **154** extending from the arm **155**.

The head slider **159** is provided at the end of the suspension **154**. The head slider **159** is provided with the magnetic head according to the embodiment.

The magnetic head assembly **158** according to the embodiment includes the magnetic head according to the embodiment, the head slider **159** provided with the magnetic head, the suspension **154** and the arm **155**. The head slider **159** is provided at one end of the suspension **154**. The arm **155** is connected to the other end of the suspension **154**.

The suspension **154** may include, for example, a wiring (not shown) for recording and reproducing signals. The suspension **154** may include, for example, a heater wiring (not shown) for adjusting the fly height. The suspension **154** may include a wiring (not shown) for, for example, an oscillator element or the like. These wires may be electrically connected to multiple electrodes provided on the magnetic head.

A signal processor **190** is provided in the magnetic recording device **150**. The signal processor **190** uses a magnetic head to record and reproduce signals on a magnetic recording medium. Input/output lines of the signal processor **190** are connected to, for example, electrode pads of the magnetic head assembly **158** and electrically connected to the magnetic head.

The magnetic recording device **150** according to the embodiment includes the magnetic recording medium, the magnetic head according to the embodiment, a movable part, a position controller, and a signal processor. The movable part separates the magnetic recording medium from the magnetic head or makes them relatively movable while they are in contact with each other. The position controller aligns the magnetic head with a predetermined recording position on the magnetic recording medium. The signal processor records and reproduces signals on the magnetic recording medium using the magnetic head.

For example, the recording medium disk **180** is used as the above magnetic recording medium. The movable part includes, for example, the head slider **159**. The position controller described above includes, for example, the magnetic head assembly **158**.

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

Configuration 1

A magnetic head comprising:
- a first magnetic pole;
- a second magnetic pole;
- a conductive part electrically insulated from the first magnetic pole and the second magnetic pole;
- a first terminal and a second terminal electrically connected to the conductive part;
- an element part provided between the first magnetic pole and the second magnetic pole and electrically connected to the first magnetic pole and the second magnetic pole, the element part being conductive;
- a third terminal electrically connected to the first magnetic pole; and
- a fourth terminal electrically connected to the second magnetic pole,
- a first magnetic pole temperature of the first magnetic pole in a first state being higher than a second magnetic pole temperature of the second magnetic pole in the first state, a first current being supplied between the first terminal and the second terminal in the first state.

Configuration 2

The magnetic head according to Configuration 1, wherein in the first state, a current is not supplied between the third terminal and the fourth terminal.

Configuration 3

The magnetic head according to Configuration 1 or 2, wherein

in a first operation, the first current is supplied between the first terminal and the second terminal, and

in the first operation, an element current is supplied between the third terminal and the fourth terminal.

Configuration 4

The magnetic head according to Configuration 3, wherein an orientation of the element current is an orientation from the fourth terminal to the third terminal.

Configuration 5

The magnetic head according to Configuration 3, wherein in the first operation, a magnetic field corresponding to the first current is generated from the first magnetic pole.

Configuration 6

The magnetic head according to Configuration 5, wherein an orientation of the magnetic field is configured to change according to an orientation of the first current.

Configuration 7

The magnetic head according to any one of Configurations 3 to 6, wherein

in the first operation, information corresponding to the orientation of the first current is recorded on a magnetic recording medium.

Configuration 8

The magnetic head according to Configuration 7, wherein

the first magnetic pole includes a first magnetic pole face facing the magnetic recording medium,

the second magnetic pole includes a second magnetic pole face facing the magnetic recording medium, and

the first magnetic pole face is smaller than the second magnetic pole face.

Configuration 9

The magnetic head according to any one of Configurations 1 to 8, wherein

in the first state, a first potential of the first magnetic pole is higher than a second potential of the second magnetic pole.

Configuration 10

A magnetic head comprising:

a first magnetic pole;

a second magnetic pole;

a conductive part electrically insulated from the first magnetic pole and the second magnetic pole;

a first terminal and a second terminal electrically connected to the conductive part;

an element part provided between the first magnetic pole and the second magnetic pole and electrically connected to the first magnetic pole and the second magnetic pole, the element part being conductive;

a third terminal electrically connected to the first magnetic pole; and

a fourth terminal electrically connected to the second magnetic pole,

a first potential of the first magnetic pole in a first state being higher than a second potential of the second magnetic pole in the first state, a first current being supplied between the first terminal and the second terminal in the first state, and

a current being not supplied between the third terminal and the fourth terminal in the first state.

Configuration 11

The magnetic head according to any one of Configurations 1 to 10, wherein

the second magnetic pole further includes a first region,

the element part includes a first region element, and

the first region element is provided between the first magnetic pole and the first region.

Configuration 12

The magnetic head according to Configuration 11, wherein

the second magnetic pole further includes a second region,

the first magnetic pole is between the second region and the first region,

the element part further includes a second region element, and

the second region element is provided between the second region and the first magnetic pole.

Configuration 13

The magnetic head according to Configuration 11 or 12, wherein

the second magnetic pole further includes a third region,

a second direction from the third region to the first magnetic pole crosses a first direction from the first magnetic pole to the first region,

the element part further includes a third region element, and

the third region element is provided between the third region and the first magnetic pole.

Configuration 14

The magnetic head according to Configuration 13, wherein

the second magnetic pole further includes a fourth region,

the first magnetic pole is between the third region and the fourth region in the second direction,

the element part further includes a fourth region element, and

the fourth region element is provided between the first magnetic pole and the fourth region.

Configuration 15

The magnetic head according to any one of Configurations 1 to 14, wherein

the element part includes a first magnetic pole side non-magnetic layer contacting the first magnetic pole, and

the first magnetic pole side non-magnetic layer includes at least one selected from the group consisting of Ru, Ta, Ir, Rh, Pd, Pt and W.

Configuration 16

The magnetic head according to Configuration 15, wherein

the element part further includes a first stacked body,

the first magnetic pole side non-magnetic layer is between the first magnetic pole and the first stacked body,

the first stacked body includes a first magnetic layer and a first non-magnetic layer, and

the first magnetic layer is between the first magnetic pole side non-magnetic layer and the first non-magnetic layer.

Configuration 17

The magnetic head according to any one of Configurations 1 to 14, wherein

the element part includes

a first magnetic pole side magnetic layer, and

a non-magnetic intermediate layer,

the first magnetic pole side magnetic layer is provided between the first magnetic pole and the non-magnetic intermediate layer,

the non-magnetic intermediate layer includes at least one selected from the group consisting of Cu, Au, Cr, V, Al and Ag, and

the first magnetic pole side magnetic layer includes

at least one selected from the group consisting of Fe, Co, and Ni, and

at least one selected from the group consisting of Cr, V, Mn, Ti, and Sc.

Configuration 18

The magnetic head according to Configuration 17, wherein

the first magnetic pole side magnetic layer contacts the non-magnetic intermediate layer.

Configuration 19

The magnetic head according to Configuration 17 or 18, wherein

the element part further includes a first stacked body, and

the non-magnetic intermediate layer is between the first magnetic pole side magnetic layer and the first non-magnetic layer.

Configuration 20

A magnetic recording device, comprising:

the magnetic head according to any one of Configurations 3 to 6;

a first circuit configured to supply the first current; and

a second circuit configured to supply the element current.

According to the embodiments, it is possible to provide a magnetic head and a magnetic recording device capable of improving characteristics.

In the specification of the application, "perpendicular" and "parallel" refer to not only strictly perpendicular and strictly parallel but also include, for example, the fluctuation due to manufacturing processes, etc. It is sufficient to 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 magnetic heads and magnetic recording devices such as magnetic poles, elements, conductive parts, magnetic layers, non-magnetic layers, terminals, controllers, 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 heads, and magnetic recording devices practicable by an appropriate design modification by one skilled in the art based on the magnetic heads, and the magnetic recording 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 head comprising:

a first magnetic pole;

a second magnetic pole;

a conductive part electrically insulated from the first magnetic pole and the second magnetic pole;

a first terminal and a second terminal electrically connected to the conductive part;

an element part provided between the first magnetic pole and the second magnetic pole and electrically connected to the first magnetic pole and the second magnetic pole, the element part being conductive;

a third terminal electrically connected to the first magnetic pole; and

a fourth terminal electrically connected to the second magnetic pole,

a first magnetic pole temperature of the first magnetic pole in a first state being higher than a second magnetic pole temperature of the second magnetic pole in the first state, a first current being supplied between the first terminal and the second terminal in the first state,

wherein

the element part includes

a first magnetic pole side magnetic layer, and

a non-magnetic intermediate layer,

the first magnetic pole side magnetic layer is provided between the first magnetic pole and the non-magnetic intermediate layer,

the non-magnetic intermediate layer includes at least one selected from the group consisting of Cu, Au, Cr, V, Al and Ag, and

the first magnetic pole side magnetic layer includes

at least one selected from the group consisting of Fe, Co, and Ni, and

at least one selected from the group consisting of Cr, V, Mn, Ti, and Sc, and

the first magnetic pole side magnetic layer physically contacts the first magnetic pole and the non-magnetic intermediate layer,

the element part further includes a first stacked body,

the non-magnetic intermediate layer is between the first magnetic pole side magnetic layer and the first stacked body,

the first stacked body includes:

a first magnetic layer provided between the non-magnetic intermediate layer and the second magnetic pole,

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

a third magnetic layer provided between the second magnetic layer and the second magnetic pole,

a first non-magnetic layer provided between the first magnetic layer and the second magnetic layer, a second non-magnetic layer provided between the second magnetic layer and the third magnetic layer, and

a third non-magnetic layer provided between the third magnetic layer and the second magnetic pole.

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

in the first state, a current is not supplied between the third terminal and the fourth terminal.

3. The head according to claim **2**, wherein

in a first operation, the first current is supplied between the first terminal and the second terminal, and

in the first operation, an element current is supplied between the third terminal and the fourth terminal.

4. The head according to claim **3**, wherein

an orientation of the element current is an orientation from the fourth terminal to the third terminal.

5. The head according to claim **3**, wherein

in the first operation, a magnetic field corresponding to the first current is generated from the first magnetic pole.

6. The head according to claim **5**, wherein

an orientation of the magnetic field is configured to change according to an orientation of the first current.

7. The head according to claim **3**, wherein

in the first operation, information corresponding to an orientation of the first current is recorded on a magnetic recording medium.

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

the first magnetic pole includes a first magnetic pole face facing the magnetic recording medium,

the second magnetic pole includes a second magnetic pole face facing the magnetic recording medium, and

the first magnetic pole face is smaller than the second magnetic pole face.

9. A magnetic recording device, comprising:

the magnetic head according to claim **3**;

a first circuit configured to supply the first current; and

a second circuit configured to supply the element current.

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

in the first state, a first potential of the first magnetic pole is higher than a second potential of the second magnetic pole.

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

the second magnetic pole further includes a first region,

the element part includes a first region element, and

the first region element is provided between the first magnetic pole and the first region.

12. The head according to claim **11**, wherein

the second magnetic pole further includes a second region,

the first magnetic pole is between the second region and the first region,

the element part further includes a second region element, and

the second region element is provided between the second region and the first magnetic pole.

13. The head according to claim **11**, wherein

the second magnetic pole further includes a third region,

a second direction from the third region to the first magnetic pole crosses a first direction from the first magnetic pole to the first region,

the element part further includes a third region element, and

the third region element is provided between the third region and the first magnetic pole.

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

the second magnetic pole further includes a fourth region,

the first magnetic pole is between the third region and the fourth region in the second direction,

the element part further includes a fourth region element, and

the fourth region element is provided between the first magnetic pole and the fourth region.

15. The head according to claim **1**, wherein

the second non-magnetic layer includes at least one selected from the group consisting of Cu, Au, Cr, V, Al, and Ag.

16. The head according to claim **1**, wherein

the first non-magnetic layer includes at least one selected from the group consisting of Cu, Au, Cr, V, Al, and Ag.

17. The head according to claim **16**, wherein

the first stacked body further includes

a fourth magnetic layer provided between the third non-magnetic layer and the second magnetic pole, and

a fourth non-magnetic layer provided between the fourth magnetic layer and the second magnetic pole.

18. A magnetic head comprising:

a first magnetic pole;

a second magnetic pole;

a conductive part electrically insulated from the first magnetic pole and the second magnetic pole;

a first terminal and a second terminal electrically connected to the conductive part;

an element part provided between the first magnetic pole and the second magnetic pole and electrically connected to the first magnetic pole and the second magnetic pole, the element part being conductive;

a third terminal electrically connected to the first magnetic pole; and

a fourth terminal electrically connected to the second magnetic pole,

a first potential of the first magnetic pole in a first state being higher than a second potential of the second magnetic pole in the first state, a first current being supplied between the first terminal and the second terminal in the first state, and

a current being not supplied between the third terminal and the fourth terminal in the first state,

wherein

the element part includes

a first magnetic pole side magnetic layer, and

a non-magnetic intermediate layer,

the first magnetic pole side magnetic layer is provided between the first magnetic pole and the non-magnetic intermediate layer,

the non-magnetic intermediate layer includes at least one selected from the group consisting of Cu, Au, Cr, V, Al and Ag, and

the first magnetic pole side magnetic layer includes

at least one selected from the group consisting of Fe, Co, and Ni, and

at least one selected from the group consisting of Cr, V, Mn, Ti, and Sc,

the first magnetic pole side magnetic layer physically contacts the first magnetic pole and the non-magnetic intermediate layer,

the element part further includes a first stacked body,

the non-magnetic intermediate layer is between the first magnetic pole side magnetic layer and the first stacked body, the first stacked body includes:

a first magnetic layer provided between the non-magnetic intermediate layer and the second magnetic pole,

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

a third magnetic layer provided between the second magnetic layer and the second magnetic pole,

a first non-magnetic layer provided between the first magnetic layer and the second magnetic layer,

a second non-magnetic layer provided between the second magnetic layer and the third magnetic layer, and

a third non-magnetic layer provided between the third magnetic layer and the second magnetic pole.

19. The head according to claim **18**, wherein

the second non-magnetic layer includes at least one selected from the group consisting of Cu, Au, Cr, V, Al, and Ag.

20. The head according to claim **18**, wherein

the first non-magnetic layer includes at least one selected from the group consisting of Cu, Au, Cr, V, Al, and Ag.

21. The head according to claim **20**, wherein

the first stacked body further includes

a fourth magnetic layer provided between the third non-magnetic layer and the second magnetic pole, and

a fourth non-magnetic layer provided between the fourth magnetic layer and the second magnetic pole.

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