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(54) **PIEZOELECTRIC DRIVING ELEMENT**

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

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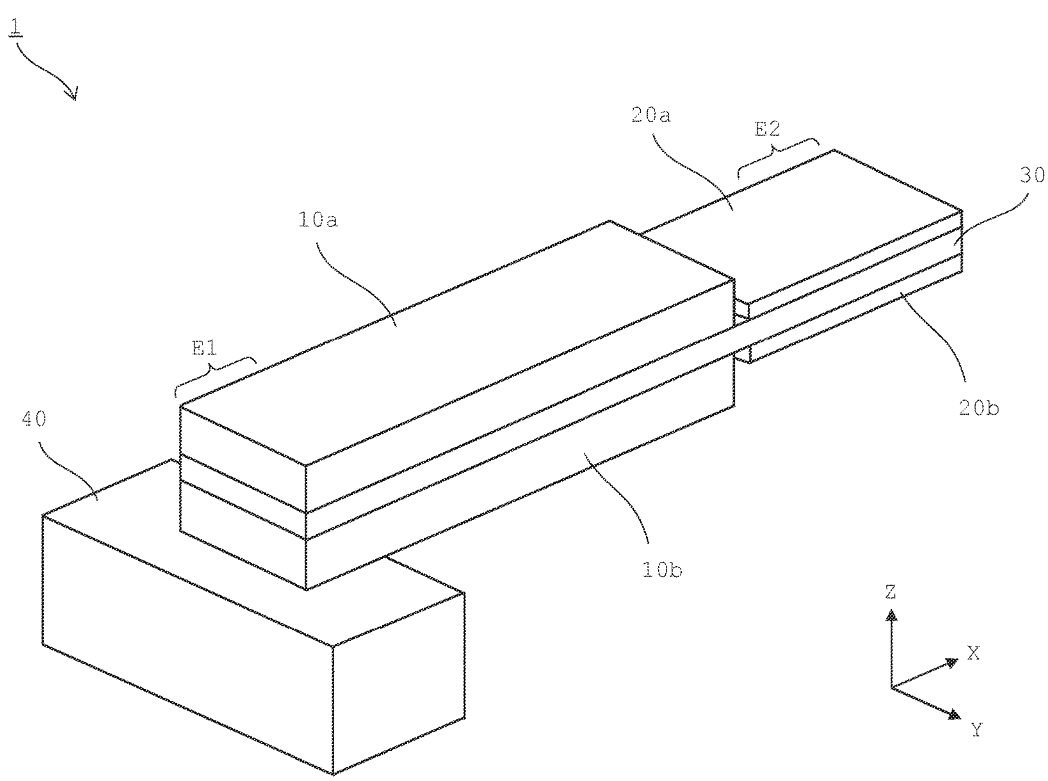
(57) **ABSTRACT**

A piezoelectric driving element is a cantilever-type piezoelectric driving element in which one end which is a fixed end is fixed to a support base and another end which is a free end is driven. The piezoelectric driving element includes: a first piezoelectric body disposed on the fixed end side; and a second piezoelectric body disposed on the free end side with respect to the fixed end. Here, a thickness of the second piezoelectric body is set to be smaller than a thickness of the first piezoelectric body.

EMBODIMENT 1



EMBODIMENT 1

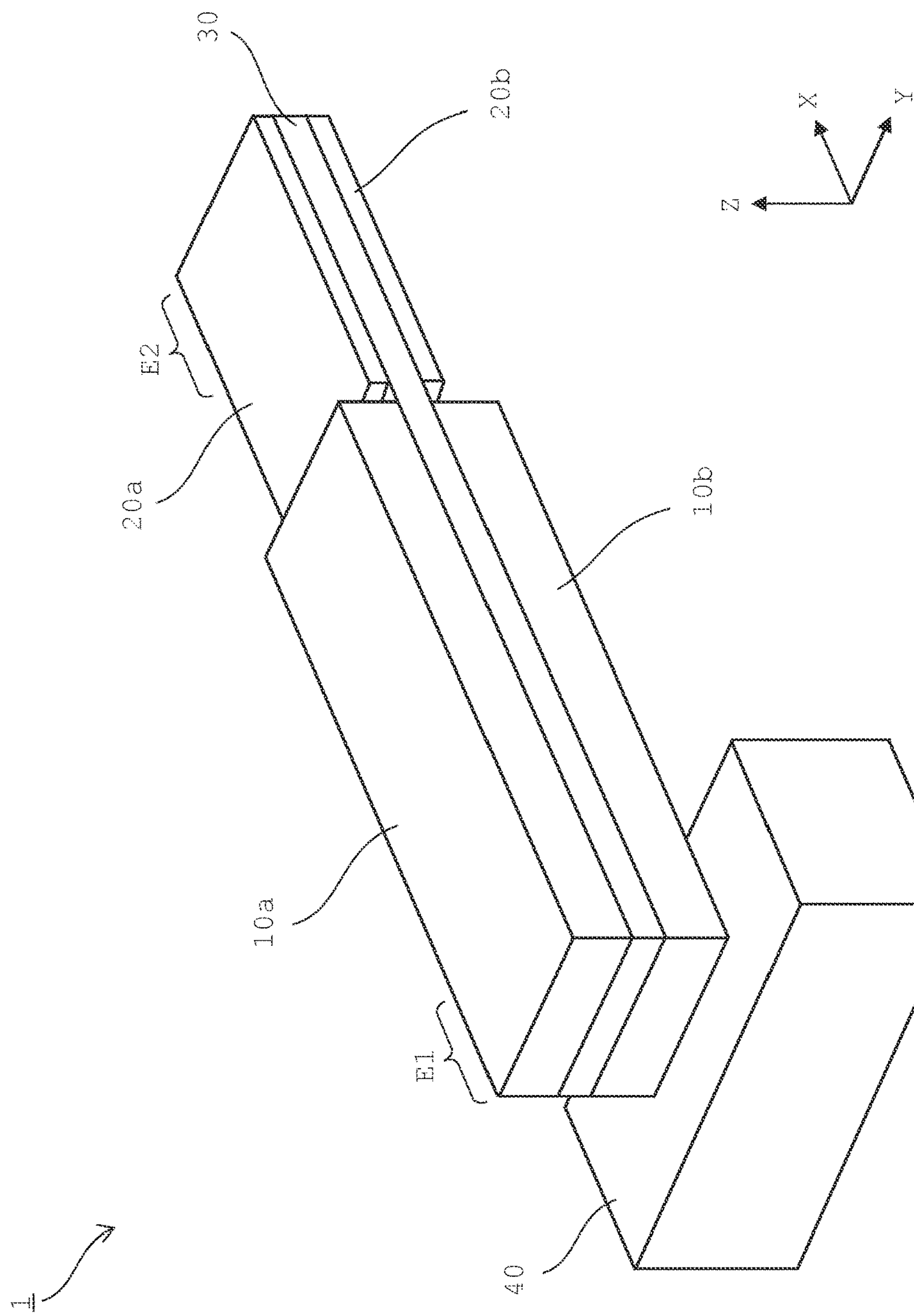
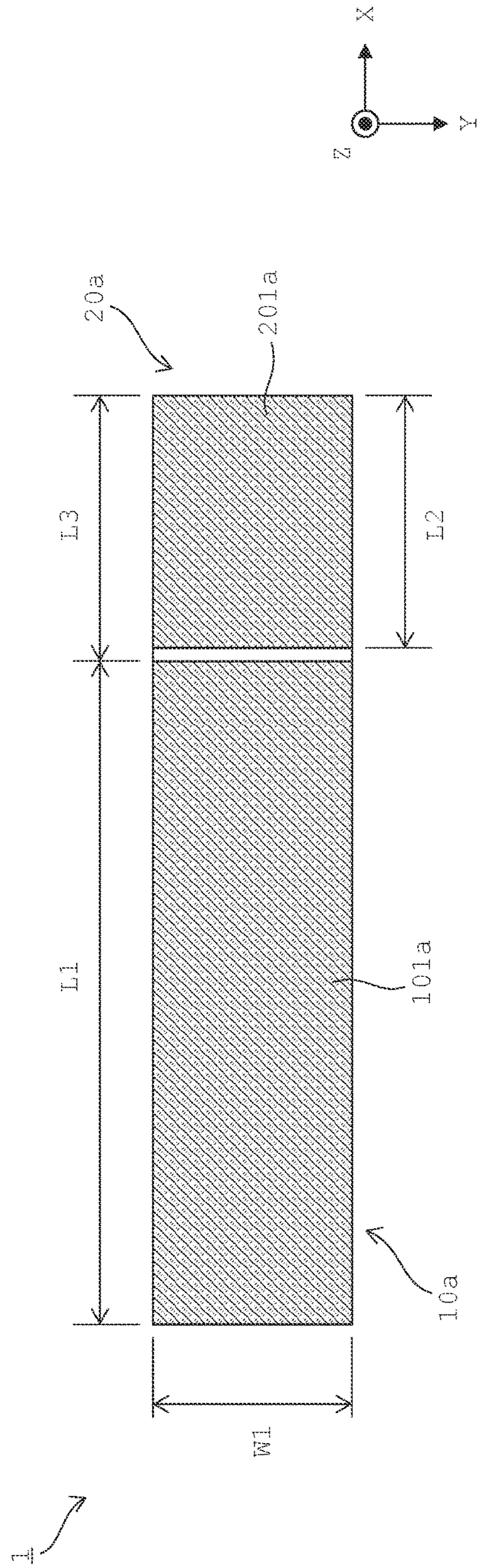


FIG. 1


X
Y
Z
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201a
L3
L2
L1
101a
10a
W1
1

FIG. 2A

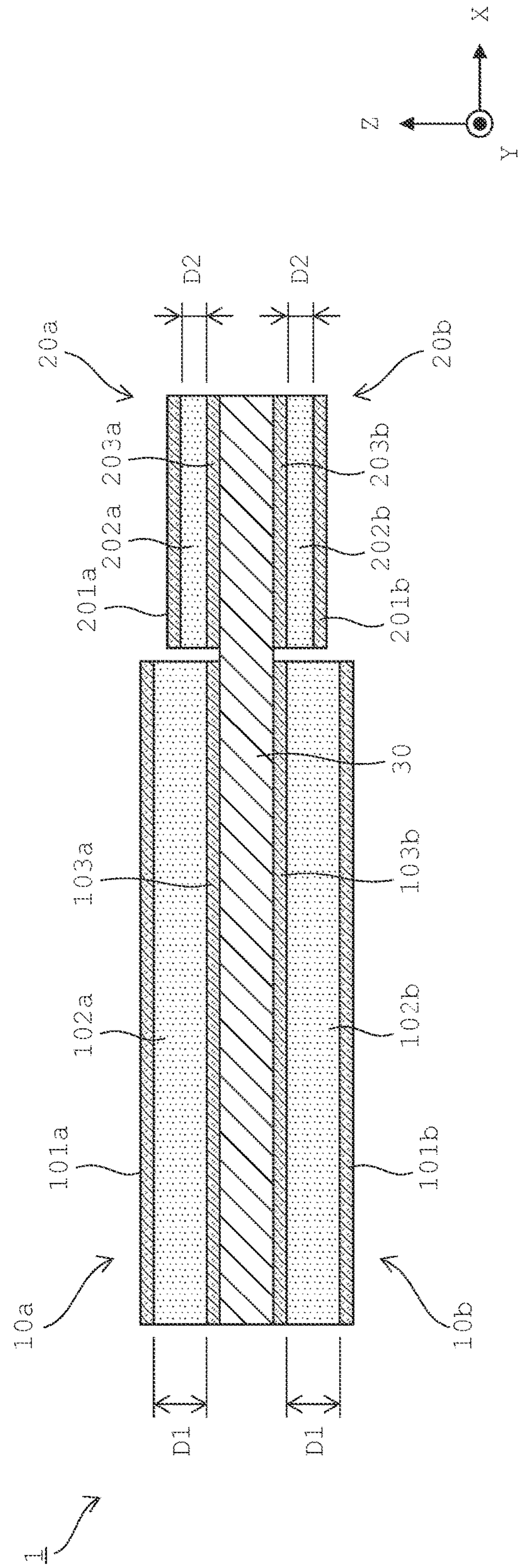

X
Z
Y
D2
D2
20a
20b
203a
203b
202a
202b
201a
201b
30
103a
103b
102a
102b
101a
101b
10a
10b
D1
D1
1

FIG. 2B

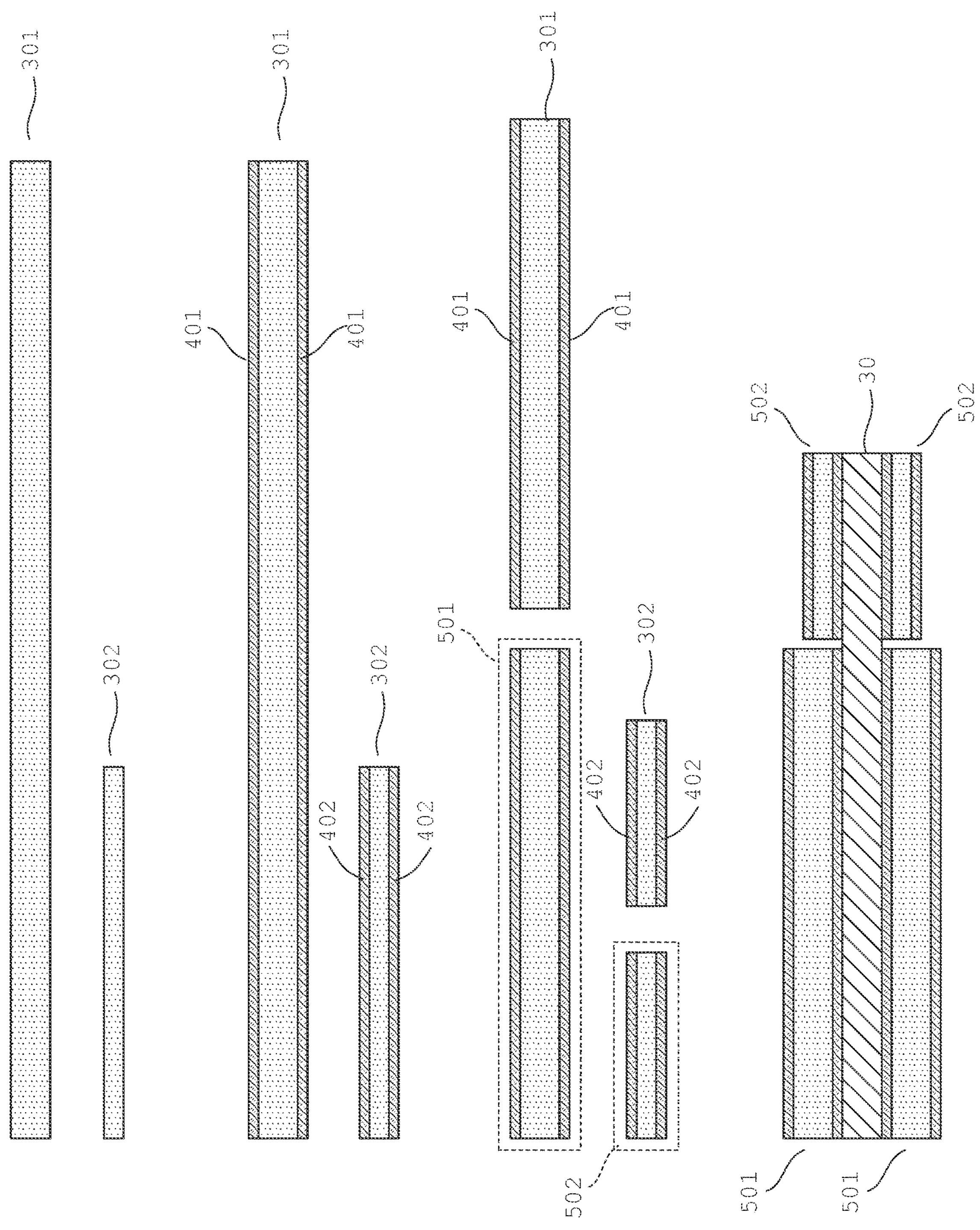


FIG. 3A

FIG. 3B

FIG. 3C

FIG. 3D

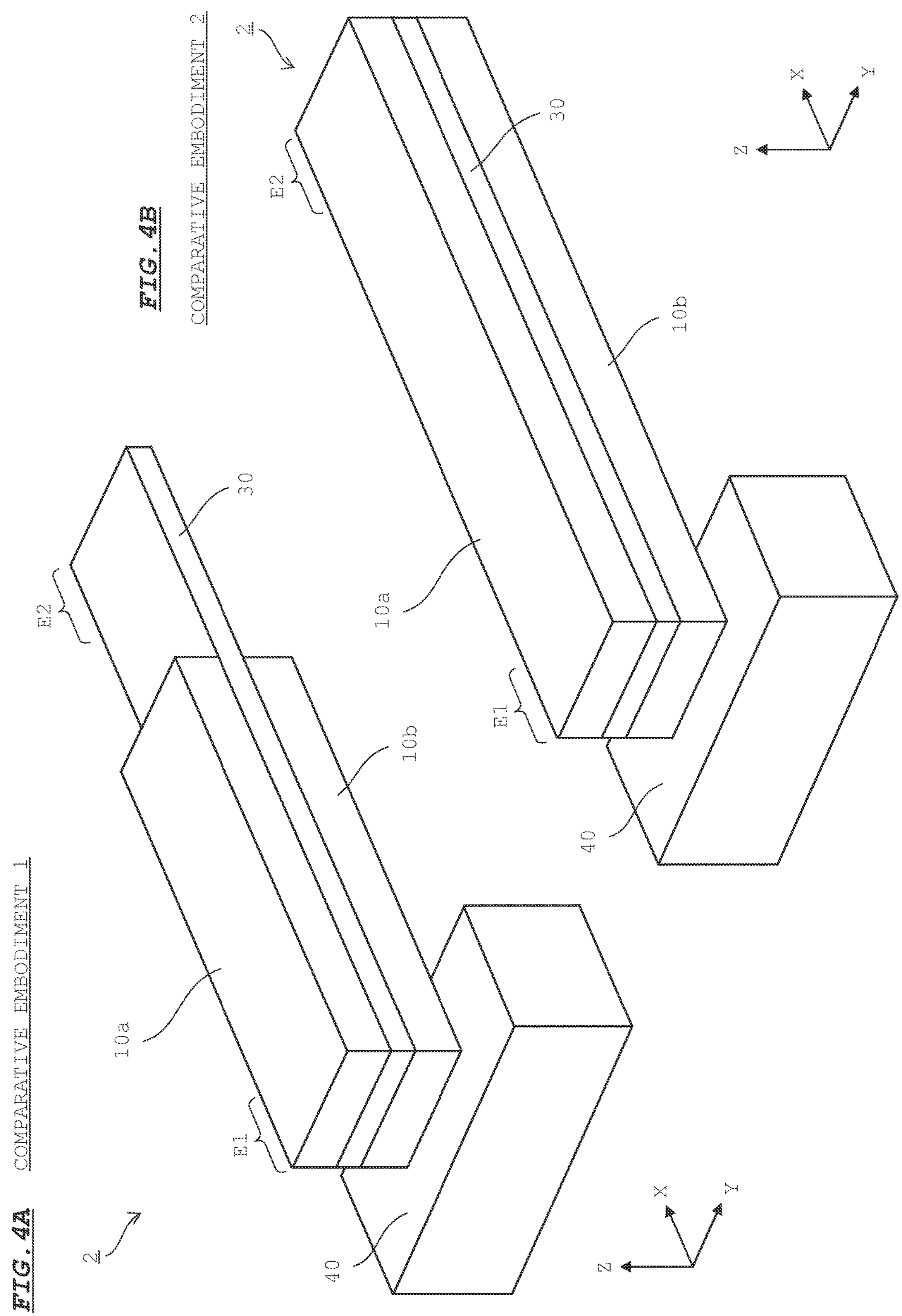

2
COMPARATIVE EMBODIMENT 1
10a
E1
40
E2
30
10b
X
Y
Z
COMPARATIVE EMBODIMENT 2
2
E2
30
10b
10a
E1
40
X
Y
Z

FIG. 4A

FIG. 4B

EMBODIMENT 2

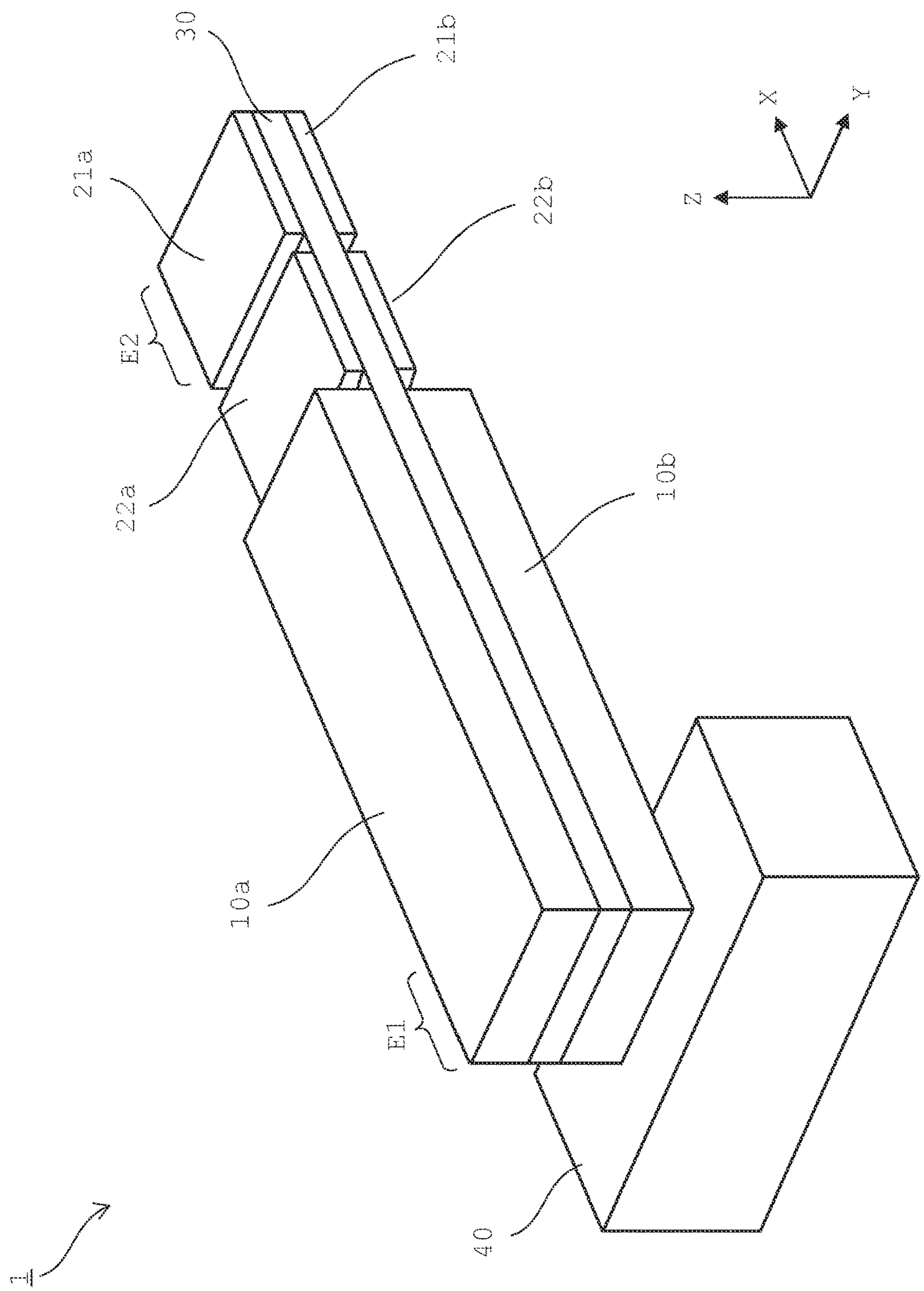


FIG. 5

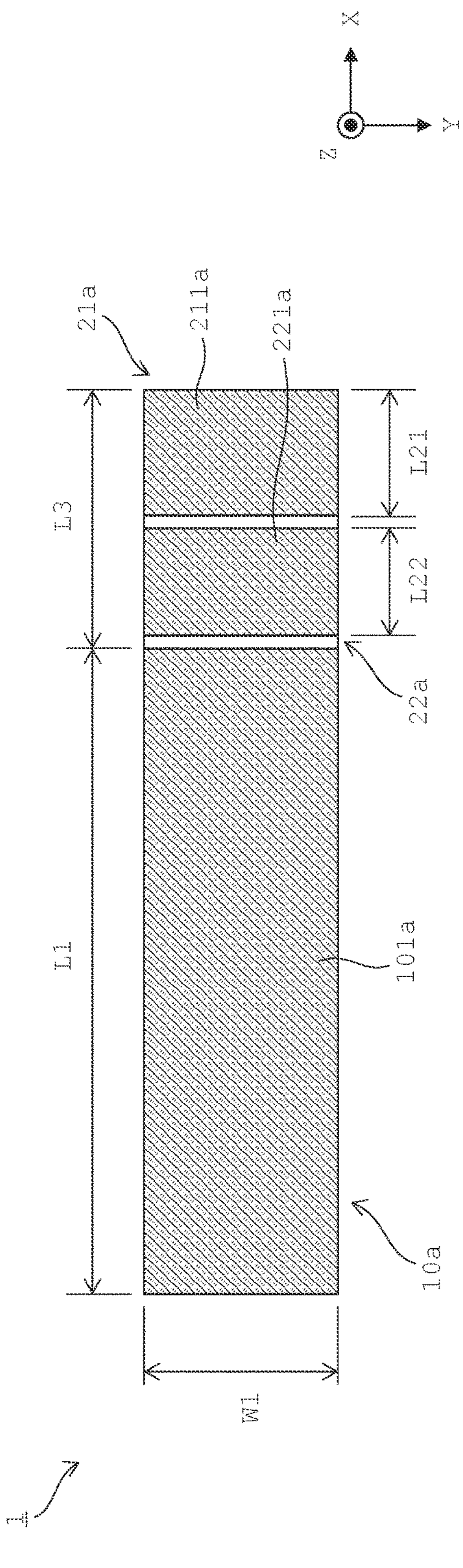

X
Y
Z
21a
211a
221a
L3
L21
L22
22a
L1
101a
10a
W1
1

FIG. 6A

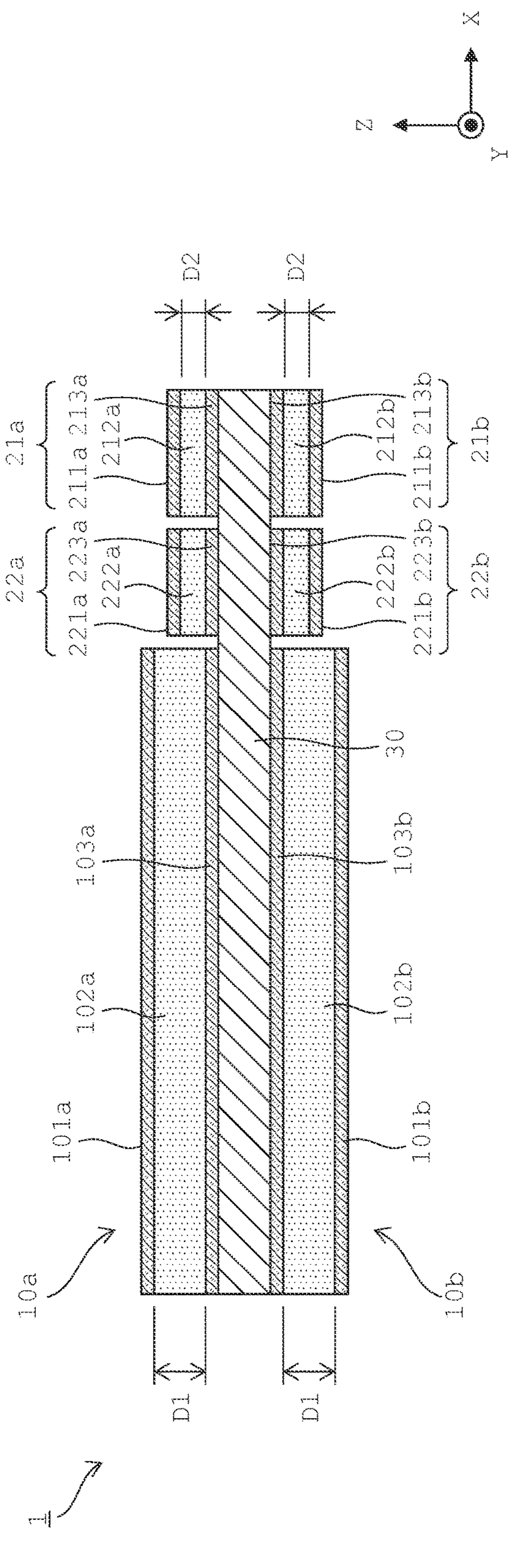

X
Z
Y
D2
D2
21a
213a
212a
211a
22a
223a
222a
221a
21b
213b
212b
211b
22b
223b
222b
221b
30
103a
103b
102a
102b
101a
101b
10a
10b
D1
D1
1

FIG. 6B

MODIFICATION

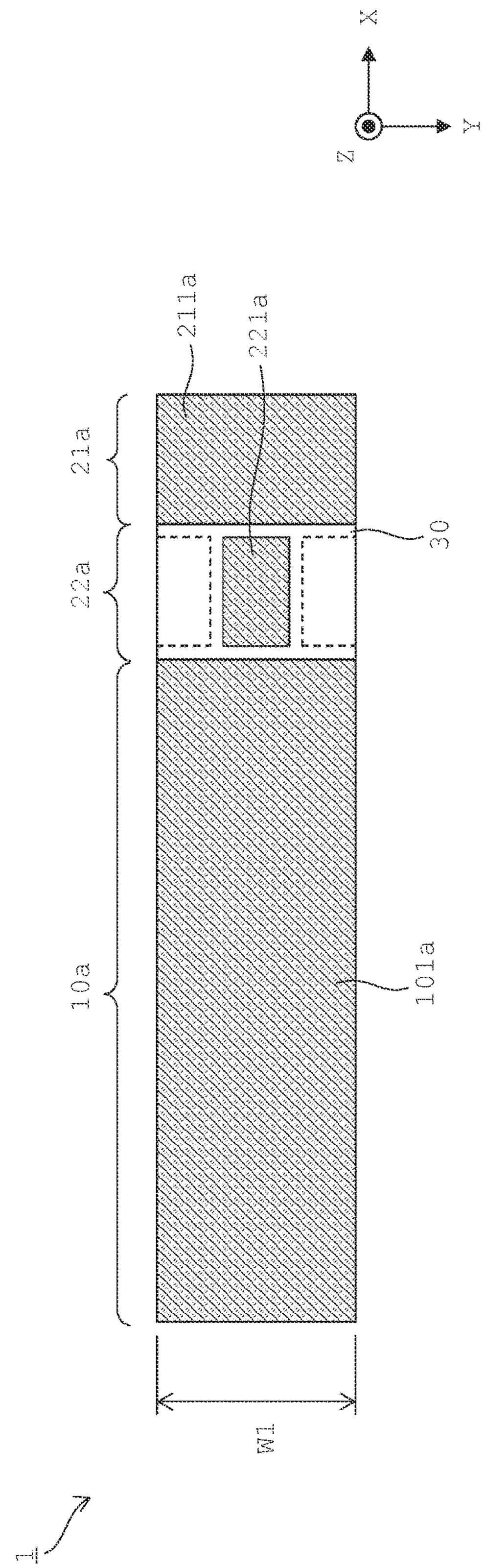


FIG. 7A

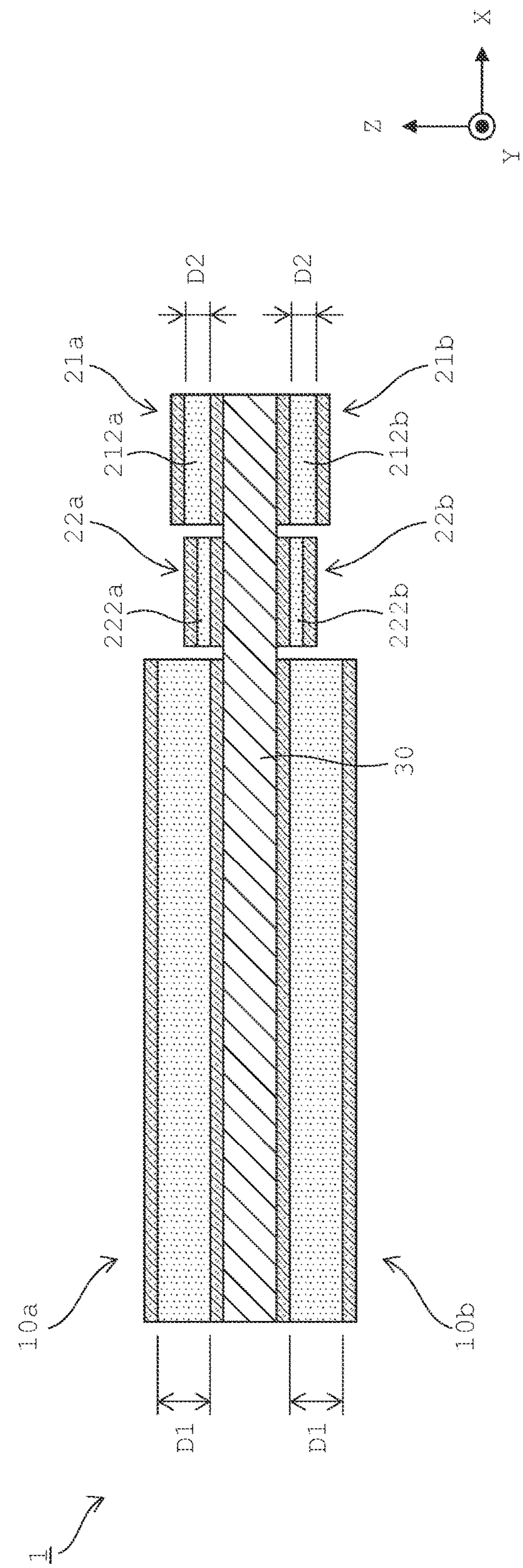


FIG. 7B

EMBODIMENT 3

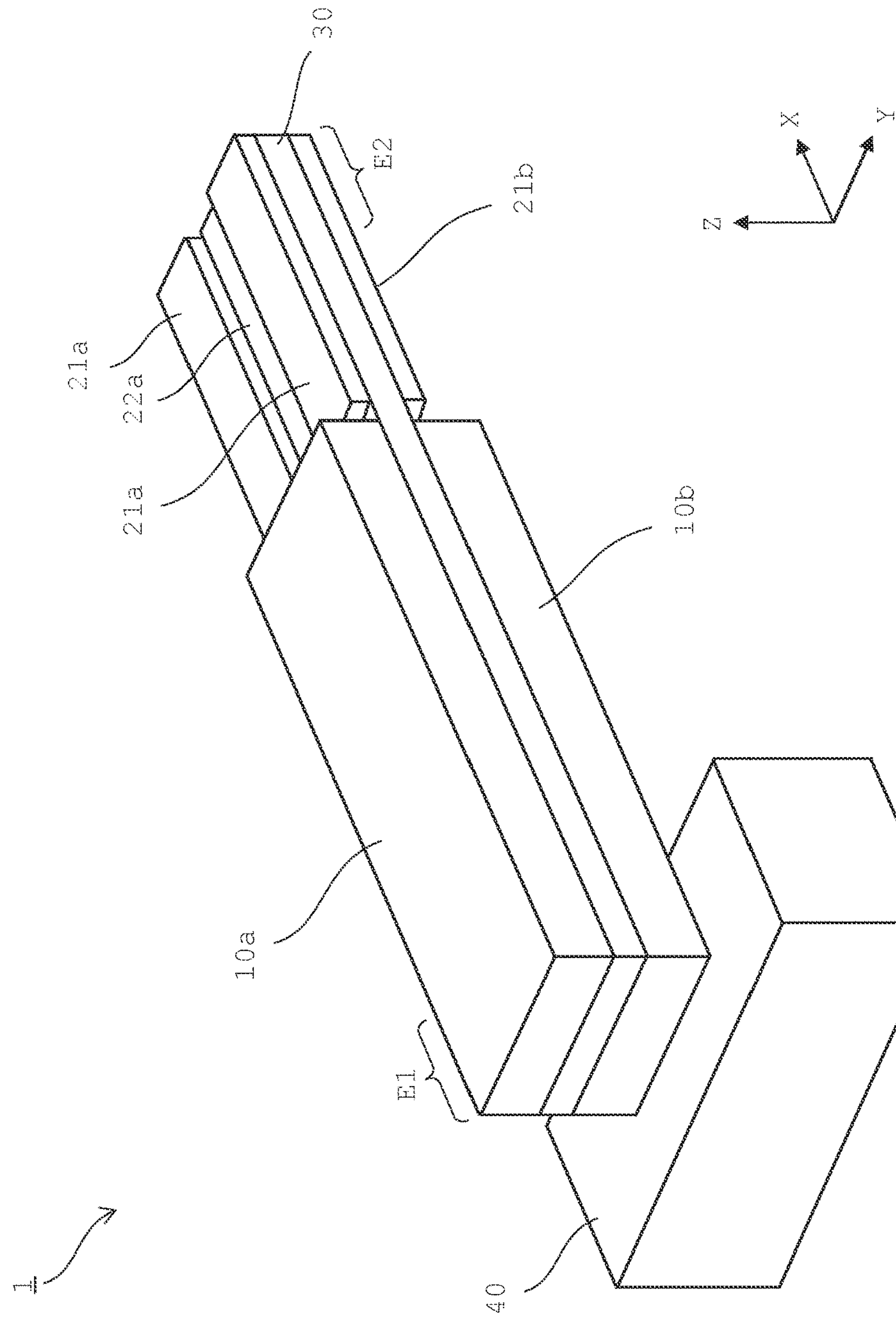


FIG. 8

FIG. 9A

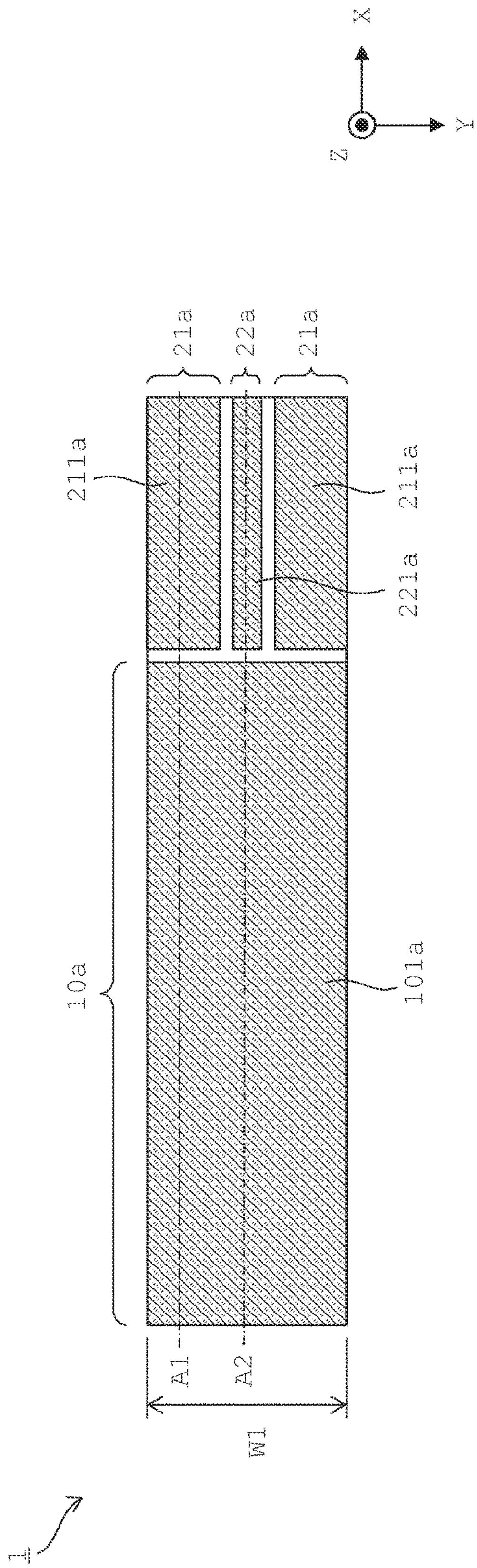
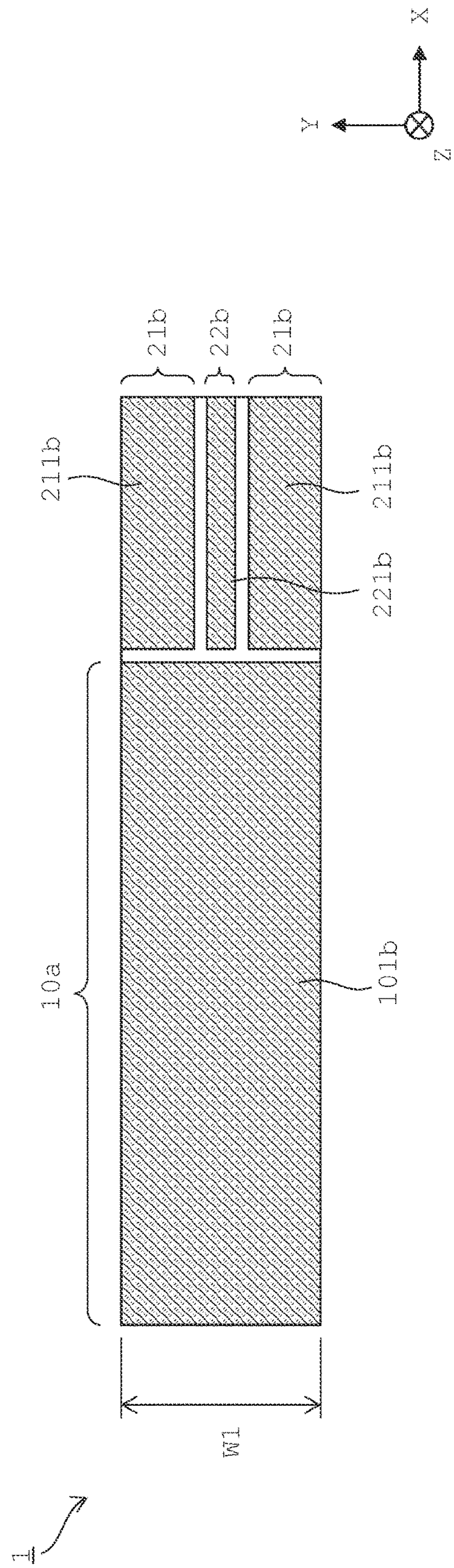

X
Y
Z
21a
22a
21a
211a
211a
221a
10a
101a
A1
A2
W1
1

FIG. 9B


X
Y
Z
21b
22b
21b
211b
211b
221b
10a
101b
W1
1

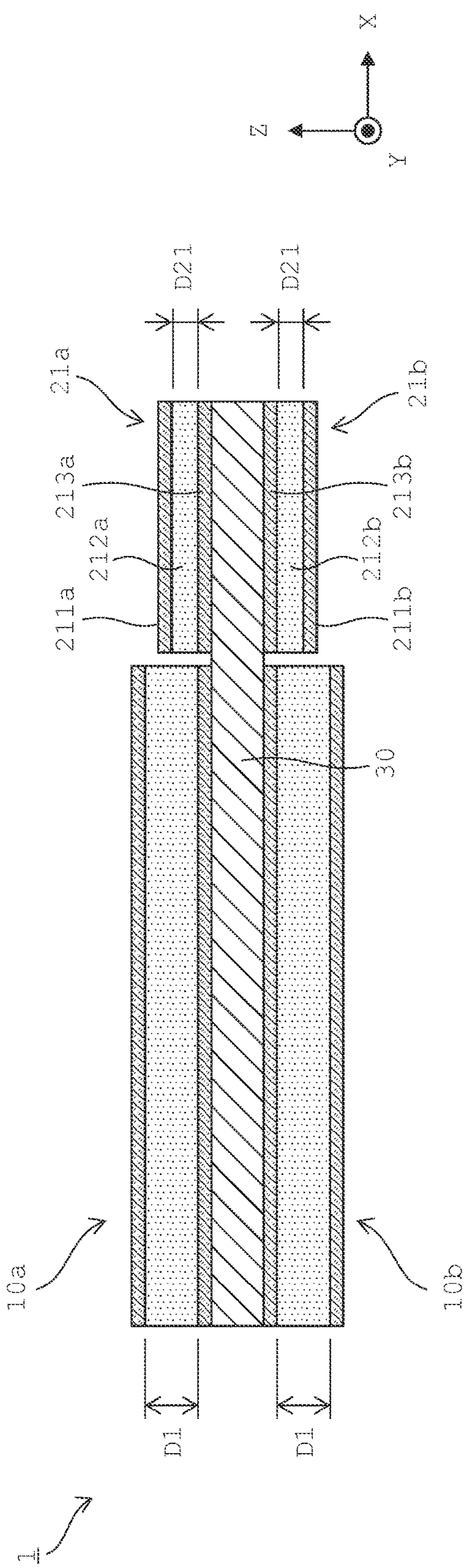


FIG. 10A

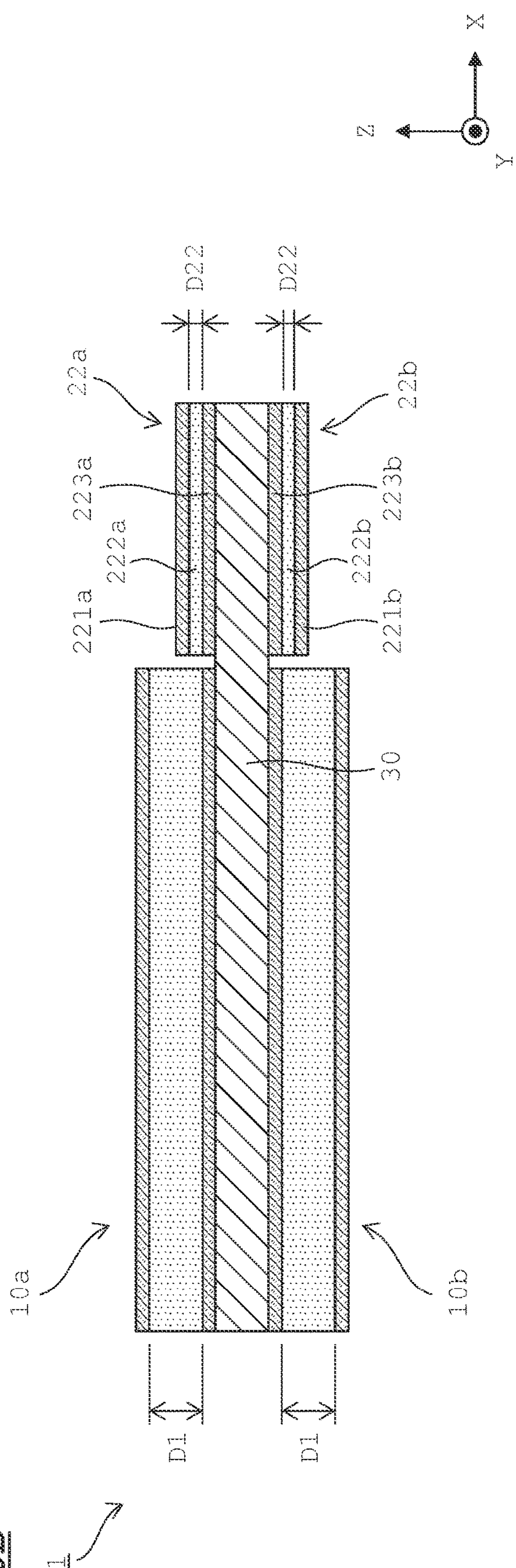


FIG. 10B

EMBODIMENT 4

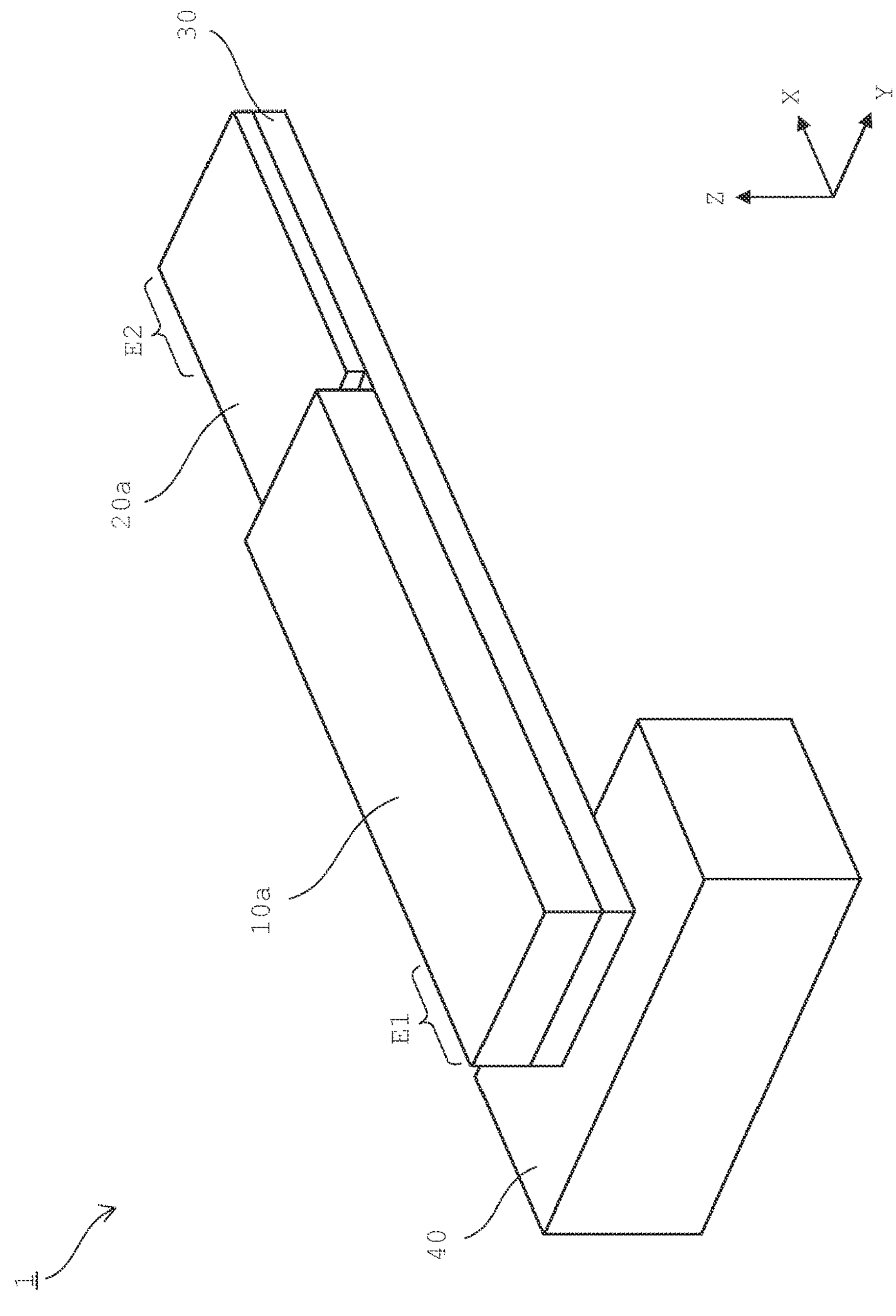


FIG. 11

EMBODIMENT 5

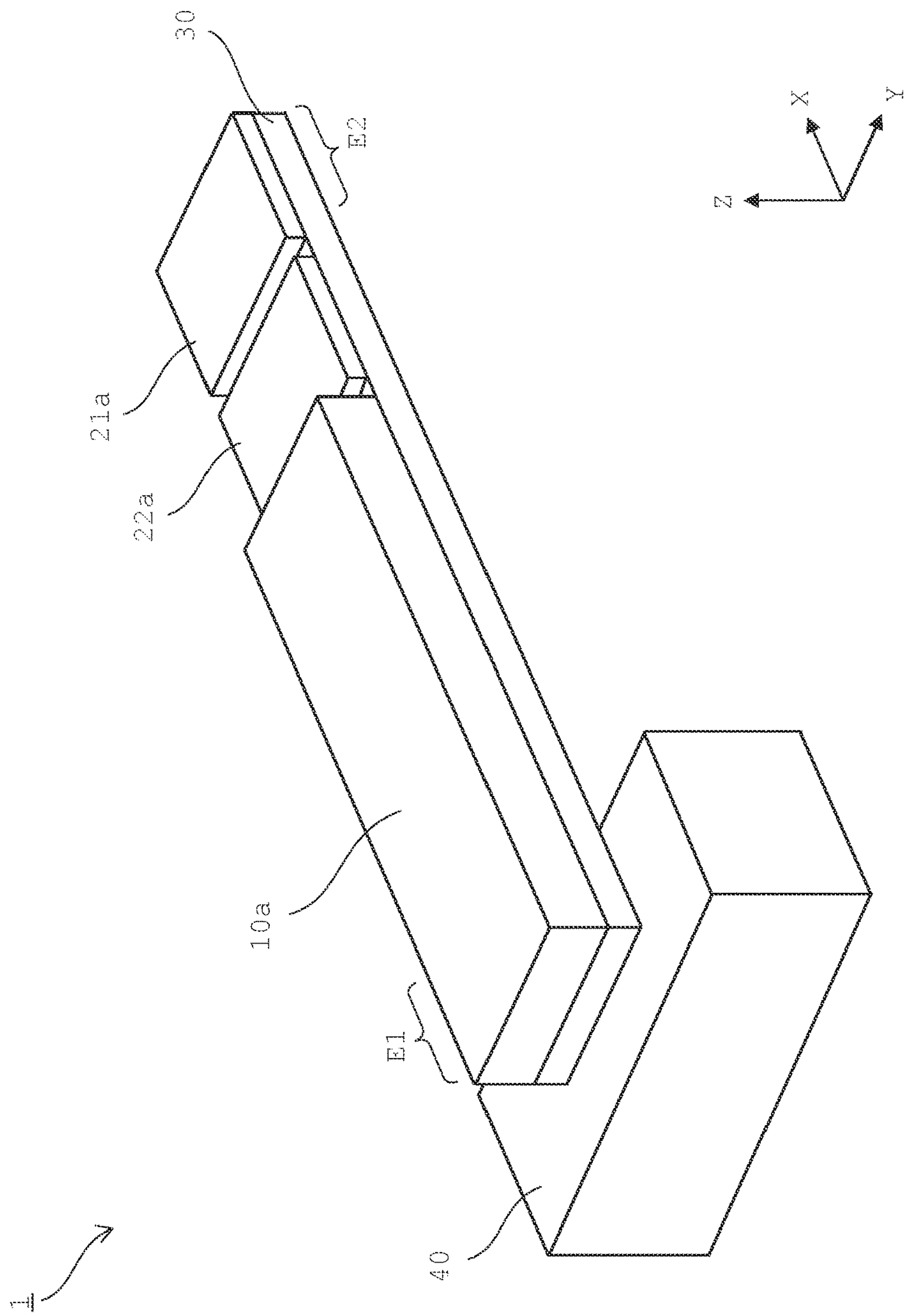


FIG. 12

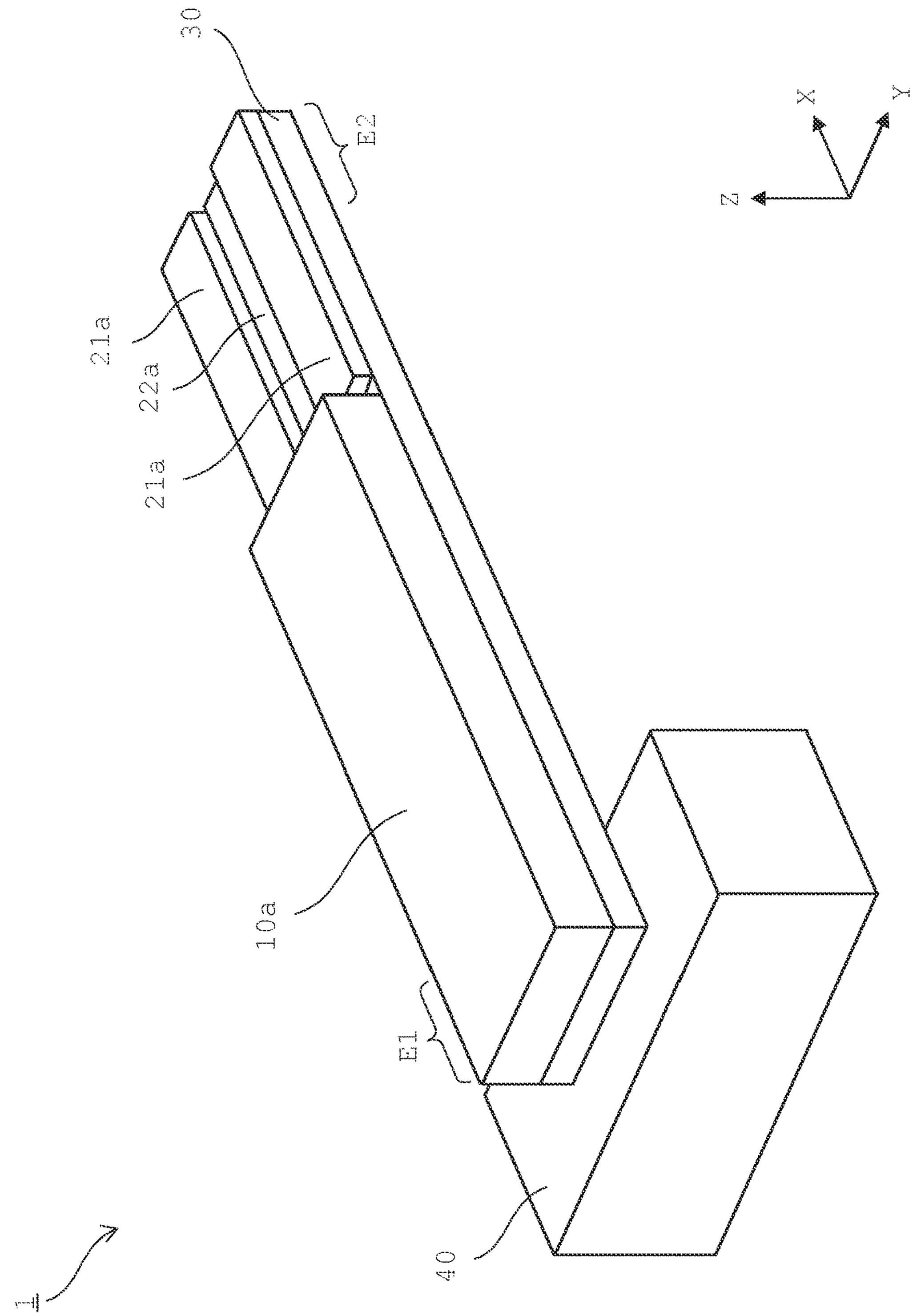
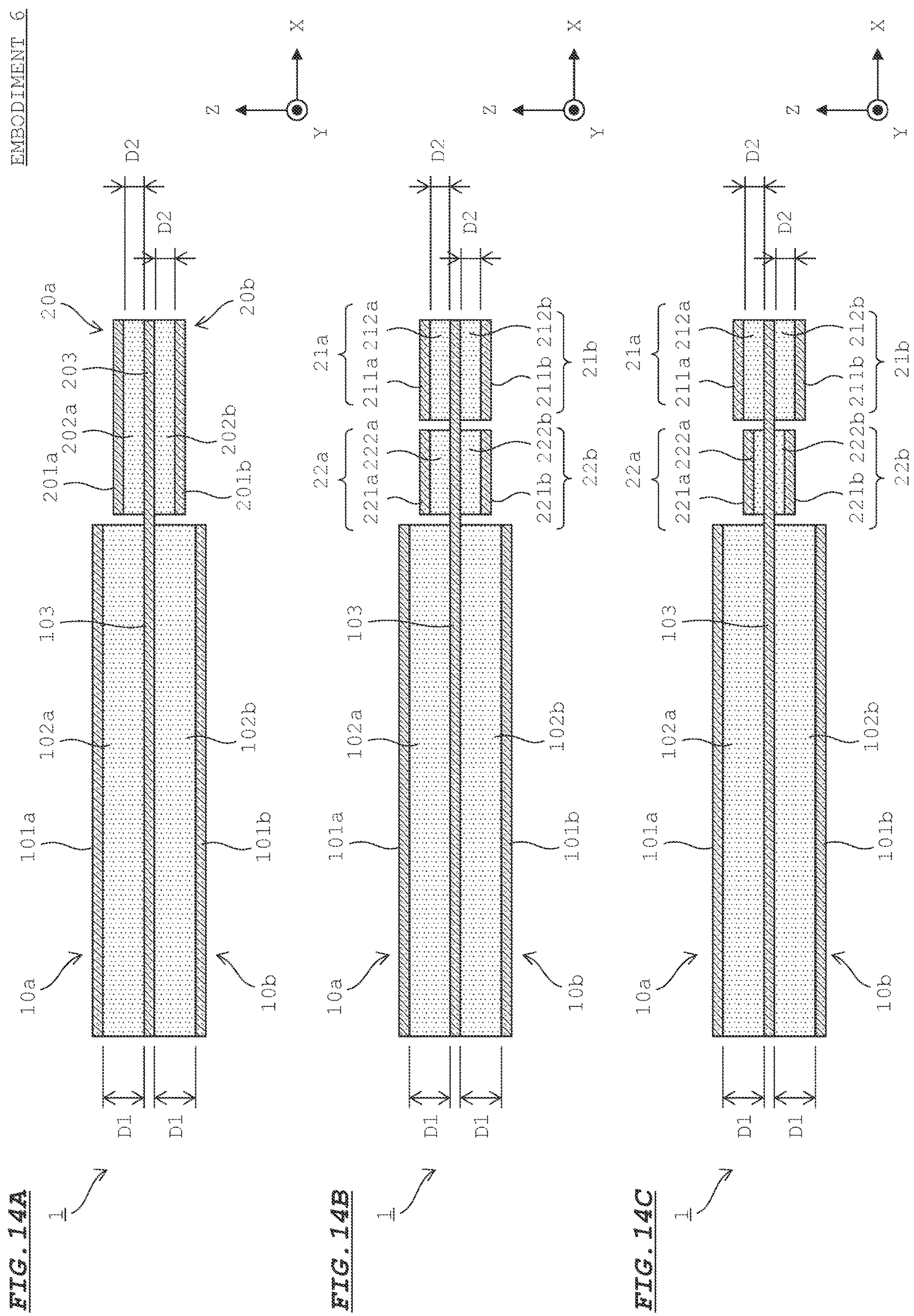


FIG. 13


EMBODIMENT 6
FIG. 14A
FIG. 14B
FIG. 14C
1
10a
10b
101a
101b
102a
102b
103
20a
20b
201a
201b
202a
202b
203
21a
21b
211a
211b
212a
212b
22a
22b
221a
221b
222a
222b
D1
D2
X
Y
Z

MODIFICATION

FIG. 15A

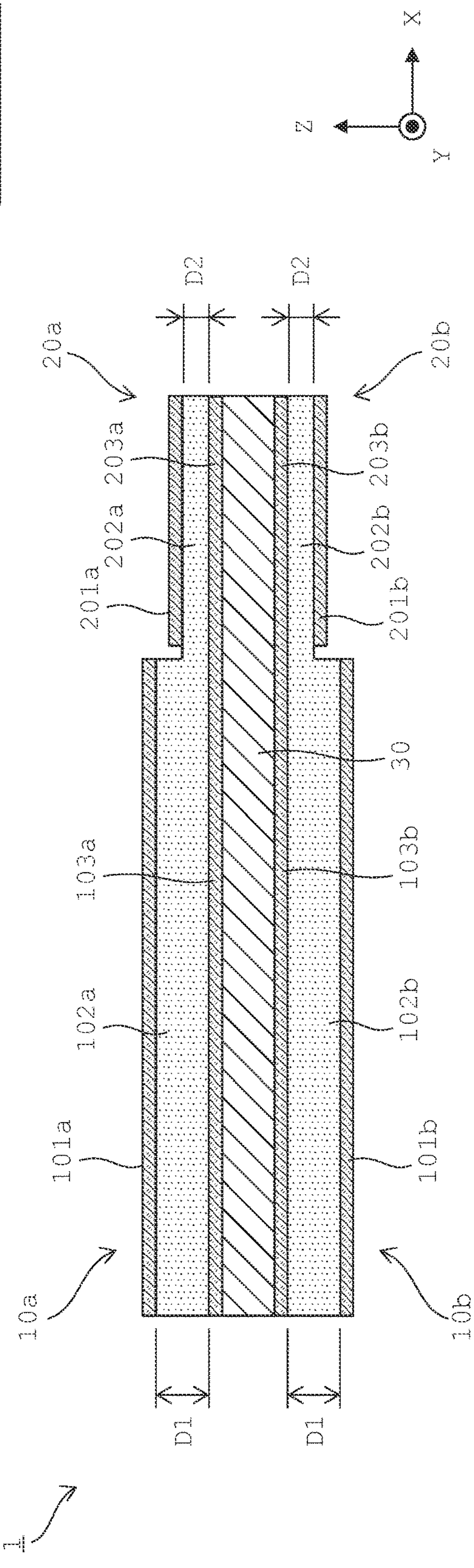
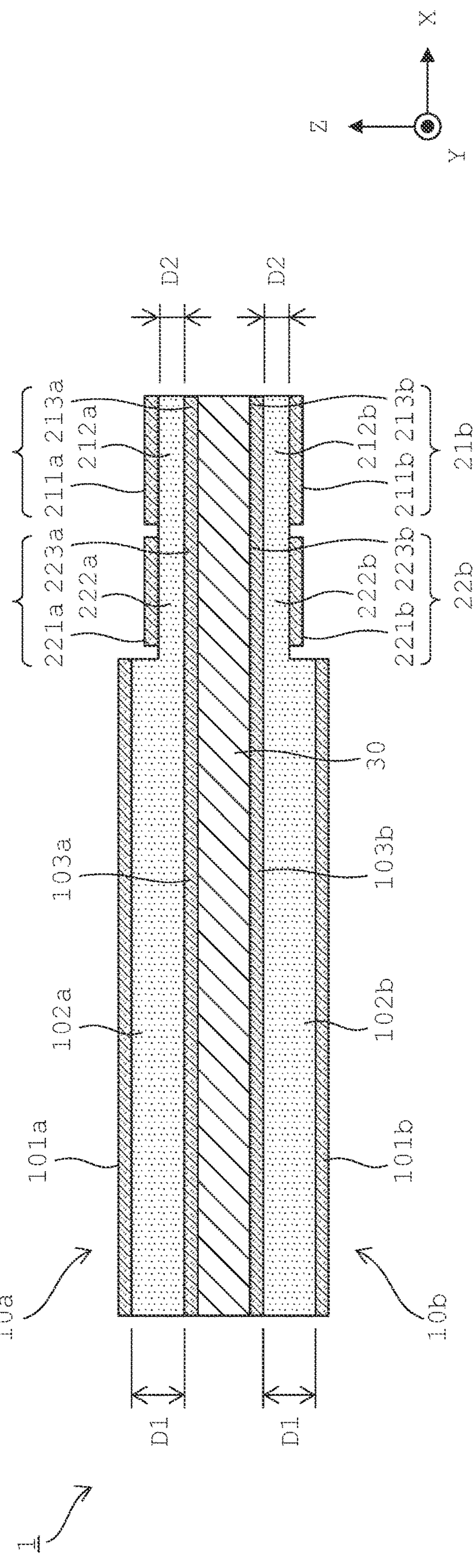


FIG. 15B



PIEZOELECTRIC DRIVING ELEMENT

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation of International Application No. PCT/JP2021/042775 filed on Nov. 22, 2021, entitled "PIEZOELECTRIC DRIVING ELEMENT", which claims priority under 35 U.S.C. Section 119 of Japanese Patent Application No. 2020-209955 filed on Dec. 18, 2020, entitled "PIEZOELECTRIC DRIVING ELEMENT". The disclosures of the above applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to a piezoelectric driving element that drives a to-be-driven body by a driving force generated from a piezoelectric body.

Description of Related Art

[0003] In recent years, piezoelectric driving elements that drive a to-be-driven body by a driving force generated from a piezoelectric body have been used in various devices. For example, a light deflector for deflecting light is configured by providing a reflection surface on a to-be-driven body. Also, a microswitch is configured by providing an electrode for opening and closing two terminals, on a to-be-driven body.

[0004] In these devices, a so-called cantilever-type piezoelectric driving element can be used. In the cantilever-type piezoelectric driving element, one end (fixed end) is fixed to a support base, and a to-be-driven body is disposed at another end (free end). In this configuration, it is required to increase the amount of displacement of the free end while increasing a force generated at the free end (hereinafter, referred to as "generated force"), and it is also required to increase the resonance frequency of the element according to the driving usage.

[0005] Japanese Patent No. 6051412 describes a configuration in which the amount of displacement of a free end can be increased by stacking vibration plates made of a plurality of materials on a piezoelectric body. Also, Japanese Patent No. 4413873 describes a configuration in which the total amount of displacement of a free end can be increased by disposing a plurality of piezoelectric layers and electrode layers.

[0006] In each of the configurations described in Japanese Patent No. 6051412 and Japanese Patent No. 4413873 above, the amount of displacement of the free end can be increased, but the amount of displacement of the free end, the generated force at the free end, and the resonance frequency cannot be increased together. In general, the amount of displacement of the free end, the generated force at the free end, and the resonance frequency of the element have a trade-off relationship with each other. For example, if the piezoelectric body is lengthened, the amount of displacement of the free end increases, but the generated force at the free end and the resonance frequency of the element decrease. In addition, if the thickness of the piezoelectric body is increased, the generated force at the free end and the resonance frequency of the element increase, but the amount of displacement of the free end decreases.

SUMMARY OF THE INVENTION

[0007] A main aspect of the present invention is directed to a cantilever-type piezoelectric driving element in which one end which is a fixed end is fixed to a support base and another end which is a free end is driven. The piezoelectric driving element according to this aspect includes: a first piezoelectric body disposed on the fixed end side; and a second piezoelectric body disposed on the free end side with respect to the fixed end. Here, a thickness of the second piezoelectric body is set to be smaller than a thickness of the first piezoelectric body.

[0008] In the driving element according to this aspect, since the thickness of the second piezoelectric body on the free end side is smaller, the mass of a portion at and near the free end is decreased, so that the resonance frequency of the element can be increased while the amount of displacement of the free end is kept large. In addition, since the portion at and near the free end is driven by the second piezoelectric body, the amount of displacement of and the generated force at the free end can be increased as compared to those in the case with only the first piezoelectric body. Therefore, in the piezoelectric driving element according to this aspect, the amount of displacement of and the generated force at the free end and the resonance frequency can all be increased.

[0009] The effects and the significance of the present invention will be further clarified by the description of the embodiments below. However, the embodiments below are merely examples for implementing the present invention. The present invention is not limited by the description of the embodiments below in any way.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a perspective view showing a configuration of a piezoelectric driving element according to Embodiment 1;

[0011] FIG. **2**A is a top view of the piezoelectric driving element according to Embodiment 1;

[0012] FIG. **2**B is a cross-sectional view of the piezoelectric driving element according to Embodiment 1;

[0013] FIG. **3**A to FIG. **3**D are each a diagram illustrating a process for forming the piezoelectric driving element according to Embodiment 1;

[0014] FIG. **4**A and FIG. **4**B are perspective views showing configurations of piezoelectric driving elements according to comparative examples, respectively;

[0015] FIG. **5** is a perspective view showing a configuration of a piezoelectric driving element according to Embodiment 2;

[0016] FIG. **6**A is a top view of the piezoelectric driving element according to Embodiment 2;

[0017] FIG. **6**B is a cross-sectional view of the piezoelectric driving element according to Embodiment 2;

[0018] FIG. **7**A is a top view showing a configuration of a piezoelectric driving element according to a modification of Embodiment 2;

[0019] FIG. **7**B is a cross-sectional view showing a configuration of a piezoelectric driving element according to another modification of Embodiment 2;

[0020] FIG. **8** is a perspective view showing a configuration of a piezoelectric driving element according to Embodiment 3;

[0021] FIG. **9**A and FIG. **9**B are a top view and a bottom view of the piezoelectric driving element according to Embodiment 3, respectively;

[0022] FIG. **10**A and FIG. **10**B are each a cross-sectional view of the piezoelectric driving element according to Embodiment 3;

[0023] FIG. **11** is a perspective view showing a configuration of a piezoelectric driving element according to Embodiment 4;

[0024] FIG. **12** is a perspective view showing a configuration of a piezoelectric driving element according to Embodiment 5;

[0025] FIG. **13** is a perspective view showing another configuration of the piezoelectric driving element according to Embodiment 5;

[0026] FIG. **14**A to FIG. **14**C are each a cross-sectional view of a piezoelectric driving element according to Embodiment 6; and

[0027] FIG. **15**A and FIG. **15**B are each a cross-sectional view of a piezoelectric driving element according to a modification.

[0028] It should be noted that the drawings are solely for description and do not limit the scope of the present invention by any degree.

DETAILED DESCRIPTION

[0029] Hereinafter, embodiments of the present invention will be described with reference to the drawings. For convenience, in each drawing, X, Y, and Z axes that are orthogonal to each other are additionally shown. The X-axis direction is the length direction of a piezoelectric body, and the Y-axis direction and the Z-axis direction are the width direction and the thickness direction of the piezoelectric body, respectively. The X-axis direction is also a direction connecting a fixed end and a free end of a piezoelectric driving element.

Embodiment 1

[0030] FIG. **1** is a perspective view showing a configuration of a piezoelectric driving element **1** according to Embodiment 1.

[0031] The piezoelectric driving element **1** includes first piezoelectric bodies **10***a* and **10***b*, second piezoelectric bodies **20***a* and **20***b*, a shim material **30**, and a support base **40**. The shim material **30** is made of, for example, a metal material such as copper (Cu), silicon, resin, ceramics made of an oxide, or the like, and the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b* are disposed on the upper surface and the lower surface of the shim material **30**, respectively. Here, the shim material **30** is a member that converts expansion and contraction of the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b* in the X-axis direction into bending in the Z-axis direction, maintains a predetermined length against the expansion and contraction of the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b* in the X-axis direction, and has flexibility that permits the bending in the Z-axis direction.

[0032] A structure composed of the first piezoelectric bodies **10***a* and **10***b*, the second piezoelectric bodies **20***a* and **20***b*, and the shim material **30** is fixed to the support base **40** at a fixed end E**1** which is one end portion in the length direction. The first piezoelectric bodies **10***a* and **10***b* are disposed on the fixed end E**1** side, and the second piezoelectric bodies **20***a* and **20***b* are disposed on a free end E**2** side which is a side opposite to the fixed end E**1**.

[0033] By a driving voltage, the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b* are caused to expand and contract in the X-axis direction, thereby driving the free end E**2** in the Z-axis direction. That is, when, by a driving voltage, the first piezoelectric body **10***a* and the second piezoelectric body **20***a* on the upper side are caused to contract in the X-axis direction, and the first piezoelectric body **10***b* and the second piezoelectric body **20***b* on the lower side are caused to expand in the X-axis direction, the free end E**2** is displaced in the Z-axis positive direction. Similarly, when the first piezoelectric body **10***a* and the second piezoelectric body **20***a* on the upper side are caused to expand in the X-axis direction, and the first piezoelectric body **10***b* and the second piezoelectric body **20***b* on the lower side are caused to contract in the X-axis direction, the free end E**2** is displaced in the Z-axis negative direction. A to-be-driven body such as a mirror or an electrode is disposed at the free end E**2**.

[0034] FIG. **2**A is a top view of the piezoelectric driving element **1**, and FIG. **2**B is a cross-sectional view of the piezoelectric driving element **1**. FIG. **2**B shows a cross-section of the piezoelectric driving element **1** obtained by cutting the piezoelectric driving element **1** at a middle position in the Y-axis direction along a plane parallel to the X-Z plane.

[0035] The first piezoelectric body **10***a* on the upper side is configured by stacking an electrode layer **101***a*, a piezoelectric layer **102***a*, and an electrode layer **103***a*. Similarly, the first piezoelectric body **10***b* on the lower side is configured by stacking an electrode layer **101***b*, a piezoelectric layer **102***b*, and an electrode layer **103***b*. In addition, the second piezoelectric body **20***a* on the upper side is configured by stacking an electrode layer **201***a*, a piezoelectric layer **202***a*, and an electrode layer **203***a*. Similarly, the second piezoelectric body **20***b* on the lower side is configured by stacking an electrode layer **201***b*, a piezoelectric layer **202***b*, and an electrode layer **203***b*.

[0036] The piezoelectric layers **102***a*, **102***b*, **201***a*, and **201***b* are made of, for example, a piezoelectric material having a high piezoelectric constant, such as lead zirconate titanate (PZT). The electrode layers **101***a*, **103***a*, **101***b*, **103***b*, **201***a*, **203***a*, **201***b*, and **203***b* are made of a material having low electrical resistance and high heat resistance, such as silver (Ag) and platinum (Pt). The first piezoelectric body **10***a* on the upper side is disposed by forming a layer structure composed of the piezoelectric layer **102***a* and the upper and lower electrode layers **101***a* and **103***a*, on the upper surface of the shim material **30**. The first piezoelectric body **10***b* on the lower side and the upper and lower second piezoelectric bodies **20***a* and **20***b* are also formed in the same manner.

[0037] As shown in FIG. **2**B, the thicknesses of the second piezoelectric bodies **20***a* and **20***b* are smaller than the thicknesses of the first piezoelectric bodies **10***a* and **10***b*. More specifically, a thickness D**2** of each of the piezoelectric layers **202***a* and **202***b* included in the second piezoelectric bodies **20***a* and **20***b* is smaller than a thickness D**1** of each of the piezoelectric layers **102***a* and **102***b* included in the first piezoelectric bodies **10***a* and **10***b*. For example, the thickness D**2** can be set to be about ⅕ of the thickness D**1**. As an example, the thickness D**1** is set to about 250 μm, and the thickness D2 is set to about 50 μm. The thicknesses of all the electrode layers are equal to each other.

[0038] As shown in FIG. **2**A, a length L**1** of each of the first piezoelectric bodies **10***a* and **10***b* is longer than a length L**2** of each of the second piezoelectric bodies **20***a* and **20***b*. Between the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b*, there is a gap corresponding to the difference between the length L**2** and a length L**3** of a portion, of the shim material **30**, on the free end E**2** side with respect to the first piezoelectric bodies **10***a* and **10***b*. The first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b* have the same width Wl.

[0039] The displacement of the free end E**2** shown in FIG. **1** is more influenced by driving by the first piezoelectric body **10***a* on the fixed end E**1** side than by driving by the second piezoelectric body **20***a* on the free end E**2** side. In order to suppress a decrease in the amount of displacement of the free end E**2**, the length L**1** of each of the first piezoelectric bodies **10***a* and **10***b* is preferably not smaller than the length L**2** of each of the second piezoelectric bodies **20***a* and **20***b*. In addition, in order to increase the generated force at the free end E**2** as much as possible by a driving force from the second piezoelectric bodies **20***a* and **20***b*, a difference ΔL between the length L**2** and the length L**3** is preferably as small as possible. For example, the length L**1** can be set to a length that is about four times the length L**2**, and the difference ΔL can be set to be about 1/10 of the length L**2**. As an example, the length L**1** is set to about 20 mm, and the length L**2** is set to about 5 mm. In addition, the difference ΔL is set to about 0.5 mm.

[0040] FIGS. **3**A to **3**D are each a diagram illustrating a process for forming the piezoelectric driving element **1**.

[0041] The method for forming the piezoelectric driving element **1** is not particularly limited. For example, the piezoelectric driving element **1** may be formed by separately producing each component and then joining the components. In addition, the piezoelectric driving element **1** may be formed using the technology for manufacturing micro electric mechanical systems (MEMS).

[0042] As an example of the forming method, a process in which the piezoelectric driving element **1** is formed by separately producing each component and then joining the components is shown here.

[0043] First, as shown in FIG. **3**A, PZT thin plates **301** and **302** are formed by press-molding and sintering ceramic powder containing Pb, Ti, and Zr. Next, as shown in FIG. **3**B, Ag electrodes **401** and **402** are formed on the front and back surfaces of the PZT thin plates **301** and **302** by printing. Furthermore, the PZT thin plates **301** and **302** having the Ag electrodes **401** and **402** printed on the front and back surfaces thereof are diced into individual pieces to form structures **501** and **502** as shown in FIG. **3**C. Then, the structures **501** and **502** are bonded to the front and back surfaces of the shim material **30** made of Cu, to form a structure shown in FIG. **3**D. The structure in FIG. **3**D is bonded to the upper surface of the support base **40** to form the piezoelectric driving element **1** in FIG. **1**.

[0044] In the piezoelectric driving element **1** having the above configuration, the amount of displacement of and the generated force at the free end E**2** and the resonance frequency of the element can all be increased. Hereinafter, this effect will be described in comparison with comparative examples.

[0045] FIGS. **4**A and **4**B are perspective views showing configurations of piezoelectric driving elements **2** according to Comparative Examples 1 and 2, respectively.

[0046] Compared to the configuration in FIG. **1**, the second piezoelectric bodies **20***a* and **20***b* are omitted in Comparative Example 1. That is, in the configuration of Comparative Example 1, on the free end E**2** side with respect to the first piezoelectric bodies **10***a* and **10***b*, no piezoelectric body is disposed, and only the shim material **30** is left. In addition, in Comparative Example 2, the second piezoelectric bodies **20***a* and **20***b* shown in FIG. **1** are omitted, and the first piezoelectric bodies **10***a* and **10***b* extend to the distal end.

[0047] For the configuration of Comparative Example 1 and the configuration of Comparative Example 2, the inventor of the present invention examined the amount of displacement of and the generated force at the free end E**2** and the resonance frequency by simulation.

[0048] In the examination, in each of Comparative Examples 1 and 2, the length in the X-axis direction of the fixed end E**1** was set to 5 mm. In addition, in Comparative Example 2, the length in the X-axis direction of each of the first piezoelectric bodies **10***a* and **10***b* excluding the fixed end E**1** was set to 26 mm, the thickness of each of the first piezoelectric bodies **10***a* and **10***b* was set to 0.3 mm, and the thickness of the shim material **30** was set to 0.1 mm. In Comparative Example 1, the length in the X-axis direction of a distal end portion at which the first piezoelectric bodies **10***a* and **10***b* were removed was set to 5 mm, and the length in the X-axis direction of each of the first piezoelectric bodies **10***a* and **10***b* excluding the fixed end E**1** was set to 21 mm. The thickness of each of the first piezoelectric bodies **10***a* and **10***b* and the thickness of the shim material **30** in Comparative Example 1 were set to 0.3 mm and 0.1 mm, respectively, as in Comparative Example 2.

[0049] In the configuration of Comparative Example 2, when the first piezoelectric bodies **10***a* and **10***b* were driven at a predetermined voltage, the amount of displacement of the free end E**2** was 128 μm, and the resonance frequency of the free end E**2** was 525 Hz. Meanwhile, in the configuration of Comparative Example 1, when the first piezoelectric bodies **10***a* and **10***b* were driven at the same voltage, the amount of displacement of the free end E**2** was 122 μm, and the resonance frequency of the free end E**2** was 725 Hz. Thus, in the configuration of Comparative Example 1, by removing the first piezoelectric bodies **10***a* and **10***b* at the distal end portion, the resonance frequency of the element was significantly increased while the amount of displacement of the free end E**2** was maintained to be substantially the same amount.

[0050] However, in the configuration of Comparative Example 1, since there is no piezoelectric body at the distal end portion, the generated force at the free end E**2** is decreased.

[0051] On the other hand, in the configuration in FIG. **1**, since the second piezoelectric bodies **20***a* and **20***b* are disposed on the free end E**2** side, the generated force at the free end E**2** is increased by the driving force generated from the second piezoelectric bodies **20***a* and **20***b*, while the rigidity of the free end E**2** is increased. In addition, in the configuration in FIG. **1**, since the thickness of each of the second piezoelectric bodies **20***a* and **20***b* is smaller than the thickness of each of the first piezoelectric bodies **10***a* and **10***b*, a significant decrease in the resonance frequency of the free end E2 due to the second piezoelectric bodies **20***a* and **20***b* being disposed is suppressed. Therefore, in the configuration in FIG. **1**, the resonance frequency of the element can be increased while the amount of displacement of and the generated force at the free end E2 are kept large.

[0052] The thickness of each of the second piezoelectric bodies **20***a* and **20***b* is set to a thickness that allows a significant decrease in the amount of displacement of and the resonance frequency at the free end E2 to be suppressed while increasing the generated force at the free end E2. From this viewpoint, the thickness D2 of each of the second piezoelectric bodies **20***a* and **20***b* is preferably set to be about ⅕ of the thickness D1 of each of the first piezoelectric bodies **10***a* and **10***b*. As an example, the thickness D1 of each of the first piezoelectric bodies **10***a* and **10***b* can be set to about 250 μm, and the thickness D2 of each of the second piezoelectric bodies **20***a* and **20***b* can be set to about 50 μm.

Effects of Embodiment 1

[0053] According to Embodiment 1 described above, the following effects are achieved.

[0054] Since the thicknesses of the second piezoelectric bodies **20***a* and **20***b* on the free end E2 side are smaller as shown in FIG. **1** and FIG. **2**B, the mass of a portion at and near the free end E2 is decreased, so that the resonance frequency of the free end E2 can be increased while the amount of displacement of the free end E2 is kept large. In addition, since the portion at and near the free end E2 is driven by the second piezoelectric bodies **20***a* and **20***b*, the amount of displacement of and the generated force at the free end E2 can be increased as compared to those in the case with only the first piezoelectric bodies **10***a* and **10***b*. Therefore, the resonance frequency of the element can be increased while the amount of displacement of and the generated force at the free end E2 are kept large.

[0055] Since the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b* are disposed on both of the upper and lower sides of the shim material **30** as shown in FIG. **1**, the driving forces by the piezoelectric bodies can be increased. Accordingly, the amount of displacement of and the generated force at the free end E2 can be effectively increased.

Embodiment 2

[0056] In Embodiment 1 described above, one second piezoelectric body **20***a* and one second piezoelectric body **20***b* are disposed on the upper and lower surfaces of the shim material **30**, respectively, but in Embodiment 2, two second piezoelectric bodies are disposed on each of the upper and lower surfaces of the shim material **30**.

[0057] FIG. **5** is a perspective view of a configuration of the piezoelectric driving element **1** according to Embodiment 2.

[0058] As shown in FIG. **5**, in Embodiment 2, second piezoelectric bodies **21***a* and **22***a* on the upper side are disposed on the upper surface of the shim material **30** so as to be aligned in a direction (X-axis direction) from the fixed end E1 toward the free end E2, and second piezoelectric bodies **21***b* and **22***b* on the lower side are disposed on the lower surface of the shim material **30** so as to be aligned in the direction (X-axis direction) from the fixed end E1 toward the free end E2. The lengths of the second piezoelectric bodies **21***a* and **21***b* in the X-axis direction are equal to each other, and the lengths of the second piezoelectric bodies **22***a* and **22***b* in the X-axis direction are equal to each other. Gaps are provided between the second piezoelectric bodies **21***a* and **21***b* and the second piezoelectric bodies **22***a* and **22***b*, and gaps are provided between the second piezoelectric bodies **22***a* and **22***b* and the first piezoelectric bodies **10***a* and **10***b*. The configurations of the first piezoelectric bodies **10***a* and **10***b* are the same as in Embodiment 1 described above.

[0059] FIG. **6**A is a top view of the piezoelectric driving element **1** according to Embodiment 2, and FIG. **6**B is a cross-sectional view of the piezoelectric driving element **1** according to Embodiment 2. FIG. **6**B shows a cross-section of the piezoelectric driving element **1** obtained by cutting the piezoelectric driving element **1** at a middle position in the Y-axis direction along a plane parallel to the X-Z plane.

[0060] Similar to the second piezoelectric bodies **20***a* and **20***b* in Embodiment 1 described above, the second piezoelectric body **21***a* is configured by stacking electrode layers **211***a* and **213***a* above and below a piezoelectric layer **212***a*, respectively, and the second piezoelectric body **21***b* is configured by stacking electrode layers **211***b* and **213***b* above and below a piezoelectric layer **212***b*, respectively. Similarly, the second piezoelectric body **22***a* is configured by stacking electrode layers **221***a* and **223***a* above and below a piezoelectric layer **222***a*, respectively, and the second piezoelectric body **22***b* is configured by stacking electrode layers **221***b* and **223***b* above and below a piezoelectric layer **222***b*, respectively.

[0061] The thickness D2 of each of the piezoelectric layers **212***a*, **212***b*, **222***a*, and **222***b* in the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* is smaller than the thickness D1 of each of the piezoelectric layers **102***a* and **102***b* of the first piezoelectric bodies **10***a* and **10***b* as in Embodiment 1 described above. The thicknesses of all the electrode layers are equal to each other. Therefore, the thickness of each of the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* is smaller than the thickness of each of the first piezoelectric bodies **10***a* and **10***b*.

[0062] The second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are formed on the upper surface or the lower surface of the shim material **30** by the same method as shown in FIGS. **3**A to **3**D in Embodiment 1 described above. In the process in FIG. **3**B, the structure on the lower side of FIG. **3**B is divided into four individual pieces according to the lengths of the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b*. In the process in FIG. **3**D, each of the four individualized structures is bonded at the corresponding position on the upper surface or the lower surface of the shim material **30**. Thus, a structure shown in FIG. **6**B is formed. As in Embodiment 1 described above, the method for forming the piezoelectric driving element **1** is not limited to this method.

[0063] In Embodiment 2, for example, the second piezoelectric bodies **21***a* and **21***b* on the distal end side are used for driving the free end E2, and the second piezoelectric bodies **22***a* and **22***b* on the proximal side are used for detecting strain of the free end E2. When the free end E2 is displaced in the Z-axis direction, one of the upper and lower second piezoelectric bodies **22***a* and **22***b* expands, and the other thereof contracts. At this time, the amount of electric charge corresponding to the amount of bending (amount of displacement) of the free end E2 can be detected by detecting electric charge generated in the piezoelectric layers **222***a* and **222***b*, at the electrode layers **221***a*, **223***a*, **221***b*, and **223***b*.

[0064] Thus, by using the second piezoelectric bodies **22***a* and **22***b* for strain detection, it is possible to monitor a signal corresponding to the amount of displacement of the free end E**2** when the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **21***a* and **21***b* are driven. Accordingly, for example, feedback control, such as adjusting a voltage applied to the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **21***a* and **21***b*, such that the free end E**2** is displaced in a target displacement amount, can be performed.

[0065] In this case, a length L**21** in the X-axis direction of each of the second piezoelectric bodies **21***a* and **21***b* and a length L**22** in the X-axis direction of each of the second piezoelectric bodies **22***a* and **22***b* are set to lengths that allow an appropriate force to be generated at the free end E**2** by the second piezoelectric bodies **21***a* and **21***b* and that enable appropriate detection of a signal corresponding to the amount of displacement of the free end E**2**. To cause a force to be generated at the free end E**2** more effectively by the second piezoelectric bodies **21***a* and **21***b*, the length L**21** is preferably longer. From this viewpoint, the length L**21** is preferably longer than the length L**22**.

Effects of Embodiment 2

[0066] In Embodiment 2 as well, as in Embodiment 1 described above, since the thicknesses of the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are smaller than the thicknesses of the first piezoelectric bodies **10***a* and **10***b*, the resonance frequency of the element can be increased while the amount of displacement of and the generated force at the free end E**2** are kept large.

[0067] Additionally, in the configuration of Embodiment 2, the second piezoelectric bodies **22***a* and **22***b* can be used as monitoring elements for detection of strain corresponding to the amount of displacement of the free end E**2**. Accordingly, feedback control, such as adjusting a voltage applied to the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **21***a* and **21***b*, such that the amount of displacement of the free end E**2** becomes a target displacement amount, can be performed.

[0068] As shown in FIG. **5** and FIGS. **6**A and **6**B, the second piezoelectric bodies **21***a* and **21***b* for driving the free end E**2** are disposed in regions symmetrical in a direction (Y-axis direction) perpendicular to the direction (X-axis direction) from the fixed end E**1** toward the free end E**2**. Accordingly, the free end E**2** can be uniformly driven by the second piezoelectric bodies **21***a* and **21***b* for driving, so that twisting of the free end E**2** can be suppressed.

[0069] As shown in FIG. **5** and FIGS. **6**A and **6**B, the second piezoelectric bodies **22***a* and **22***b* for detecting strain of the free end E**2** are disposed in regions symmetrical in the direction (Y-axis direction) perpendicular to the direction (X-axis direction) from the fixed end E**1** toward the free end E**2**. Since the second piezoelectric bodies **22***a* and **22***b* are uniformly disposed, without being non-uniformly distributed on one side in the Y-axis direction, as described above, twisting in the bending of the free end E**2** due to the second piezoelectric bodies **22***a* and **22***b* becoming unbalanced loads can be suppressed. Therefore, the free end E**2** can be satisfactorily displaced by the second piezoelectric bodies **21***a* and **22***a* for driving while strain of the free end E**2** is detected by the second piezoelectric bodies **22***a* and **22***b*.

[0070] In the above, among the second piezoelectric bodies **21***a* and **21***b* and the second piezoelectric bodies **22***a* and **22***b*, the second piezoelectric bodies **22***a* and **22***b* are used for strain detection. However, the second piezoelectric bodies **21***a* and **21***b* may be used for detecting strain of the free end E**2**, and the second piezoelectric bodies **22***a* and **22***b* may be used for driving the free end E**2**.

Modifications

[0071] FIG. **7**A is a top view showing a configuration of the piezoelectric driving element **1** according to a modification of Embodiment 2. For convenience, FIG. **7**A shows a top view of the piezoelectric driving element **1**, and the second piezoelectric body **22***b* disposed on the lower surface side of the piezoelectric driving element **1** also has the same configuration as the second piezoelectric body **22***a* on the upper surface side.

[0072] In this modification, the width in the Y-axis direction of each of the second piezoelectric bodies **22***a* and **22***b* is smaller than the width in the Y-axis direction of the shim material **30**, that is, the width in the Y-axis direction of each of the second piezoelectric bodies **21***a* and **21***b* on the distal end side. The sizes of the upper and lower second piezoelectric bodies **22***a* and **22***b* are the same as each other. The second piezoelectric bodies **22***a* and **22***b* have a rectangular shape in a plan view, and are disposed at the center in the Y-axis direction.

[0073] In this modification as well, the second piezoelectric bodies **22***a* and **22***b* can be used as monitoring elements for detection of strain corresponding to the amount of displacement of the free end E**2**. In this case, as shown by broken lines in FIG. **7**A, second piezoelectric bodies for driving may be further disposed on the Y-axis positive and negative sides of the second piezoelectric bodies **22***a* and **22***b*, respectively, so as to extend in the X-axis direction. Accordingly, as compared to the configuration of Embodiment 2, the generated force at the free end E**2** can be increased.

[0074] In the configuration in FIG. **7**A as well, the second piezoelectric bodies **22***a* and **22***b* for detecting strain corresponding to the amount of displacement of the free end E**2** are disposed in regions symmetrical in the direction (Y-axis direction) perpendicular to the direction (X-axis direction) from the fixed end E**1** toward the free end E**2**. Since the second piezoelectric bodies **22***a* and **22***b* are uniformly disposed, without being non-uniformly distributed on one side in the Y-axis direction, as described above, twisting in the bending of the free end E**2** due to the second piezoelectric bodies **22***a* and **22***b* becoming unbalanced loads can be suppressed. Therefore, the free end E**2** can be satisfactorily displaced by the second piezoelectric bodies **21***a* and **22***a* for driving while the amount of strain corresponding to the amount of displacement of the free end E**2** is detected by the second piezoelectric bodies **22***a* and **22***b*.

[0075] FIG. **7**B is a cross-sectional view showing a configuration of the piezoelectric driving element **1** according to another modification of Embodiment 2. Similar to FIG. **6**B, FIG. **7**B shows a cross-section of the piezoelectric driving element **1** obtained by cutting the piezoelectric driving element **1** at the center position thereof in the Y-axis direction.

[0076] In this modification, the thickness of each of the piezoelectric layers **222***a* and **222***b* of the second piezoelectric bodies **22***a* and **22***b* is smaller than the thickness D**2** of each of the piezoelectric layers **212***a* and **212***b* of the second piezoelectric bodies **21***a* and **21***b* on the distal end side. The thicknesses of the upper and lower second piezoelectric bodies **22***a* and **22***b* are equal to each other. In addition, the thicknesses of the respective electrode layers of the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are equal to each other. Therefore, the thicknesses of the second piezoelectric bodies **22***a* and **22***b* are smaller than the thicknesses of the second piezoelectric bodies **21***a* and **21***b*. The configurations of the second piezoelectric bodies **22***a* and **22***b* in a plan view are the same as in Embodiment 2.

[0077] In this modification as well, the second piezoelectric bodies **22***a* and **22***b* can be used as detection elements for monitoring the amount of strain corresponding to the amount of displacement of the free end E**2**. Here, in the case where the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are all used as piezoelectric bodies for driving, as the thickness of any of the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* is increased, the generated force at the free end E**2** in the piezoelectric driving element **1** can be increased, but the resonance frequency of the element is decreased. However, in this modification, the second piezoelectric bodies **22***a* and **22***b* which are used as elements for monitoring an amount of strain do not require a driving force, that is, a generated force, and only have to have a thickness or size required for electric charge detection. In this modification, since the second piezoelectric bodies **22***a* and **22***b* are smaller than those in Embodiment 2, the resonance frequency of the element can be increased while the ability to detect strain is ensured.

[0078] In the case where the thicknesses of the second piezoelectric bodies **22***a* and **22***b* are small as in the modification in FIG. **7**B, the electrode layers and the piezoelectric layers included in the second piezoelectric bodies **22***a* and **22***b* can be formed on the upper and lower surfaces of the shim material **30** by a sputtering method using a metal mask. In this case, first, the second piezoelectric bodies **22***a* and **22***b* may be formed on the upper and lower surfaces of the shim material **30**, and then the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **21***a* and **21***b* formed by the same process as in FIGS. **3**A to **3**C may be bonded to the upper and lower surfaces of the shim material **30**.

[0079] Also, in the modification in FIG. **7**B as well, as in FIG. **7**A, the widths in the Y-axis direction of the second piezoelectric bodies **22***a* and **22***b* may be narrowed. In this case as well, second piezoelectric bodies for driving may be further disposed on the Y-axis positive and negative sides of the second piezoelectric bodies **22***a* and **22***b*, respectively, so as to extend in the X-axis direction.

Embodiment 3

[0080] In Embodiment 2 described above, the second piezoelectric body is divided in the X-axis direction. On the other hand, in Embodiment 3, the second piezoelectric body is divided in the Y-axis direction.

[0081] FIG. **8** is a perspective view showing a configuration of the piezoelectric driving element **1** according to Embodiment 3. FIGS. **9**A and **9**B are a top view and a bottom view of the piezoelectric driving element **1** according to Embodiment 3, respectively, and FIGS. **10**A and **10**B are each a cross-sectional view of the piezoelectric driving element **1** according to Embodiment 3. FIG. **10**A shows a cross-sectional view of the piezoelectric driving element **1** taken at a position A**1** in FIG. **9**A, and FIG. **10**B shows a cross-sectional view of the piezoelectric driving element **1** taken at a position A**2** in FIG. **9**A. A cross-sectional view taken at the position of the second piezoelectric body **21***a* on the Y-axis positive side is the same as FIG. **10**A.

[0082] As shown in FIG. **8** to FIG. **10**B, in Embodiment 3, the second piezoelectric body is divided in the Y-axis direction. That is, a plurality of second piezoelectric bodies are disposed so as to be aligned in a direction (Y-axis direction) intersecting the direction from the fixed end E**1** toward the free end E**2**. On the free end E**2** side of the piezoelectric driving element **1**, the second piezoelectric bodies **22***a* and **22***b* are disposed at the center in the Y-axis direction, and the second piezoelectric bodies **21***a* and **21***b* are disposed on both ends in the Y-axis direction. Gaps are provided between the second piezoelectric bodies **21***a* and **21***b* and the second piezoelectric bodies **22***a* and **22***b*. The piezoelectric driving element **1** has a structure symmetrical in the Y-axis direction.

[0083] A thickness D**22** of each of the piezoelectric layers **222***a* and **222***b* of the second piezoelectric bodies **22***a* and **22***b* is smaller than a thickness D**21** of each of the piezoelectric layers **212***a* and **212***b* of the second piezoelectric bodies **21***a* and **21***b*. The thicknesses of the respective electrode layers of the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are equal to each other. Therefore, the thicknesses of the second piezoelectric bodies **22***a* and **22***b* are smaller than the thicknesses of the second piezoelectric bodies **21***a* and **21***b*. The configurations of the first piezoelectric bodies **10***a* and **10***b* are the same as in Embodiment 2.

[0084] The central second piezoelectric bodies **22***a* and **22***b* can be formed by a sputtering method using a metal mask, as in the modification in FIG. **7**B. In this case as well, first, the central second piezoelectric bodies **22***a* and **22***b* are formed on the upper and lower surfaces of the shim material **30**, and then a structure composed of the first piezoelectric bodies **10***a* and **10***b* and a structure composed of the second piezoelectric bodies **21***a* and **21***b* are bonded to the upper and lower surfaces of the shim material **30**.

Effects of Embodiment 3

[0085] In Embodiment 3 as well, as in Embodiments 1 and 2 described above, since the thicknesses of the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are smaller than the thicknesses of the first piezoelectric bodies **10***a* and **10***b*, the resonance frequency of the element can be increased while the amount of displacement of and the generated force at the free end E**2** are kept large.

[0086] Also, in Embodiment 3 as well, as in Embodiment 2, the second piezoelectric bodies **22***a* and **22***b* can be used for detecting strain of the free end E**2**. In this case, in Embodiment 3, the second piezoelectric bodies **21***a* and **21***b* for driving extend from the free end E**2** to the vicinity of the boundary of the first piezoelectric bodies **10***a* and **10***b*, and the second piezoelectric bodies **21***a* and **21***b* are formed continuously in the X-axis direction from the fixed end E**1** to the free end E**2** while having a slight distance from the first piezoelectric bodies **10***a* and **10***b*. Therefore, as compared to Embodiment 2, the amount of displacement and the force generated by the second piezoelectric bodies **21***a* and **21***b* can be increased. In addition, the second piezoelectric bodies **22***a* and **22***b* for strain detection extend from the vicinity of the boundary of the first piezoelectric bodies **10***a* and **10***b* to the distal end of the piezoelectric driving element **1** in the X-axis direction in which a change in the amount of bending is larger than in Embodiment 2, and driving parts composed of the second piezoelectric bodies **21**a and **21**b are also formed at positions, near the second piezoelectric bodies **22**a and **22**b, aligned in the direction (Y-axis direction) intersecting the direction from the fixed end E**1** toward the free end E**2**. Therefore, the amount of electric charge detected by the second piezoelectric bodies **22**a and **22**b is increased, so that strain corresponding to the amount of displacement of the free end E**2** can be monitored more accurately.

[0087] Also, as shown in FIG. **8** and FIGS. **9**A and **9**B, the second piezoelectric bodies **21**a and **21**b for driving the free end E**2** are disposed in regions symmetrical in the direction (Y-axis direction) perpendicular to the direction (X-axis direction) from the fixed end E**1** toward the free end E**2**. Accordingly, the free end E**2** can be uniformly driven by the second piezoelectric bodies **21**a and **21**b for driving, so that twisting of the free end E**2** can be suppressed.

[0088] In addition, as shown in FIG. **8** and FIGS. **9**A and **9**B, the second piezoelectric bodies **22**a and **22**b for detecting strain of the free end E**2** are disposed in the regions symmetrical in the direction (Y-axis direction) perpendicular to the direction (X-axis direction) from the fixed end E**1** toward the free end E**2**. Since the second piezoelectric bodies **22**a and **22**b are uniformly disposed, without being non-uniformly distributed on one side in the Y-axis direction, as described above, twisting in the bending of the free end E**2** due to the second piezoelectric bodies **22**a and **22**b becoming unbalanced loads can be suppressed. Therefore, the free end E**2** can be satisfactorily displaced by the second piezoelectric bodies **21**a and **22**a for driving while strain of the free end E**2** is detected by the second piezoelectric bodies **22**a and **22**b.

[0089] In the configuration in FIG. **8** to FIG. **10**B, the second piezoelectric bodies **22**a and **22**b for strain detection are disposed at the center in the Y-axis direction. However, the second piezoelectric bodies **21**a and **21**b for driving may be disposed at the center in the Y-axis direction, and the second piezoelectric bodies **22**a and **22**b for strain detection may be disposed on both sides in the Y-axis direction.

[0090] Also, in the configuration in FIG. **8** to FIG. **10**B, the thicknesses of the second piezoelectric bodies **22**a and **22**b for detection are smaller than the thicknesses of the second piezoelectric bodies **21**a and **21**b for driving. However, as in the case of FIG. **5** and FIGS. **6**A and **6**B, the thicknesses of the second piezoelectric bodies **22**a and **22**b for detection may be equal to the thicknesses of the second piezoelectric bodies **21**a and **21**b for driving.

[0091] Also, in the configuration in FIG. **8** to FIG. **10**B, the length of the second piezoelectric body **21**a and the length of the second piezoelectric body **22**a are equal to each other. However, the length of the second piezoelectric body **21**a may be different from the length of the second piezoelectric body **22**a.

Embodiment 4

[0092] In Embodiment 1 described above, the first piezoelectric bodies **10**a and **10**b and the second piezoelectric bodies **20**a and **20**b are disposed on the upper and lower surfaces of the shim material **30**, but a first piezoelectric body and a second piezoelectric body may be disposed on only one of the upper and lower surfaces of the shim material **30**.

[0093] FIG. **11** is a perspective view showing a configuration of the piezoelectric driving element **1** according to Embodiment 4.

[0094] In the configuration example in FIG. **11**, the first piezoelectric body **10**a and the second piezoelectric body **20**a are disposed on only the upper surface of the shim material **30**. The configurations of the first piezoelectric body **10**a and the second piezoelectric body **20**a are the same as in Embodiment 1. The first piezoelectric body **10**a and the second piezoelectric body **20**a are disposed on the upper surface of the shim material **30**, for example, through the same process as in FIGS. **3**A to **3**D. In the configuration example in FIG. **11**, after the first piezoelectric body **10**a and the second piezoelectric body **20**a are disposed on the upper surface of the shim material **30**, an end portion on the fixed end E**1** side of the shim material **30** is bonded to the support base **40**.

[0095] When a driving voltage is applied to the first piezoelectric body **10**a and the second piezoelectric body **20**a, the first piezoelectric body **10**a and the second piezoelectric body **20**a expand and contract in the longitudinal direction (X-axis direction). At this time, the expansion and contraction of the first piezoelectric body **10**a and the second piezoelectric body **20**a near the surfaces of the first piezoelectric body **10**a and the second piezoelectric body **20**a to which the shim material **30** is bonded is reduced by being restrained by the shim material **30**, but the expansion and contraction of the first piezoelectric body **10**a and the second piezoelectric body **20**a near the surfaces of the first piezoelectric body **10**a and the second piezoelectric body **20**a that are opposite to the surfaces to which the shim material **30** is bonded is increased. Therefore, when the first piezoelectric body **10**a and the second piezoelectric body **20**a expand and contract in the longitudinal direction (X-axis direction), the shim material **30** and also the free end E**2** are displaced in the Z-axis direction. Accordingly, a to-be-driven body disposed at the free end E**2** is driven.

Effects of Embodiment 4

[0096] In Embodiment 4 as well, as in Embodiments 1 to 3 described above, since the thickness of the second piezoelectric body **20**a is smaller than the thickness of the first piezoelectric body **10**a, the resonance frequency of the element can be increased while the amount of displacement of and the generated force at the free end E**2** are kept large.

[0097] In the configuration example in FIG. **11**, the first piezoelectric body **10**a and the second piezoelectric body **20**a are disposed on only the upper surface of the shim material **30**. However, the first piezoelectric body **10**a and the second piezoelectric body **20**a may be omitted from the configuration in FIG. **1**, and the first piezoelectric body **10**b and the second piezoelectric body **20**b may be disposed on only the lower surface of the shim material **30**.

[0098] In the configuration in FIG. **11**, since the first piezoelectric body **10**a and the second piezoelectric body **20**a are disposed on only one surface of the shim material **30**, the driving force is decreased as compared to that in the case where the first piezoelectric bodies **10**a and **10**b and the second piezoelectric bodies **20**a and **20**b are disposed on both surfaces of the shim material **30** as in Embodiment 1 described above. Therefore, in order to increase the amount of displacement of the free end E**2** by exerting a larger generated force on the free end E**2**, the first piezoelectric body and the second piezoelectric body are preferably disposed above and below a flat surface from the fixed end E1 toward the free end E2 (on the upper and lower surfaces of the shim material 30), respectively, as in Embodiment 1 described above.

Embodiment 5

[0099] In Embodiment 5, the second piezoelectric body **20***a* in the configuration in Embodiment 4 is further divided into a plurality of parts.

[0100] FIG. **12** is a perspective view showing a configuration of the piezoelectric driving element **1** according to Embodiment 5.

[0101] In the configuration of FIG. **12**, the second piezoelectric body is divided in the X-axis direction. The second piezoelectric bodies **21***a* and **22***a* are disposed so as to be aligned in the direction (X-axis direction) from the fixed end E**1** toward the free end E**2**. The piezoelectric driving element **1** in FIG. **12** has a configuration in which the first piezoelectric body **10***b* and the second piezoelectric bodies **22***a* and **22***b* on the lower side are omitted from the piezoelectric driving element **1** of Embodiment 2 shown in FIG. **5** to FIG. **6**B. In this configuration as well, after the first piezoelectric body **10***a* and the second piezoelectric body **20***a* are disposed on the upper surface of the shim material **30**, the end portion on the fixed end E**1** side of the shim material **30** is bonded to the support base **40**.

[0102] In the configuration in FIG. **12** as well, as in Embodiment 2, the second piezoelectric body **22***a* can be used for detecting strain of the free end E**2**. As in the case of FIG. **7**B, the thickness of the second piezoelectric body **22***a* may be smaller than the thickness of the second piezoelectric body **21***a*. In addition, as in the case of FIG. **7**A, the width of the second piezoelectric body **22***a* may be smaller than the width of the second piezoelectric body **21***a*, and second piezoelectric bodies for driving may be further disposed in the regions shown by the broken lines in FIG. **7**A.

[0103] FIG. **13** is a perspective view showing another configuration of the piezoelectric driving element **1** according to Embodiment 5.

[0104] In the configuration in FIG. **13**, two second piezoelectric bodies **21***a* and a second piezoelectric body **22***a* are disposed so as to be aligned in the direction (Y-axis direction) intersecting the direction from the fixed end E**1** toward the free end E**2**. The second piezoelectric body **22***a* is disposed at the center in the Y-axis direction, and the two second piezoelectric bodies **21***a* are disposed on both sides in the Y-axis direction. The thickness of the central second piezoelectric body **22***a* is smaller than the thickness of each of the second piezoelectric bodies **21***a* on both sides.

[0105] The piezoelectric driving element **1** in FIG. **13** has a configuration in which the first piezoelectric body **10***b* and the second piezoelectric bodies **22***a* and **22***b* are omitted from the piezoelectric driving element **1** of Embodiment 3 shown in FIG. **8** to FIG. **10**B. In this configuration as well, after the first piezoelectric body **10***a* and the second piezoelectric body **20***a* are disposed on the upper surface of the shim material **30**, the end portion on the fixed end E**1** side of the shim material **30** is bonded to the support base **40**.

[0106] In the configuration in FIG. **13** as well, as in Embodiment 3 described above, the second piezoelectric body **22***a* can be used for detecting strain of the free end E**2**. As in the case of Embodiment 3 described above, the thickness of the second piezoelectric body **22***a* may be equal to the thickness of each second piezoelectric body **21***a*. In addition, as in the case of Embodiment 3 described above, the second piezoelectric body **21***a* for driving may be disposed at the center in the Y-axis direction, and the second piezoelectric body **22***a* for strain detection may be disposed on each of both sides in the Y-axis direction. The length of each second piezoelectric body **21***a* and the length of the second piezoelectric body **22***a* may be different from each other.

[0107] In the configuration examples in FIG. **12** and FIG. **13**, as in the configuration example in FIG. **11**, when a voltage is applied to the first piezoelectric body **10***a* and each second piezoelectric body **21***a*, the expansion and contraction of the first piezoelectric body **10***a* and the second piezoelectric body **21***a* near the surfaces of the first piezoelectric body **10***a* and the second piezoelectric body **21***a* to which the shim material **30** is bonded is different from that near the surfaces of the first piezoelectric body **10***a* and the second piezoelectric body **21***a* that are opposite to the surfaces to which the shim material **30** is bonded, whereby the shim material **30** and also the free end E**2** are displaced in the Z-axis direction. Accordingly, a to-be-driven body disposed at the free end E**2** is driven. At this time, the electric charge corresponding to the amount of displacement of the free end E**2** can be detected using the second piezoelectric body **22***a*. Accordingly, feedback control for displacing the free end E**2** by a target displacement amount is performed. In the configuration in FIG. **13**, the second piezoelectric body **22***a* for strain detection extends from the vicinity of the boundary of the first piezoelectric body **10***a* to the distal end of the piezoelectric driving element **1** in the X-axis direction in which a change in the amount of bending is larger than in the configuration in FIG. **12**, and driving parts composed of the second piezoelectric bodies **21***a* are also formed at positions, near the second piezoelectric body **22***a*, aligned in the direction (Y-axis direction) intersecting the direction from the fixed end E**1** toward the free end E**2**. Therefore, the amount of electric charge detected by the second piezoelectric body **22***a* is increased, so that the amount of strain corresponding to the amount of displacement of the free end E**2** can be monitored more accurately.

Effects of Embodiment 5

[0108] In Embodiment 5 as well, as in Embodiments 1 to 4 described above, since the thicknesses of the second piezoelectric bodies **21***a* and **22***a* are smaller than the thickness of the first piezoelectric body **10***a*, the resonance frequency of the element can be increased while the amount of displacement of and the generated force at the free end E**2** are kept large.

[0109] In addition, by using the second piezoelectric body **22***a* for detecting displacement of the free end E**2**, feedback control can be performed such that the amount of displacement of the free end E**2** becomes a target displacement amount, while the generated force at the free end E**2** is compensated for by the second piezoelectric body **21***a*.

[0110] In the configurations in FIG. **12** and FIG. **13**, since the first piezoelectric body **10***a* and the second piezoelectric bodies **21***a* and **22***a* are disposed on only one surface of the shim material **30**, the driving force is decreased as compared to that in the case where the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are disposed on both surfaces of the shim material **30** as in Embodiments 2 and 3. Therefore, in order to increase the amount of displacement of the free end E**2** by exerting a larger generated force on the free end E**2**, the first piezoelectric body and the second piezoelectric body are preferably disposed above and below a flat surface from the fixed end E**1** toward the free end E**2** (on the upper and lower surfaces of the shim material **30**), respectively, as in Embodiment 1 described above.

Embodiment 6

[0111] In Embodiments 1 to 3 described above, the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are disposed on the upper and lower surfaces of the shim material **30**. However, in Embodiment 6, the shim material **30** is omitted.

[0112] FIG. **14**A is a cross-sectional view showing a configuration of the piezoelectric driving element **1** in which the shim material **30** is omitted from the configuration of Embodiment 1 shown in FIG. **1** to FIG. **2**B. FIG. **14**A shows a cross-sectional view of a structure of the piezoelectric driving element **1** excluding the support base **40**, taken at the center position in the Y-axis direction along a plane parallel to the X-Z plane.

[0113] FIG. **14**B is a cross-sectional view showing a configuration of the piezoelectric driving element **1** in which the shim material **30** is omitted from the configuration of Embodiment 2 shown in FIG. **5** to FIG. **6**B. FIG. **14**B shows a cross-sectional view of a structure of the piezoelectric driving element **1** excluding the support base **40**, taken at the center position in the Y-axis direction along a plane parallel to the X-Z plane.

[0114] FIG. **14**C is a cross-sectional view showing a configuration of the piezoelectric driving element **1** in which the shim material **30** is omitted from the configuration of the modification of Embodiment 2 shown in FIG. **7**B. FIG. **14**C shows a cross-sectional view of a structure of the piezoelectric driving element **1** excluding the support base **40**, taken at the center position in the Y-axis direction along a plane parallel to the X-Z plane.

[0115] In the configuration of FIG. **14**A, an electrode layer **103** is shared by the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b*, and in the configurations in FIGS. **14**B and **14**C, an electrode layer **103** is shared by the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b*. The shared electrode layer **103** is connected to a ground, and a driving voltage is applied to the electrode layers **101***a*, **101***b*, **201***a*, **201***b*, **211***a*, and **211***b*. At this time, in the case where the polarization directions of the respective piezoelectric layers **102***a*, **202***a*, and **212***a* of the first piezoelectric bodies **10***a*, **20***a*, and **21***a* and the respective piezoelectric layers **102***b*, **202***b*, and **212***b* of the second piezoelectric bodies **10***b*, **20***b*, and **21***b* are made to be substantially the same on the positive and negative sides in the Z-axis direction, expansion of the first piezoelectric bodies **10***a*, **20***a*, and **21***a* and contraction of the second piezoelectric bodies **10***b*, **20***b*, and **21***b*, or contraction of the first piezoelectric bodies **10***a*, **20***a*, and **21***a* and expansion of the second piezoelectric bodies **10***b*, **20***b*, and **21***b* can be simultaneously caused by applying a voltage having a phase opposite to that of the ground potential of the electrode layer **103**, to the electrode layers **101***a*, **201***a*, and **211***a* and the electrode layers **101***b*, **201***b*, and **211***b*. On the other hand, in the case where the polarization directions of the respective piezoelectric layers **102***a*, **202***a*, and **212***a* of the first piezoelectric bodies **10***a*, **20***a*, and **21***a* and the respective piezoelectric layers **102***b*, **202***b*, and **212***b* of the second piezoelectric bodies **10***b*, **20***b*, and **21***b* are made to be substantially opposite to each other on the positive and negative sides in the Z-axis direction, expansion of the first piezoelectric bodies **10***a*, **20***a*, and **21***a* and contraction of the second piezoelectric bodies **10***b*, **20***b*, and **21***b*, or contraction of the first piezoelectric bodies **10***a*, **20***a*, and **21***a* and expansion of the second piezoelectric bodies **10***b*, **20***b*, and **21***b* can be simultaneously caused by applying a voltage having the same phase as the ground potential of the electrode layer **103**, to the electrode layers **101***a*, **201***a*, and **211***a* and the electrode layers **101***b*, **201***b*, and **211***b*. Here, the polarization directions of the respective piezoelectric layers **102***a*, **202***a*, and **212***a* of the first piezoelectric bodies **10***a*, **20***a*, and **21***a* and the respective piezoelectric layers **102***b*, **202***b*, and **212***b* of the second piezoelectric bodies **10***b*, **20***b*, and **21***b* are determined by the polarity of a voltage during a polarization treatment including a step of applying in advance a voltage, which is higher than the driving voltage to be used, between the electrode layer **103** and each of the electrode layers **101***a*, **101***b*, **201***a*, **201***b*, **211***a*, and **211***b* after the piezoelectric driving element **1** is produced. The free end E**2** is displaced in the Z-axis direction by such expansion and contraction in the longitudinal direction (X-axis direction) of the upper and lower first piezoelectric bodies **10***a* and **10***b* and the upper and lower second piezoelectric bodies **20***a* and **20***b* or the upper and lower first piezoelectric bodies **10***a* and **10***b* and the upper and lower second piezoelectric bodies **21***a* and **21***b*.

[0116] Also, in the configurations in FIGS. **14**B and **14**C, the second piezoelectric bodies **22***a* and **22***b* can be used as detection elements for monitoring the amount of strain corresponding to the amount of displacement of the free end E**2**. In this case, in the configuration in FIG. **14**C, the thicknesses of the second piezoelectric bodies **22***a* and **22***b* (the thicknesses of the piezoelectric layers **222***a* and **222***b*) are smaller than those in the configuration in FIG. **14**B, so that the resonance frequency of the element can be increased while the ability to detect an amount of strain is ensured.

[0117] The piezoelectric driving element **1** shown in FIG. **14**A is formed, for example, as follows.

[0118] The Ag electrodes **401** and **402** are formed by printing on only one surfaces of the PZT thin plates **301** and **302** formed by the same method as in FIG. **3**A. Next, the PZT thin plates **301** and **302** having the Ag electrodes **401** and **402** printed on the surfaces thereof are diced into individual pieces. The thus-individualized structures are bonded to the upper and lower surfaces of a conductive plate composed of a copper plate or the like. Accordingly, the structure in FIG. **14**A is formed.

[0119] The PZT thin plate **301** and the PZT thin plate **302** correspond to the piezoelectric layers **102***a* and **102***b* and the piezoelectric layers **202***a* and **202***b* in FIG. **14**A, respectively, and the Ag electrode **401** and the Ag electrode **402** correspond to the electrode layers **101***a* and **101***b* and the electrode layers **201***a* and **201***b* in FIG. **14**A, respectively. In addition, the conductive plate corresponds to the electrode layer **103** in FIG. **14**A. As described above, the electrode layer **103** is shared by the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a* and **20***b*.

[0120] In FIGS. **14**B and **14**C as well, the structures composed of the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* formed by the same method are bonded to the upper and lower surfaces of the shared electrode layer **103** which is composed of a conductive plate, whereby the piezoelectric driving element **1** is formed. In the configuration in FIG. **14**C, as in the case of FIG. **7**B, the second piezoelectric bodies **22***a* and **22***b* may be formed by a sputtering method using a metal mask.

Effects of Embodiment 6

[0121] In Embodiment 6 as well, as in Embodiments 1 to 5 described above, since the thicknesses of the second piezoelectric bodies **21***a*, **21***b*, **22***a*, and **22***b* are smaller than the thicknesses of the first piezoelectric bodies **10***a* and **10***b*, the resonance frequency of the element can be increased while the amount of displacement of and the generated force at the free end E**2** are kept large.

[0122] In addition, by using the second piezoelectric body **22***a* for detecting strain corresponding to the amount of displacement of the free end E**2**, feedback control can be performed such that the amount of displacement of the free end E**2** becomes a target displacement amount, while the generated force at the free end E**2** is compensated for by the second piezoelectric bodies **21***a* and **21***b*.

[0123] In the above, the configurations in which the shim material **30** is omitted from the configurations of Embodiment 1, Embodiment 2, and the modifications of Embodiment 2 are shown, but the piezoelectric driving element **1** may be configured by omitting the shim material **30** from the configuration of Embodiment 3 shown in FIG. **8** to FIG. **10**B. In this case as well, the same effects as described above can be achieved.

Other Modifications

[0124] In Embodiments 1 to 6 described above, gaps are provided between the first piezoelectric bodies **10***a* and **10***b* and the second piezoelectric bodies **20***a*, **20***b*, **21***a*, **21***b*, **22***a*, and **22***b*, but the piezoelectric layers of the first piezoelectric bodies **10***a* and **10***b* and the piezoelectric layers of the second piezoelectric bodies **20***a*, **20***b*, **21***a*, **21***b*, **22***a*, and **22***b* may be connected to each other.

[0125] FIG. **15**A is a diagram showing a configuration example in which in the configuration of Embodiment 1, the piezoelectric layer **102***a* and the piezoelectric layer **202***a* are connected to each other and the piezoelectric layer **102***b* and the piezoelectric layer **202***b* are connected to each other. FIG. **15**B is a diagram showing a configuration example in which in the configuration of Embodiment 2, the piezoelectric layer **102***a*, the piezoelectric layer **222***a*, and the piezoelectric layer **212***a* are connected to each other and the piezoelectric layer **102***b*, the piezoelectric layer **222***b*, and the piezoelectric layer **212***b* are connected to each other.

[0126] In these configuration examples as well, the thickness D**2** of each of the piezoelectric layers **212***a*, **212***b*, **222***a*, and **222***b* is smaller than the thickness D**1** of each of the piezoelectric layers **102***a* and **102***b*. In addition, the electrodes on the surface side of the first piezoelectric bodies **10***a* and **10***b* and the electrodes on the surface side of the second piezoelectric bodies **20***a*, **20***b*, **21***a*, **21***b*, **22***a*, and **22***b* are separated from each other. The electrodes on the shim material **30** side of the first piezoelectric bodies **10***a* and **10***b* and the electrodes on the shim material **30** side of the second piezoelectric bodies **20***a*, **20***b*, **21***a*, **21***b*, **22***a*, and **22***b* may be shared as shown in FIGS. **15**A and **15**B.

[0127] In the configurations in FIGS. **15**A and **15**B as well, by connecting the shared electrode layers **103***a* and **103***b* to a ground and applying a driving voltage to the electrode layers **101***a*, **101***b*, **201***a*, **201***b*, **211***a*, and **211***b* on the surface side, the free end E**2** can be displaced. Also, in the configuration in FIG. **15**B, the second piezoelectric bodies **22***a* and **22***b* can be used for detecting the amount of strain corresponding to the amount of displacement of the free end E**2**.

[0128] In the embodiments and the modifications other than Embodiments 1 and 2 as well, similarly, the piezoelectric layers of the first piezoelectric bodies **10***a* and **10***b* and the piezoelectric layers of the second piezoelectric bodies **20***a*, **20***b*, **21***a*, **21***b*, **22***a*, and **22***b* may be connected to each other.

[0129] In Embodiments 2, 3, and 5 described above, the second piezoelectric bodies **22***a* and **22***b* are used for detecting the amount of strain corresponding to the amount of displacement of the free end E**2**, but both or either one of these piezoelectric bodies may be used for driving the free end E**2**. In the configurations of Embodiment 6 shown in FIGS. **14**B and **14**C and the configuration of the modification shown in FIG. **15**B as well, both or either one of the second piezoelectric bodies **22***a* and **22***b* may be used for driving the free end E**2**.

[0130] In Embodiments 1 to 6 and the modifications described above, the first piezoelectric bodies **10***a* and **10***b* are integrally formed, but the first piezoelectric bodies **10***a* and **10***b* may each be divided into a plurality of parts in the length direction (X-axis direction) or the width direction (Y-axis direction).

[0131] The number of parts into which the second piezoelectric body is divided is not limited to the numbers shown in Embodiments 2, 3, 5, and 6 described above, and the second piezoelectric body may be divided into another number of parts.

[0132] The size and the material of each part of the piezoelectric driving element **1** and the manufacturing method for the piezoelectric driving element **1** are not limited to those shown in Embodiments 1 to 6 and the modifications described above, and can be changed as appropriate.

[0133] In addition to the above, various modifications can be made as appropriate to the embodiments of the present invention, without departing from the scope of the technological idea defined by the claims.

What is claimed is:

1. A cantilever-type piezoelectric driving element in which one end which is a fixed end is fixed to a support base and another end which is a free end is driven, the piezoelectric driving element comprising:
- a first piezoelectric body disposed on the fixed end side; and
- a second piezoelectric body disposed on the free end side with respect to the fixed end, wherein
- a thickness of the second piezoelectric body is smaller than a thickness of the first piezoelectric body.

2. The piezoelectric driving element according to claim **1**, wherein the second piezoelectric body is divided into a plurality of second piezoelectric bodies.

3. The piezoelectric driving element according to claim **2**, wherein the plurality of divided second piezoelectric bodies are aligned in a direction from the fixed end toward the free end.

4. The piezoelectric driving element according to claim **2**, wherein the plurality of divided second piezoelectric bodies are aligned in a direction intersecting a direction from the fixed end toward the free end.

5. The piezoelectric driving element according to claim **2**, wherein a thickness of one of the plurality of divided second piezoelectric bodies is smaller than a thickness of another one(s) of the plurality of divided second piezoelectric bodies.

6. The piezoelectric driving element according to claim **2**, wherein the plurality of second piezoelectric bodies are classified into a piezoelectric body for driving the free end and a piezoelectric body for detecting strain of the free end.

7. The piezoelectric driving element according to claim **6**, wherein a thickness of the second piezoelectric body for detecting strain of the free end is smaller than a thickness of the second piezoelectric body for driving the free end.

8. The piezoelectric driving element according to claim **6**, wherein the second piezoelectric body for driving the free end is disposed in each of regions symmetrical in a direction perpendicular to a direction from the fixed end toward the free end.

9. The piezoelectric driving element according to claim **6**, wherein the second piezoelectric body for detecting strain of the free end is disposed in each of regions symmetrical in a direction perpendicular to a direction from the fixed end toward the free end.

10. The piezoelectric driving element according to claim **1**, wherein the first piezoelectric body and the second piezoelectric body are disposed so as to be overlaid on a plate-shaped shim material.

11. The piezoelectric driving element according to claim **1**, wherein the first piezoelectric body and the second piezoelectric body are disposed above and below a flat surface from the fixed end toward the free end.

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