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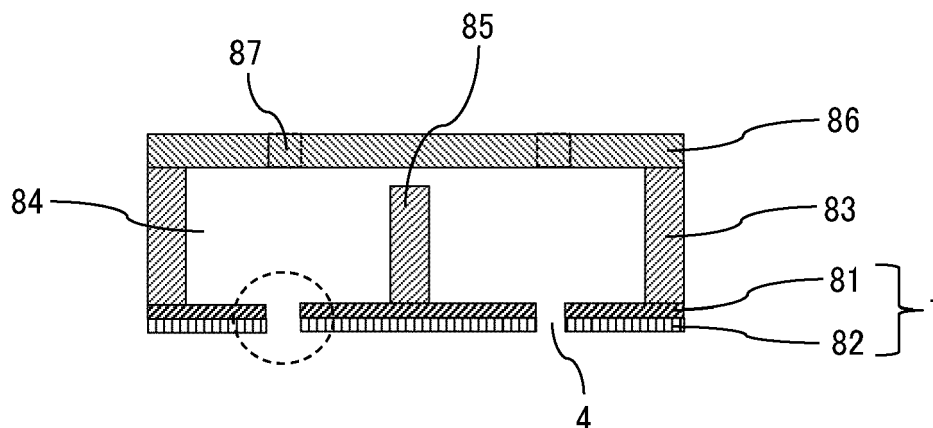
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(54) **LIQUID DISCHARGE HEAD, LIQUID DISCHARGE APPARATUS, AND METHOD FOR MANUFACTURING LIQUID DISCHARGE HEAD**

(57) A liquid discharge head (100) includes a nozzle plate (1) configured to vibrate to discharge liquid. The nozzle plate includes a substrate (81), a piezoelectric body (82), and a nozzle orifice (4). The piezoelectric body (82) is disposed closer to a discharge target than the substrate, the piezoelectric body (82) including lead zir-

conate titanate (PZT). The nozzle orifice (4) penetrates the substrate and the piezoelectric body. When a direction from one opening to another opening in the nozzle orifice is a discharge direction of the liquid, the PZT has a crystal structure extending parallel with the discharge direction.

FIG. 1



Description

BACKGROUND

Technical Field

[0001] Embodiments of the present invention relate to a liquid discharge head, a liquid discharge apparatus, and a method of manufacturing the liquid discharge head.

Related Art

[0002] As a liquid discharge head using a piezoelectric body, for example, a liquid discharge head is known that vibrates a nozzle surface to discharge ink. In such a liquid discharge head, a large vibration is needed to discharge ink. For example, a bulk piezo having a large piezoelectric multiplier is attached to a thin nozzle plate to form a unimorph shape, thus allowing large displacement to be obtained.

[0003] JP-H03-065350-A discloses a head structure provided with nozzle orifices penetrating a nozzle substrate plate and a piezoelectric thin film. The head structure is described to increase the energy for discharging ink droplets and allow stable ink discharge.

[0004] JP-3427608-B (JP-H09-226111-A) discloses a technique in which a nozzle portion of a vibration substrate is vibrated to generate a standing wave toward the center of a nozzle in the vicinity of a surface of ink as liquid held by the nozzle, thus causing a droplet to fly from the surface of ink at the center of the nozzle. JP-3427608-B describes that such a configuration allows small droplets to be discharged with high energy efficiency. In addition, JP-H03-065350-A discloses an embodiment in which two substrates are bonded to each other, a nozzle penetrating both substrates is formed, and the substrates around the nozzle are vibrated to discharge a liquid droplet.

[0005] However, in conventional techniques, there is a problem in which, when the nozzle orifice is processed, a part of the wall surface of the nozzle orifice falls off and the shape of the wall surface inside the nozzle orifice cannot be processed to be linear. There is also a problem in which, when the shape of the nozzle orifice cannot be processed into a straight line, discharge deviation occurs when discharging the liquid.

SUMMARY

[0006] In light of the above-described problem, a purpose of the present invention is to restrain deviation of liquid discharge in a liquid discharge head that vibrates a nozzle plate to discharge liquid.

[0007] According to an aspect of the present disclosure, there is provided a liquid discharge head that includes a nozzle plate configured to vibrate to discharge liquid. The nozzle plate includes a substrate, a piezoelectric body, and a nozzle orifice. The piezoelectric body

is disposed closer to a discharge target than the substrate, the piezoelectric body including lead zirconate titanate (PZT). The nozzle orifice penetrates the substrate and the piezoelectric body. When a direction from one opening to another opening in the nozzle orifice is a discharge direction of the liquid, the PZT has a crystal structure extending parallel with the discharge direction.

[0008] According to another aspect of the present disclosure, there is provided a method of manufacturing the liquid discharge head. The method includes stacking the PZT on the substrate by a sputtering method or a chemical vapor deposition (CVD) method, to form the piezoelectric body.

[0009] According to the present invention, deviation in liquid discharge can be restrained in a liquid discharge head that vibrates a nozzle plate to discharge liquid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] A more complete appreciation of the disclosure and many of the attendant advantages and features thereof can be readily obtained and understood from the following detailed description with reference to the accompanying drawings, wherein:

FIG. 1 is a schematic cross-sectional view of a liquid discharge head according to an embodiment of the present invention;

FIGS. 2A, 2B, and 2C are schematic cross-sectional views of a portion of the liquid discharge head of FIG. 1;

FIGS. 3A, 3B, and 3C are schematic exploded perspective views of a portion of the liquid discharge head of FIG. 1;

FIGS. 4A, 4B, and 4C are schematic exploded perspective views of a portion of the liquid discharge head of FIG. 1;

FIG. 5 is a schematic cross-sectional view of a liquid discharge head according to a comparative example;

FIGS. 6A, 6B, and 6C are schematic cross-sectional views of a portion of the liquid discharge head according to the comparative example of FIG. 5;

FIGS. 7A, 7B, and 7C are exploded perspective views of a portion of the liquid discharge head according to the comparative example of FIG. 5;

FIG. 8 is a schematic cross-sectional view of a liquid discharge head according to another embodiment of the present invention;

FIG. 9 is another schematic cross-sectional view of the liquid discharge head of FIG. 8;

FIG. 10 is a schematic cross-sectional view of a liquid discharge head according to still another embodiment of the present invention;

FIG. 11 is a schematic cross-sectional view of the liquid discharge head of FIG. 10;

FIG. 12 is a schematic view of a liquid discharge apparatus according to an embodiment of the

present invention;

FIG. 13 is a schematic view of an example of a head unit of the liquid discharge apparatus of FIG. 12;

FIG. 14 is a block diagram of a liquid circulating apparatus according to an embodiment of the present invention.

FIG. 15 is a schematic view of a liquid discharge apparatus according to another embodiment of the present invention;

FIG. 16 is a schematic side view of the liquid discharge apparatus of FIG. 15;

FIG. 17 is a schematic view of an example of a liquid discharge device according to an embodiment of the present invention; and

FIG. 18 is a schematic view of a liquid discharge device according to another embodiment of the present invention.

[0011] The accompanying drawings are intended to depict embodiments of the present disclosure and should not be interpreted to limit the scope thereof. The accompanying drawings are not to be considered as drawn to scale unless explicitly noted.

DETAILED DESCRIPTION

[0012] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0013] In describing embodiments illustrated in the drawings, specific terminology is employed for the sake of clarity. However, the disclosure of this specification is not intended to be limited to the specific terminology so selected and it is to be understood that each specific element includes all technical equivalents that have a similar function, operate in a similar manner, and achieve a similar result.

[0014] Hereinafter, a liquid discharge head, a liquid discharge apparatus, and a method of manufacturing the liquid discharge head according to embodiments of the present invention are described with reference to the drawings. Embodiments of the present invention are not limited to embodiments hereinafter described, and changes such as other embodiments, additions, modifications, and deletions may be made within the scope conceivable by those skilled in the art. Any aspects are included in the scope of the present invention as long as the actions and effects of the present invention are exhibited.

[0015] A liquid discharge head according to the present embodiment is a liquid discharge head that vibrates a nozzle plate to discharge liquid. The nozzle plate includes a substrate and a piezoelectric body provided closer to a discharge target than the substrate. The nozzle plate includes a nozzle orifice penetrating the substrate and

the piezoelectric body. When a direction from one opening to the other opening in the nozzle orifice is a liquid discharge direction, the piezoelectric body includes lead zirconate titanate (PZT) and the PZT has a crystal structure extending in parallel with the discharge direction.

[0016] A liquid discharge apparatus according to the present embodiment includes the liquid discharge head according to the present embodiment. The liquid discharge apparatus includes other means as necessary.

[0017] A liquid discharge head according to an embodiment of the present invention is described. FIG. 1 is a schematic cross-sectional view of a liquid discharge head according to the present embodiment. FIG. 1 depicts a nozzle plate 1, nozzle orifices 4, a substrate 81, a piezoelectric body 82, a common liquid chamber plate 83, a common liquid chamber 84, a partition wall 85, a ceiling plate 86, and a supply passage 87. In FIG. 1, only main parts are illustrated for describing the liquid discharge head according to the present embodiment, and other members may be provided as necessary.

[0018] Liquid (for example, ink) is supplied to the common liquid chamber 84 in the common liquid chamber plate 83 through the supply passage 87 provided in the ceiling plate 86. As the ceiling plate 86, for example, a metal member can be used. As a material of the common liquid chamber plate 83, for example, silicon (Si) can be used.

[0019] The nozzle plate 1 includes the substrate 81 and the piezoelectric body 82 that is provided on the discharge target side of the substrate 81. The nozzle plate 1 vibrates to discharge the liquid in the common liquid chamber 84 from the nozzle orifice 4. The number, arrangement, and shape of the nozzle orifices 4 can be appropriately changed.

[0020] The nozzle orifice 4 is formed so as to penetrate through the substrate 81 and the piezoelectric body 82. In the present embodiment, a direction from one opening to the other opening in the nozzle orifice 4 is defined as a liquid discharge direction. For example, an opening on the common liquid chamber 84 side is defined as one opening, and an opening on the opposite side is defined as the other opening.

[0021] The substrate 81 can be appropriately changed, and for example, a Si substrate can be used. The thickness of the substrate 81 is preferably, for example, 200 μm to 900 μm .

[0022] The piezoelectric body 82 includes lead zirconate titanate (PZT). The thickness of the piezoelectric body 82 is preferably, for example, 1 μm to 6 μm .

[0023] The nozzle plate 1 may be provided with an electrode so that the nozzle plate 1 vibrates to discharge the liquid. As a material of the electrode, a known material can be used.

[0024] FIGS. 2A, 2B, and 2C are schematic cross-sectional views of the nozzle plate 1 according to the present embodiment. FIGS. 2A, 2B, and 2C are enlarged schematic cross-sectional views of a portion indicated by a broken line circle in FIG. 1. FIG. 2 A is a schematic view

illustrating a state in which the nozzle orifice 4 is formed in the nozzle plate 1. In the present embodiment, the piezoelectric body 82 has a crystal structure extending parallel to the discharge direction.

[0025] With the above-described crystal structure of the piezoelectric body 82, even when the nozzle orifice 4 is processed, the drop-off does not occur, and the shape of the nozzle orifice can be processed to be linear. As illustrated in FIG. 2A, when the nozzle orifice 4 is formed, irregularities are less likely to occur on the wall surface of the nozzle orifice 4, and the nozzle orifice 4 can be processed straight.

[0026] In order to form the crystal structure extending in parallel with the discharge direction in the piezoelectric body 82, the crystal structure is formed by, for example, a stacking method instead of a method in which nozzle orifices are formed in the substrate 81 and the piezoelectric body 82 and then the substrate 81 and the piezoelectric body 82 are bonded to each other. Details of the stacking method are described later.

[0027] FIG. 2B is a diagram schematically illustrating an example of a case in which liquid 88 flows through the nozzle orifice 4 or a case in which the liquid 88 is accumulated in the nozzle orifice 4. Since the nozzle orifice 4 is processed straight, the liquid 88 flows straight in the nozzle orifice 4.

[0028] FIG. 2C is a diagram schematically illustrating an example of a case in which the liquid 88 is discharged from the nozzle orifice 4. An arrow in FIG. 2C schematically depicts a direction in which the liquid 88 is discharged. Since the nozzle orifice 4 is processed to be straight, the liquid 88 is discharged without being deviated with respect to the discharge direction. According to the present embodiment, discharge deviation in discharging liquid can be restrained, thus further enhancing image quality.

[0029] On the other hand, in the case in which the crystal structure does not extend in parallel with the discharge direction as in the case of, for example, a bulk structure, particles forming a piezoelectric body may drop off when nozzle orifices are processed. In a related art, for example, two substrates having different characteristics are bonded to each other, and a piezoelectric body obtained by polishing a bulk is used as the piezoelectric body due to a manufacturing method thereof. In the case of a manufacturing method in which a bulk piezoelectric body is attached to a nozzle plate, when a nozzle orifice is formed in the bulk piezoelectric body or after the nozzle orifice is formed in the bulk piezoelectric body, particles of a part of the bulk piezoelectric body may drop off. When the drop-off of particles occurs, the shape of the nozzle orifice is not straight, thus causing discharge deviation.

[0030] Here, a description is given of a liquid discharge head according to a comparative example, which is further described later. FIG. 5 is a schematic cross-sectional view of a liquid discharge head according to a comparative example. FIGS. 6A, 6B, and 6C are similar diagrams to FIGS. 2A, 2B, and 2C and are enlarged schematic

cross-sectional views of a portion indicated by a broken line circle in FIG. 5. In FIGS. 6A, 6B, and 6C, a bulk piezoelectric body 82a having a bulk structure is illustrated. Particles are gathered to form the bulk piezoelectric body 82a.

[0031] As illustrated in FIG. 6A, particle drop-offs 91 or detachment of particles occur in the bulk piezoelectric body 82a. When the particle drop-offs 91 occurs, a nozzle orifice 4a does not have a straight shape. When liquid 88 is supplied to the nozzle orifice 4a in such a state, as illustrated in FIG. 6B, the liquid 88 enters portions from which particles have detached. In such a case, as illustrated in FIG. 6C, when the liquid 88 is discharged, the discharged liquid may be deviated or discharge failure may occur.

[0032] In the present embodiment, the crystal structure extending parallel to the discharge direction is preferably a columnar crystal. Other than the columnar crystal, for example, a needle-shaped crystal structure or the like may be used. Whether the piezoelectric body has a crystal structure extending parallel to the discharge direction can be determined by observation with, for example, a scanning electron microscope (SEM).

[0033] Next, a method of manufacturing the liquid discharge head according to the present embodiment is described. The method of manufacturing the liquid discharge head according to the present embodiment uses a stacking method in which a piezoelectric body is stacked on a substrate instead of bonding the substrate and the piezoelectric body together.

[0034] A method of manufacturing the liquid discharge head according to the present embodiment is described with reference to FIGS. 3A to 3C and FIGS. 4A to 4C. FIGS. 3A to 3C are schematic perspective views of a case in which the nozzle orifices 4 are formed after a piezoelectric body 82 is formed on a substrate 81.

[0035] As illustrated in FIG. 3B, the piezoelectric body 82 is formed on the substrate 81 illustrated in FIG. 3A by a stacking method. The piezoelectric body formed by the stacking method is likely to be a columnar crystal. Accordingly, the piezoelectric body 82 having a crystal structure extending parallel to the discharge direction can be formed.

[0036] In the stacking method, PZT is stacked on the substrate 81 using, e.g., a sputtering method or a chemical vapor deposition (CVD) method, to form the piezoelectric body 82. Alternatively, a sol-gel method may be used.

[0037] As illustrated in FIG. 3C, after the piezoelectric body 82 having the crystal structure is formed on the substrate 81, nozzle processing is performed. Thus, the nozzle positions of the piezoelectric body and the substrate can be aligned. Accordingly, no step is formed between the piezoelectric body and the substrate, and the discharge direction is stabilized.

[0038] The method of forming the nozzle orifices 4 is not limited to any particular method and may be performed by, for example, dry etching.

[0039] On the other hand, in the bonding method illustrated in FIGS. 7A, 7B, and 7C described later, the substrate and the piezoelectric body are bonded after nozzle orifices are formed in the substrate and the piezoelectric body. In this case, a step is likely to be formed between the piezoelectric body and the substrate, and the discharge direction may be unstable. In a related art, a large displacement is needed to vibration a nozzle plate to discharge ink, thus requiring displacement of a bulk piezoelectric body having a high piezoelectric constant. When such a bulk piezoelectric body is used, members having different characteristics (the bulk piezoelectric body and the substrate) need be bonded to each other, which may cause the above-described problem.

[0040] FIGS. 4A, 4B, and 4C are other views illustrating the method of manufacturing the liquid discharge head according to the present embodiment. FIGS. 4A, 4B, and 4C are schematic exploded perspective views illustrating the bonding step in the present embodiment.

[0041] FIG. 4A is a schematic perspective view of the ceiling plate 86. The supply passage 87 is formed in the ceiling plate 86. FIG. 4B is a schematic perspective view of the common liquid chamber plate 83. The common liquid chamber 84 is formed in the common liquid chamber plate 83. FIG. 4C is a schematic perspective view of the nozzle plate 1 illustrated in FIGS. 3A to 3C.

[0042] Members illustrated in FIGS. 4A, 4B, and 4C are bonded to obtain the liquid discharge head according to the present embodiment illustrated in FIG. 1.

[0043] Example 1 and Comparative Example 1 In Example 1, the liquid discharge head illustrated in FIG. 1 is manufactured by the stacking method illustrated in FIGS. 3A, 3B, and 3C. First, a 10 μm thick silicon dioxide (SiO_2) film was formed on a Si substrate to form the substrate 81. Next, a 10 μm thick PZT film was formed on the SiO_2 film of the substrate 81 by a stacking method using a sputtering method, to form the piezoelectric body 82. Thus, the nozzle plate 1 was formed. Next, the nozzle plate 1 was subjected to dry etching to form nozzle orifices 4 each having a diameter of 25 μm .

[0044] Next, as illustrated in FIGS. 4A, 4B, and 4C, the respective members are bonded together. The common liquid chamber plate 83 was made of Si, and the common liquid chamber 84 and the partition wall 85 having the shapes illustrated in FIGS. 1 and 4B were formed. A metal member is used as the ceiling plate 86, and the supply passage 87 was formed in the ceiling plate 86. Next, the respective members were bonded to produce the liquid discharge head of Example 1 illustrated in FIG. 1. An electrode was formed to have a thickness of 0.1 μm on an upper portion of the piezoelectric body 82. Another electrode was formed to have a thickness of 0.1 μm on a lower portion of the piezoelectric body 82. With respect to the liquid discharge head thus obtained, when the amount of displacement of the nozzle plate 1 in the vicinity of the nozzle orifice 4 was examined, the amount of displacement of the nozzle was 600 nm.

[0045] Next, with respect to the obtained liquid dis-

charge head, discharge evaluation of discharging ink to a medium was performed to measure a deviation amount. The measurement conditions were as follows.

5 [Measurement Conditions]

[0046]

Number of nozzles: 1024 nozzles
 10 Droplet speed: 7 m/sec
 Distance between head and medium: 1mm
 Ink type: Aqueous pigment ink
 Viscosity of ink: 5cp

15 **[0047]** As a result, the average value of the deviation amount 3σ (μm) in the liquid discharge head of Example 1 was 3.3 μm , and it was found that the discharge deviation was restrained.

[0048] Next, as Comparative Example 1, a nozzle plate is formed using a bonding method instead of the stacking method in Example 1, to produce a liquid discharge head. In Comparative Example 1, the configuration and method illustrated in FIGS. 5 to 7C are employed. In Comparative Example 1, nozzle orifice 4a were formed for each of a substrate 81a and a bulk piezoelectric body 82a, and the substrate 81a and the bulk piezoelectric body 82a are bonded together with adhesive 92 to form a nozzle plate 1a. Next, a ceiling plate 86, a common liquid chamber plate 83, and the nozzle plate 1a were bonded together to obtain a liquid discharge head of Comparative Example 1.

[0049] The liquid discharge head obtained in Comparative Example 1 was measured in the same manner as in Example 1. As a result, the average value of the deviation amount 3σ (μm) in the liquid discharge head of Comparative Example 1 was 15.1 μm , and it was found that discharge deviation occurred.

[0050] Hereinafter, a liquid discharge head and a liquid discharge apparatus according to other embodiments of the present invention are described. FIG. 8 is a cross-sectional view of the liquid discharge head taken along a direction (pressure-chamber longitudinal direction) orthogonal to a nozzle arrangement direction of the liquid discharge head according to an embodiment of the present invention. FIG. 9 is a cross-sectional view of the liquid discharge head taken along the nozzle arrangement direction.

[0051] A liquid discharge head 100 according to the present embodiment includes a nozzle plate 1, a channel plate 2, and a diaphragm member 3 that are stacked and bonded. The nozzle plate 1 includes a piezoelectric body. The channel plate 2 is an individual channel member as an individual channel substrate. The diaphragm member 3 as a diaphragm substrate is a wall member. A common channel member 20 as a common channel substrate also serves as a frame member (frame substrate) of the head. In addition, a piezoelectric actuator 11 that displaces a vibration region (diaphragm) 30 of the diaphragm mem-

ber 3 may be further provided.

[0052] The nozzle plate 1 has a plurality of nozzles (nozzle orifices) 4 that discharge liquid.

[0053] The channel plate 2 forms a plurality of pressure chambers 6 communicating with the plurality of nozzles 4, a plurality of individual supply channels 7 that are individual channels communicating with the respective pressure chambers 6, and a plurality of intermediate supply channels 8 that are liquid introduction portions each communicating with one or a plurality of individual supply channels 7 (e.g., one individual supply channel in the present embodiment).

[0054] The diaphragm member 3 includes a plurality of displaceable diaphragms (vibration regions) 30 that form wall surfaces of the pressure chambers 6 of the channel plate 2. Here, the diaphragm member 3 has a two-layer structure and includes a first layer 3A forming a thin portion and a second layer 3B forming a thick portion in this order from a side facing the channel plate 2. Note that the structure of the diaphragm substrate is not limited to such a two-layer structure and may be any suitable layer structure.

[0055] The displaceable vibration region 30 is formed in a portion corresponding to the pressure chamber 6 in the first layer 3A that is a thin portion. In the vibration region 30, a convex portion 30a is formed as a thick portion joined to the piezoelectric actuator 11 in the second layer 3B.

[0056] The piezoelectric actuator 11 including an electromechanical transducer element serving as a driving device (an actuator device or a pressure generator device) to deform the vibration region 30 of the diaphragm member 3 is disposed on a side of the diaphragm member 3 opposite a side facing the pressure chamber 6.

[0057] In the piezoelectric actuator 11, a piezoelectric member bonded on the base 13 is grooved by half-cut dicing, to form a desired number of columnar piezoelectric elements 12 at predetermined intervals in the nozzle arrangement direction so as to have a comb shape. The piezoelectric element 12 is bonded to the convex portion 30a that is a thick portion in the vibration region 30 of the diaphragm member 3.

[0058] The piezoelectric element 12 includes piezoelectric layers and internal electrodes alternately laminated on each other. Each internal electrode is led out to an end surface and connected to an external electrode (end surface electrode). The external electrode is connected with a flexible wiring member 15.

[0059] The common channel member 20 forms a common supply channel 10 communicated with the plurality of pressure chambers 6. The common supply channel 10 is communicated with the intermediate supply channel 8 as a liquid introduction portion via an opening 9 provided in the diaphragm member 3 and is communicated with the individual supply channel 7 via the intermediate supply channel 8.

[0060] In the liquid discharge head 100, for example, the voltage to be applied to the piezoelectric element 12

is lowered from a reference potential (intermediate potential) so that the piezoelectric element 12 contracts to pull the vibration region 30 of the diaphragm member 3 to increase the volume of the pressure chamber 6. As a result, liquid flows into the pressure chamber 6.

[0061] Thereafter, the voltage applied to the piezoelectric element 12 is increased to extend the piezoelectric element 12 in the stacking direction, and the vibration region 30 of the diaphragm member 3 is deformed in the direction toward the nozzle 4 to contract the volume of the pressure chamber 6. Accordingly, the liquid in the pressure chamber 6 is pressurized and discharged from the nozzle 4.

[0062] FIG. 10 is a cross-sectional view of a liquid discharge head according to another embodiment, taken along a direction (pressure-chamber longitudinal direction) orthogonal to a nozzle arrangement direction of the liquid discharge head. FIG. 11 is a schematic perspective view of the liquid discharge head according to the present embodiment.

[0063] A liquid discharge head 100 according to the present embodiment is a circulation type liquid discharge head, and includes a nozzle plate 1, a channel plate 2, and a diaphragm member 3 as a wall member, which are stacked and bonded together. The liquid discharge head 100 further includes a piezoelectric actuator 11 to displace a vibration region (diaphragm) 30 of the diaphragm member 3 and a common channel member 20 that also serves as a frame member of the liquid discharge head 100.

[0064] The channel plate 2 forms a plurality of pressure chambers 6 communicating with the plurality of nozzles 4 via nozzle communication passages 5, individual supply channels 7 also serving as a plurality of fluid restrictors communicating with the plurality of pressure chambers 6, and intermediate supply channels 8 serving as one or a plurality of liquid introduction portions communicating with two or more individual supply channels 7.

[0065] Similarly to the above-described embodiment, the individual supply channel 7 includes two channel portions, i.e., a first channel portion 7A and a second channel portion 7B having a higher fluid resistance than the pressure chamber 6, and a third channel portion 7C disposed between the first channel portion 7A and the second channel portion 7B and having a lower fluid resistance than each of the first channel portion 7A and the second channel portion 7B.

[0066] The channel plate 2 has a configuration in which a plurality of plate members 2A to 2E are stacked one on another. However, the configuration of the channel plate is not limited thereto.

[0067] The channel plate 2 forms a plurality of individual collection channels 57 and a plurality of intermediate collection channels 58. The plurality of individual collection channels 57 are formed along the surface direction of the channel plate 2 that respectively communicate with the plurality of pressure chambers 6 via the nozzle communication passages 5. The intermediate collection

channels 58 serves as one or a plurality of liquid lead-out portions that communicate with two or more individual collection channels 57.

[0068] The individual collection channel 57 includes two channel portions, i.e., a first channel portion 57A and a second channel portion 57B having a higher fluid resistance than the pressure chamber 6, and a third channel portion 57C disposed between the first channel portion 57A and the second channel portion 57B and having a lower fluid resistance than each of the first channel portion 57A and the second channel portion 57B. In the individual collection channel 57, a channel portion 57D downstream from the second channel portion 57B in the direction of circulation of the liquid has the same channel width as the third channel portion 57C.

[0069] The common channel member 20 forms a common supply channel 10 and a common collection channel 50. In the present embodiment, the common supply channel 10 includes a channel portion 10A that is disposed side by side with the common collection channel 50 in the nozzle arrangement direction and a channel portion 10B that is not disposed side by side with the common collection channel 50.

[0070] The common supply channel 10 is communicated with the intermediate supply channel 8 as a liquid introduction portion via an opening 9 provided in the diaphragm member 3 and is communicated with the individual supply channel 7 via the intermediate supply channel 8. The common collection channel 50 is communicated with the intermediate collection channel 58 via an opening 59 provided in the diaphragm member 3 and is communicated with the individual collection channel 57 via the intermediate collection channel 58.

[0071] The common supply channel 10 communicates with supply ports 71. The common collection channel 50 communicates with collection ports 72.

[0072] The layer structure of the diaphragm member 3 and the structure of the piezoelectric actuator 11 are the same as those in the above-described embodiment.

[0073] Also in the liquid discharge head 100, in the same manner as above, the piezoelectric element 12 is extended in the stacking direction, and the vibration region 30 of the diaphragm member 3 is deformed in the direction toward the nozzle 4 to contract the volume of the pressure chamber 6. Accordingly, the liquid in the pressure chamber 6 is pressurized and discharged from the nozzle 4.

[0074] The liquid not discharged from the nozzle 4 passes by the nozzle 4, is collected from the individual collection channel 57 to the common collection channel 50, and is supplied again from the common collection channel 50 to the common supply channel 10 through an external circulation passage. In addition, even when the liquid is not discharged from the nozzle 4, the liquid circulates from the common supply channel 10 to the common collection channel 50 through the pressure chamber 6 and is supplied again to the common supply channel 10 through the external circulation passage.

[0075] Accordingly, also in the present embodiment, the pressure fluctuation accompanying liquid discharge can be attenuated with a simple configuration, thus restraining propagation to the common supply channel 10 and the common collection channel 50.

[0076] Next, a liquid discharge apparatus according to an embodiment of the present invention is described with reference to FIGS. 12 and 13. FIG. 12 is a schematic view of the liquid discharge apparatus according to the present embodiment. FIG. 13 is a plan view of an example of a head unit of the liquid discharge apparatus.

[0077] A printing apparatus 500 serving as the liquid discharge apparatus according to the present embodiment includes, e.g., a feeder 501, a guide conveyor 503, a printer 505, a drier 507, and a carrier 509. The feeder 501 feeds a continuous medium (or a web) 510 inward. The guide conveyor 503 guides and conveys the continuous medium 510 such as a continuous sheet of paper or a sheet medium fed inward from the feeder 501. The printer 505 performs printing by discharging liquid onto the conveyed continuous medium 510 to form an image. The drier 507 dries the continuous medium 510 with the image formed. The carrier 509 feeds the dried continuous medium 510 outward.

[0078] The continuous medium 510 is sent out from an original winding roller 511 of the feeder 501, is guided and conveyed by rollers of the feeder 501, the guide conveyor 503, the drier 507, and the carrier 509, and is wound up by a wind-up roller 591 of the carrier 509.

[0079] In the printer 505, the continuous medium 510 is conveyed on a conveyance guide 559 so as to face a head unit 550 and a head unit 555. An image is formed with the liquid discharged from the head unit 550, and post-processing is performed with the processing liquid discharged from the head unit 555.

[0080] In the head unit 550, for example, full-line head arrays 551A, 551B, 551C, and 551D for four colors (hereinafter referred to as the "head arrays 551" unless the colors distinguished) are arranged in this order from the upstream side in a direction of conveyance of the continuous medium 510.

[0081] The head arrays 551A, 551B, 551C, and 551D are liquid dischargers to discharge liquids of, for example, black (K), cyan (C), magenta (M), and yellow (Y), respectively, onto the continuous medium 510 being conveyed. Note that the type and number of colors are not limited to the above-described example.

[0082] In the head array 551, for example, the liquid discharge heads 100 (which may be simply referred to as "heads 100") according to an embodiment of the present invention are arranged in a staggered manner on a base 552. Note that embodiments of the present invention are not limited to the arrangement and may be any other suitable head arrangement.

[0083] The liquid discharge head and the liquid discharge apparatus according to embodiments of the present invention may have a configuration of circulating liquid, and may be, for example, a liquid circulating ap-

paratus using the liquid discharge head. An example of the liquid circulating apparatus is described with reference to FIG. 14. FIG. 14 is a block diagram of an example of the liquid circulating apparatus. Although only one head is illustrated in FIG. 14, in a case in which a plurality of heads are arranged, a supply-side liquid path and a collection-side liquid path, respectively, are connected to the supply side and the collection side of a plurality of heads via, e.g., a manifold.

[0084] A liquid circulating apparatus 600 illustrated in FIG. 14 includes, for example, a supply tank 601, a collection tank 602, a main tank 603, a first liquid feed pump 604, a second liquid feed pump 605, a compressor 611, a regulator 612, a vacuum pump 621, a regulator 622, a supply-side pressure sensor 631, and a collection-side pressure sensor 632.

[0085] The compressor 611 and the vacuum pump 621 together generate a pressure difference between the supply tank 601 and the collection tank 602.

[0086] The supply-side pressure sensor 631 is disposed between the supply tank 601 and the head 100 and connected to a supply-side liquid path connected to a supply port 71 of the head 100. The collection-side pressure sensor 632 is disposed between the head 100 and the collection tank 602 and connected to a collection-side liquid path connected to a collection port 72 of the head 100.

[0087] One end of the collection tank 602 is connected to the supply tank 601 via the first liquid feed pump 604, and the other end of the collection tank 602 is connected to the main tank 603 via the second liquid feed pump 605.

[0088] Accordingly, the liquid flows into the head 100 from the supply tank 601 through the supply port 71, is collected to the collection tank 602 from the collection port 72, and is sent from the collection tank 602 to the supply tank 601 by the first liquid feed pump 604, thereby forming a circulation path through which the liquid circulates.

[0089] Here, the compressor 611 is connected to the supply tank 601 and is controlled so that a predetermined positive pressure is detected by the supply-side pressure sensor 631. On the other hand, the vacuum pump 621 is connected to the collection tank 602 and is controlled so that a predetermined negative pressure is detected by the collection-side pressure sensor 632.

[0090] Thus, the negative pressure of the meniscus can be kept constant while the liquid is circulated through the head 100.

[0091] When the liquid is discharged from the nozzles 4 of the head 100, the amount of liquid in the supply tank 601 and the collection tank 602 decreases. Therefore, the liquid is appropriately replenished from the main tank 603 to the collection tank 602 using the second liquid feed pump 605.

[0092] The timing of liquid replenishment from the main tank 603 to the collection tank 602 can be controlled based on, for example, the detection result of a liquid level sensor provided in the collection tank 602. In such

a case, for example, liquid replenishment may be performed when the liquid level of the liquid in the collection tank 602 falls below a predetermined height.

[0093] Next, another example of a printing apparatus as a liquid discharge apparatus according to an embodiment of the present invention is described with reference to FIGS. 15 and 16. FIG. 15 is a plan view of a main part of the printing apparatus. FIG. 16 is a side view of the main part of the printing apparatus.

[0094] A printing apparatus 500 serving as the liquid discharge apparatus according to the present embodiment is a serial-type apparatus in which a main-scanning moving mechanism 493 reciprocates a carriage 403 in main scanning directions. A main-scanning moving mechanism 493 includes, e.g., a guide 401, a main-scanning motor 405, and a timing belt 408. The guide 401 is bridged between left and right side plates 491A and 491B to moveably hold the carriage 403. The main-scanning motor 405 reciprocates the carriage 403 in the main-scanning directions via the timing belt 408 bridged between a drive pulley 406 and a driven pulley 407.

[0095] A liquid discharge device 440 including a liquid discharge head 100 and a head tank 441 as a single unit is mounted on the carriage 403. The liquid discharge head 100 of the liquid discharge device 440 discharges color liquids of, for example, yellow (Y), cyan (C), magenta (M), and black (K). The liquid discharge head 100 is mounted on the carriage 403 such that a nozzle row including a plurality of nozzles is arranged in a sub-scanning direction perpendicular to the main scanning direction and a direction of discharge of color liquid is downward.

[0096] The liquid discharge head 100 is connected to the liquid circulating apparatus 600 described above, and liquid of desired colors is circulated and supplied.

[0097] The printing apparatus 500 includes a conveyance mechanism 495 to convey a sheet 410. The conveyance mechanism 495 includes a conveyance belt 412 serving as a conveyor and a sub-scanning motor 416 to drive the conveyance belt 412.

[0098] The conveyance belt 412 attracts the sheet 410 and conveys the sheet 410 to a position facing the liquid discharge head 100. The conveyance belt 412 is an endless belt stretched between a conveyance roller 413 and a tension roller 414. The sheet 410 is attracted to the conveyance belt 412 by electrostatic force or air aspiration.

[0099] The conveyance belt 412 circumferentially moves in the sub-scanning direction as the conveyance roller 413 is rotationally driven by the sub-scanning motor 416 via a timing belt 417 and a timing pulley 418.

[0100] On one side of the carriage 403 in the main scanning direction, a maintenance mechanism 420 that maintains and recovers the liquid discharge head 100 is disposed lateral to the conveyance belt 412.

[0101] The maintenance mechanism 420 includes, for example, a cap 421 to cap a nozzle face (i.e., a face on which nozzles are formed) of the liquid discharge head

100 and a wiper 422 to wipe the nozzle face.

[0102] The main-scanning moving mechanism 493, the maintenance mechanism 420, and the conveyance mechanism 495 are installed onto a housing including the side plates 491A and 491B and a back plate 491C.

[0103] In the printing apparatus 500 having the above-described configuration, the sheet 410 is fed and attracted onto the conveyance belt 412 and conveyed in the sub-scanning direction by the circumferential movement of the conveyance belt 412.

[0104] The liquid discharge head 100 is driven in response to an image signal while moving the carriage 403 in the main scanning direction to discharge the liquid onto the sheet 410 not in motion, thereby recording an image.

[0105] Next, an example of a liquid discharge device using a liquid discharge head according to an embodiment of the present invention is described with reference to FIG. 17. FIG. 17 is a plan view of a main part of the liquid discharge device.

[0106] A liquid discharge device 440 according to the present embodiment includes a housing including side plates 491A and 491B and a back plate 491C, a main-scanning moving mechanism 493, a carriage 403, and a liquid discharge head 100, among the components or members of the printing apparatus 500 as the liquid discharge apparatus described above.

[0107] Note that a liquid discharge device may have a configuration in which the above-described maintenance mechanism 420 is further attached to, for example, the side plate 491B of the liquid discharge device 440.

[0108] Next, still another example of the liquid discharge device is described with reference to FIG. 18. FIG. 18 is a front view of a main part of the liquid discharge device.

[0109] The liquid discharge device 440 includes a liquid discharge head 100 to which a channel component 444 is attached and tubes 456 connected to the channel component 444.

[0110] The channel component 444 is disposed inside a cover 442. In some embodiments, the liquid discharge device 440 may include the head tank 441 described above instead of the channel component 444. A connector 443 for electrically connecting to the liquid discharge head 100 is provided on the channel component 444.

[0111] In the present invention, the liquid to be discharged is not limited to a particular liquid as long as the liquid has a viscosity or surface tension to be discharged from a head (a liquid discharge head). However, preferably, the viscosity of the liquid is not greater than 30 mPa·s under ordinary temperature and ordinary pressure or by heating or cooling. More specifically, the liquid to be discharged is a solution, a suspension liquid, an emulsion, or the like containing a solvent such as water or an organic solvent, a colorant such as a dye or a pigment, a function-imparting material such as a polymerizable compound, a resin, or a surfactant, a biocompatible material such as deoxyribonucleic acid (DNA), amino acid, protein, or calcium, or an edible material such as a natural

pigment, which can be used, for example, for an inkjet ink, a surface treatment liquid, a liquid for forming a constituent element of an electronic element or a light emitting element or an electronic circuit resist pattern, a three-dimensional modeling material liquid, or the like.

[0112] Examples of an energy source for generating energy to discharge liquid include a piezoelectric actuator (a laminated piezoelectric element or a thin-film piezoelectric element), a thermal actuator that employs a thermoelectric conversion element, such as a thermal resistor, and an electrostatic actuator including a diaphragm and opposed electrodes.

[0113] The liquid discharge device is an integrated unit including the liquid discharge head and a functional part(s) or unit(s), and is an assembly of parts relating to liquid discharge. Examples of the liquid discharge device include a combination of a liquid discharge head with at least one of a head tank, a carriage, a supply mechanism, a maintenance mechanism, a main-scanning moving mechanism, and a liquid circulating apparatus.

[0114] Herein, the terms "combined" or "integrated" mean attaching the liquid discharge head and the functional parts (or mechanism) to each other by fastening, screwing, binding, or engaging and holding one of the liquid discharge head and the functional parts to the other movably relative to the other. The liquid discharge head, functional component, and mechanism may also be detachably attached to one another.

[0115] For example, the liquid discharge head and the head tank are integrated as the liquid discharge device. Alternatively, the liquid discharge head may be coupled with the head tank through a tube or the like to integrally form the liquid discharge device. Here, a unit including a filter may further be added to a portion between the head tank and the liquid discharge head.

[0116] In another example, the liquid discharge device may include a liquid discharge head integrated with a carriage as a single unit.

[0117] Examples of the liquid discharge device further include those in which a liquid discharge head and a scanning moving mechanism are integrated in such a manner that the liquid discharge head is movably held by a guide that constitutes a part of the scanning moving mechanism. Examples of the liquid discharge device include discharge devices in which a liquid discharge head, a carriage, and a main-scanning moving mechanism are integrated as a single unit.

[0118] In still another example, the cap that forms part of the maintenance unit is secured to the carriage mounting the liquid discharge head so that the liquid discharge head, the carriage, and the maintenance unit are integrated as a single unit to form the liquid discharge device.

[0119] Further, in still another example, the liquid discharge device includes tubes connected to the head tank or the head mounting the channel member so that the liquid discharge head and the supply unit are integrated as a single unit. Through the tubes, the liquid of a liquid storage source such as an ink cartridge is supplied to the

head.

[0120] The main-scanning moving mechanism may be a guide only. The supply mechanism may be a tube(s) only or a loading unit only.

[0121] The term "liquid discharge apparatus" used herein also represents an apparatus including the head or the liquid discharge device to discharge liquid by driving the head. The liquid discharge apparatus may be, for example, an apparatus capable of discharging liquid to a material to which liquid can adhere or an apparatus to discharge liquid toward gas or into liquid.

[0122] The liquid discharge apparatus may include a means relating to feeding, conveyance, and sheet ejection of the material to which liquid can adhere and also include a pre-treatment apparatus and a post-processing apparatus.

[0123] The liquid discharge apparatus may be, for example, an image forming apparatus to form an image on a sheet by discharging ink, or a three-dimensional apparatus to discharge a molding liquid to a powder layer in which powder material is formed in layers, so as to form a three-dimensional article.

[0124] The liquid discharge apparatus is not limited to an apparatus that discharges liquid to visualize meaningful images such as letters or figures. For example, the liquid discharge apparatus may be an apparatus that forms meaningless images such as meaningless patterns or an apparatus that fabricates three-dimensional images.

[0125] The above-described term "material to which liquid can adhere" denotes, for example, a material or a medium to which liquid can adhere at least temporarily, a material or a medium to which liquid can attach and firmly adhere, or a material or a medium to which liquid can adhere and into which the liquid permeates. Examples of the "material to which liquid can adhere" include recording media or medium such as a paper sheet, a recording paper, and a recording sheet of paper, film, and cloth, electronic components such as an electronic substrate and a piezoelectric element, and media or medium such as a powder layer, an organ model, and a testing cell. The "material onto which liquid adheres" includes any material on which liquid can adhere unless particularly limited.

[0126] Examples of the material to which liquid can adhere include any materials to which liquid can adhere even temporarily, such as paper, thread, fiber, fabric, leather, metal, plastic, glass, wood, and ceramic.

[0127] The liquid discharge apparatus may be an apparatus to relatively move a liquid discharge head and a material on which liquid can adhere. However, the liquid discharge apparatus is not limited to such an apparatus. For example, the liquid discharge apparatus may be a serial head apparatus that moves the liquid discharge head or a line head apparatus that does not move the liquid discharge head.

[0128] Examples of the liquid discharge apparatus further include a treatment liquid coating apparatus to dis-

charge a treatment liquid to a sheet to coat the treatment liquid on a sheet surface to reform the sheet surface and an injection granulation apparatus in which a composition liquid including raw materials dispersed in a solution is discharged through nozzles to granulate fine particles of the raw materials.

[0129] The terms "image formation", "recording", "printing", "image printing", and "fabricating" are herein used as synonyms.

Claims

1. A liquid discharge head (100), comprising:

a nozzle plate (1) configured to vibrate to discharge liquid,
the nozzle plate including:

a substrate (81);
a piezoelectric body (82) disposed closer to a discharge target than the substrate, the piezoelectric body (82) including lead zirconate titanate (PZT); and
a nozzle orifice (4) penetrating the substrate and the piezoelectric body,

wherein, when a direction from one opening to another opening in the nozzle orifice is a discharge direction of the liquid, the PZT has a crystal structure extending parallel with the discharge direction.

2. The liquid discharge head according to claim 1, wherein the crystal structure is a columnar crystal.

3. A liquid discharge apparatus (500) comprising the liquid discharge head (100) according to claim 1 or 2.

4. A method of manufacturing the liquid discharge head (100) according to claim 1 or 2, the method comprising stacking the PZT on the substrate by a sputtering method or a chemical vapor deposition (CVD) method, to form the piezoelectric body (82).

5. The method according to claim 4, further comprising performing dry etching on the substrate and the piezoelectric body, after the piezoelectric body is formed on the substrate, to form the nozzle orifice (4).

FIG. 1

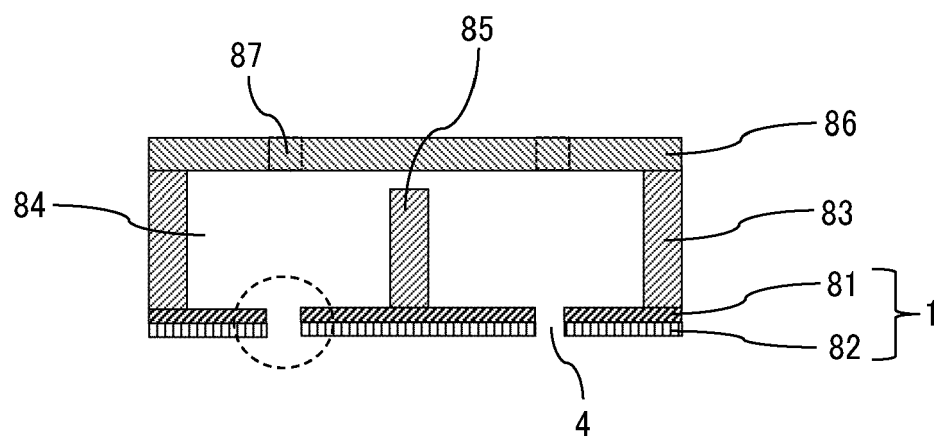


FIG. 2A

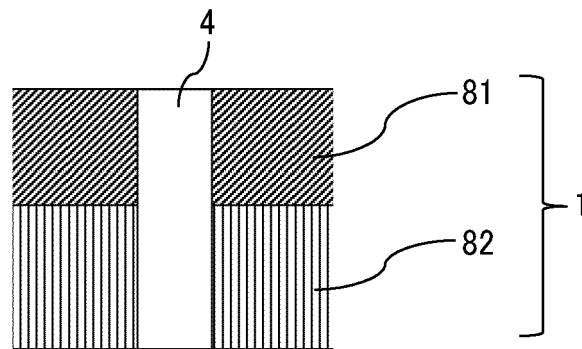


FIG. 2B

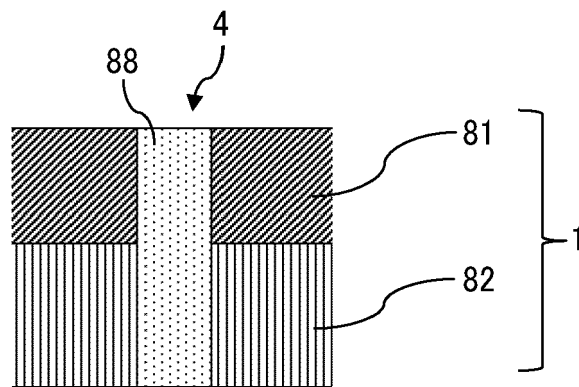


FIG. 2C

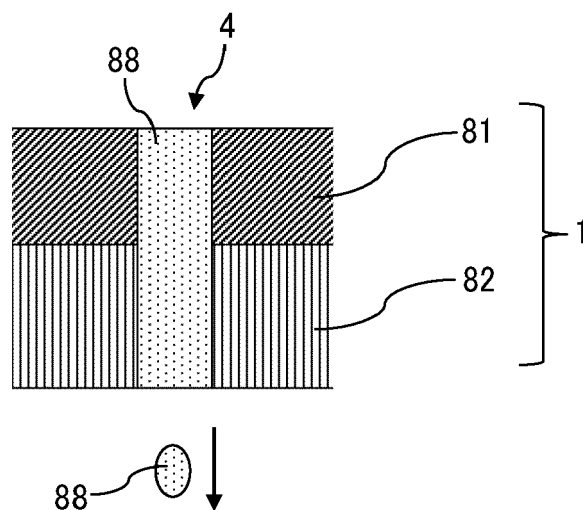


FIG. 3A

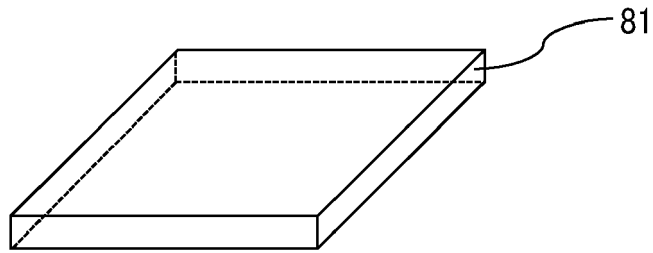


FIG. 3B

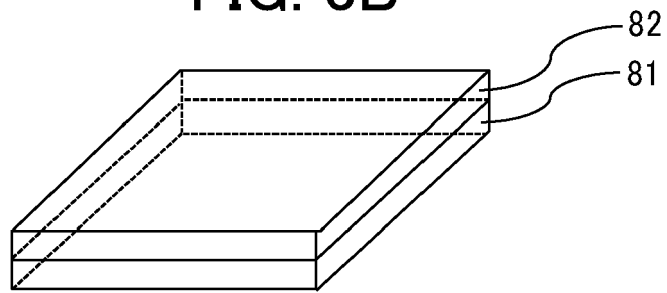


FIG. 3C

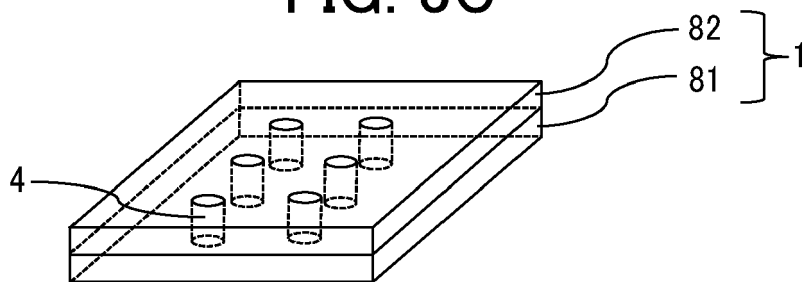


FIG. 4A

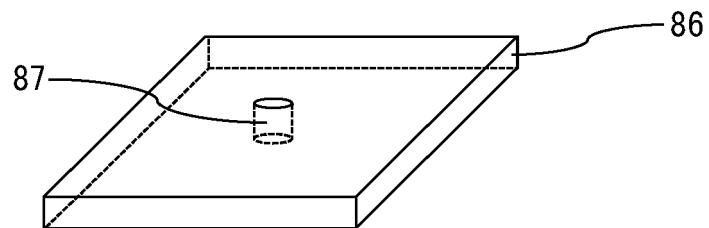


FIG. 4B

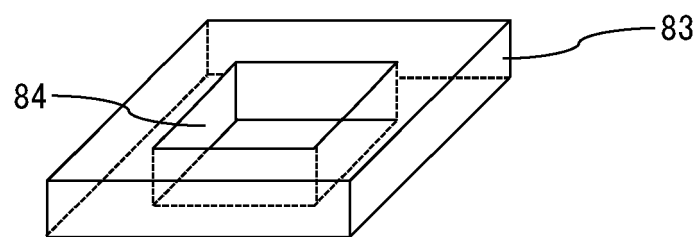


FIG. 4C

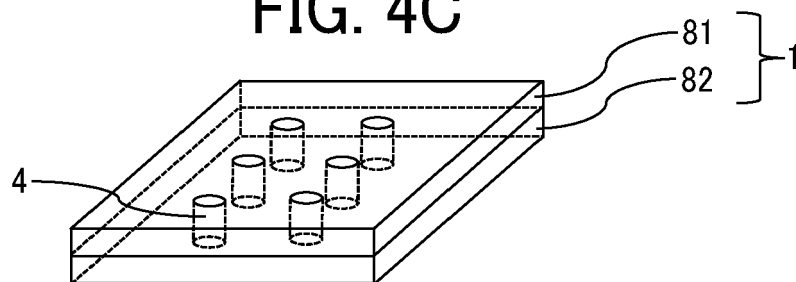


FIG. 5

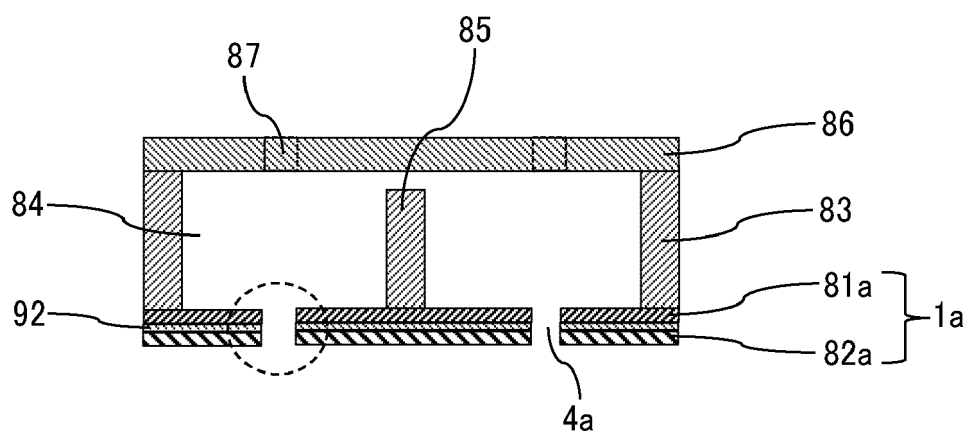


FIG. 6A

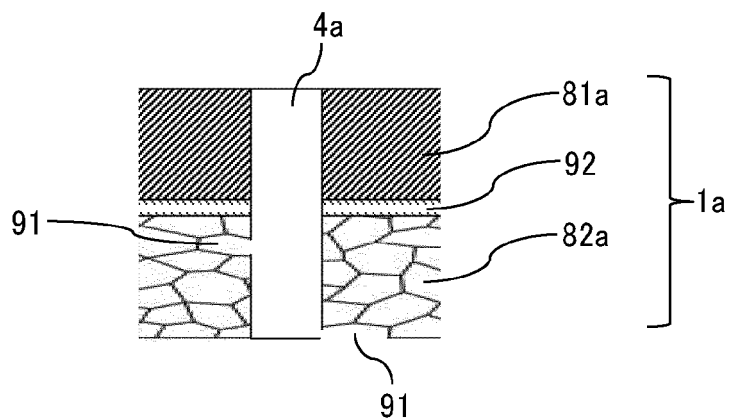


FIG. 6B

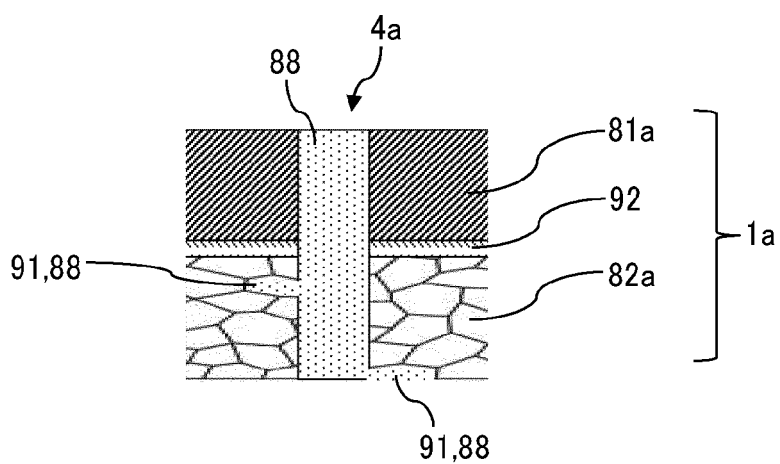


FIG. 6C

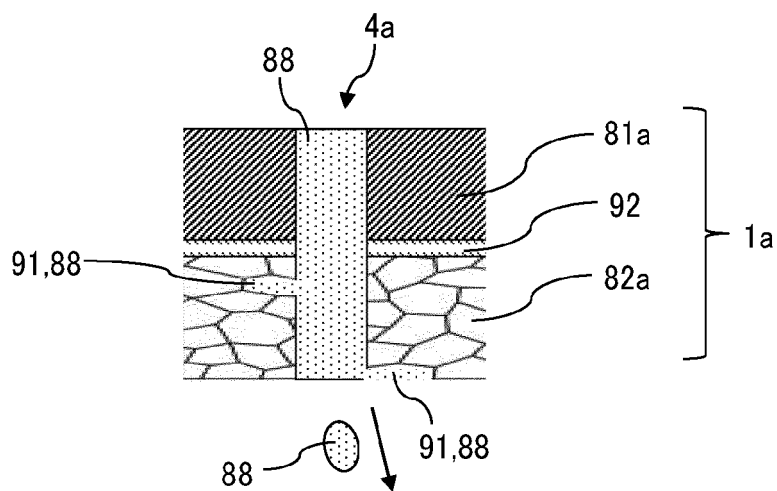


FIG. 7A

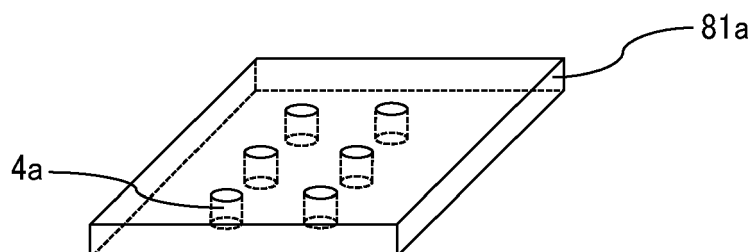


FIG. 7B

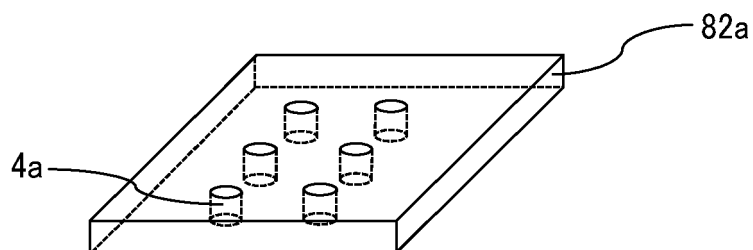


FIG. 7C

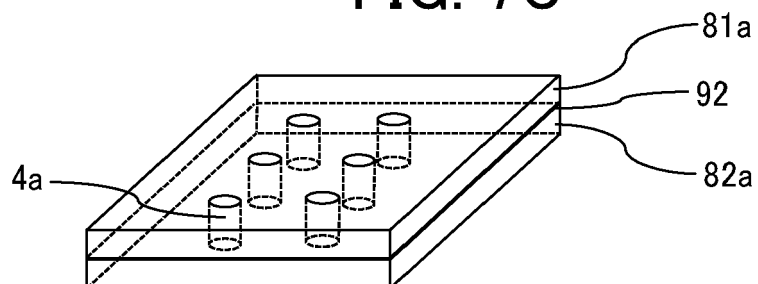


FIG. 8

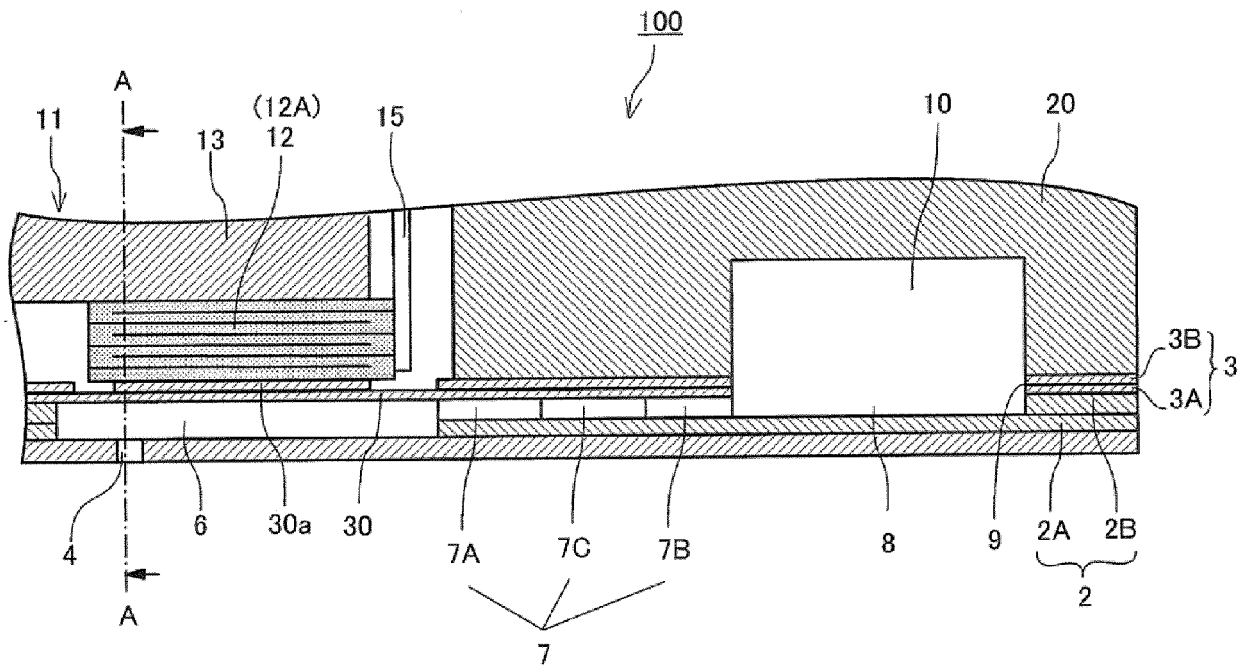


FIG. 9

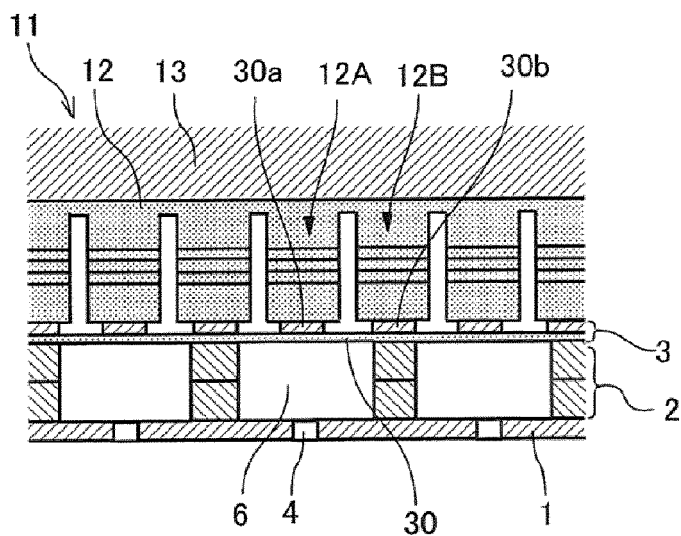


FIG. 10

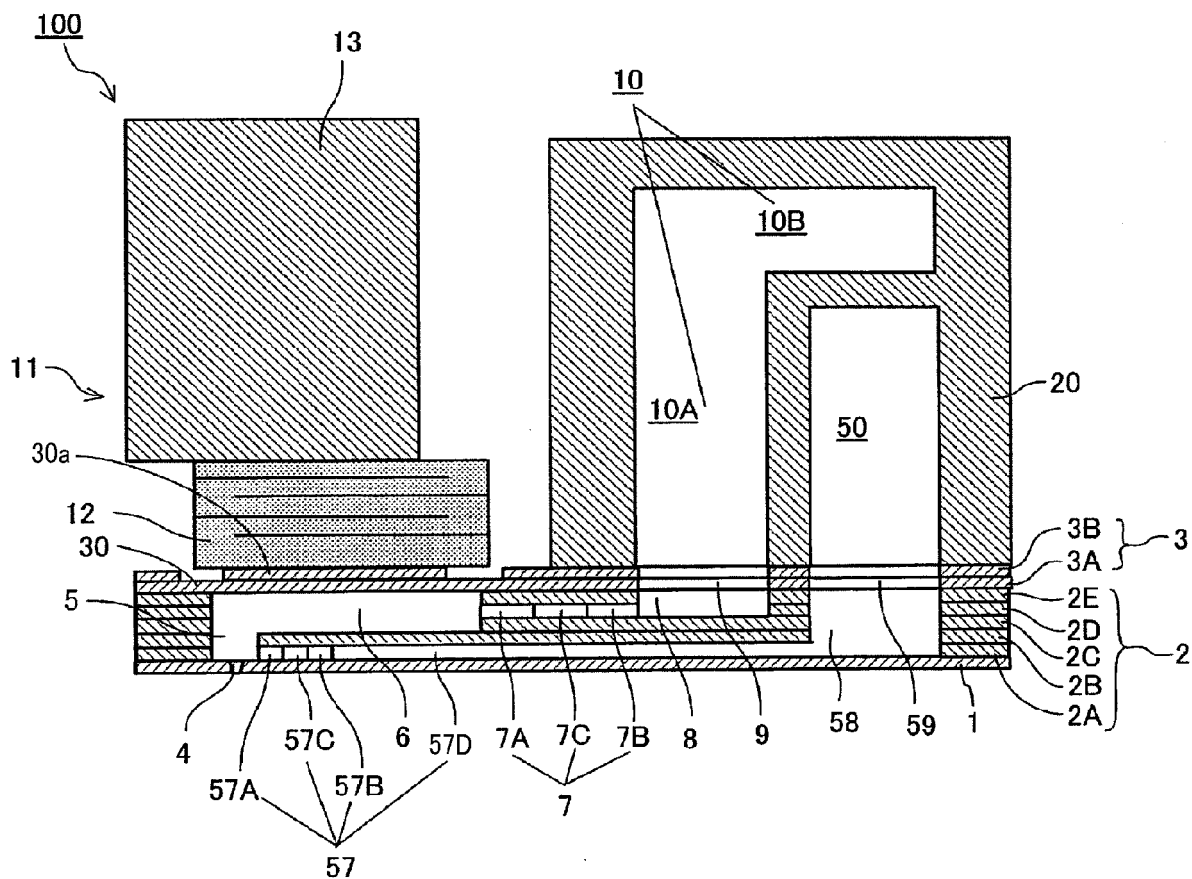


FIG. 11

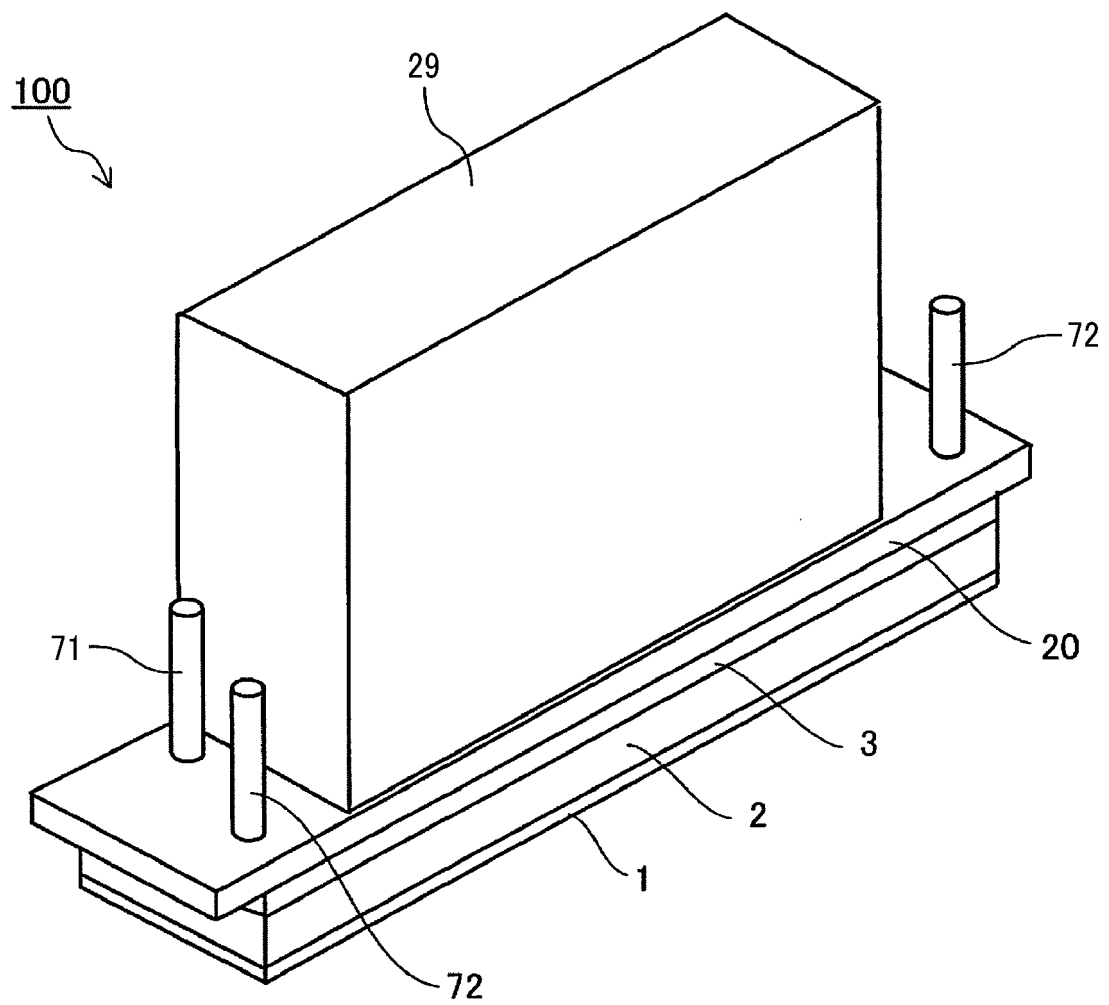


FIG. 12

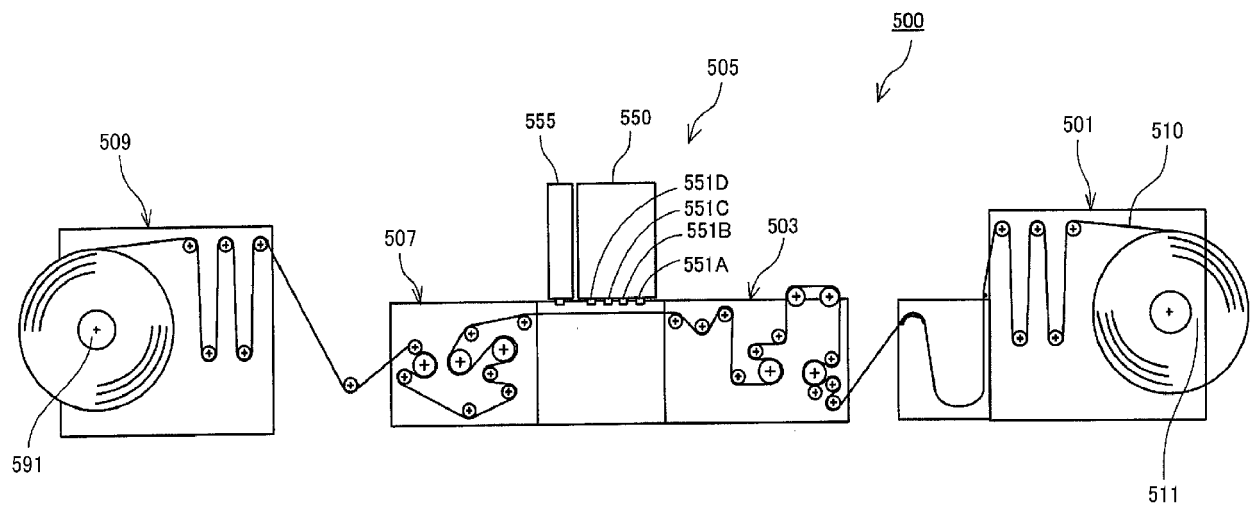


FIG. 13

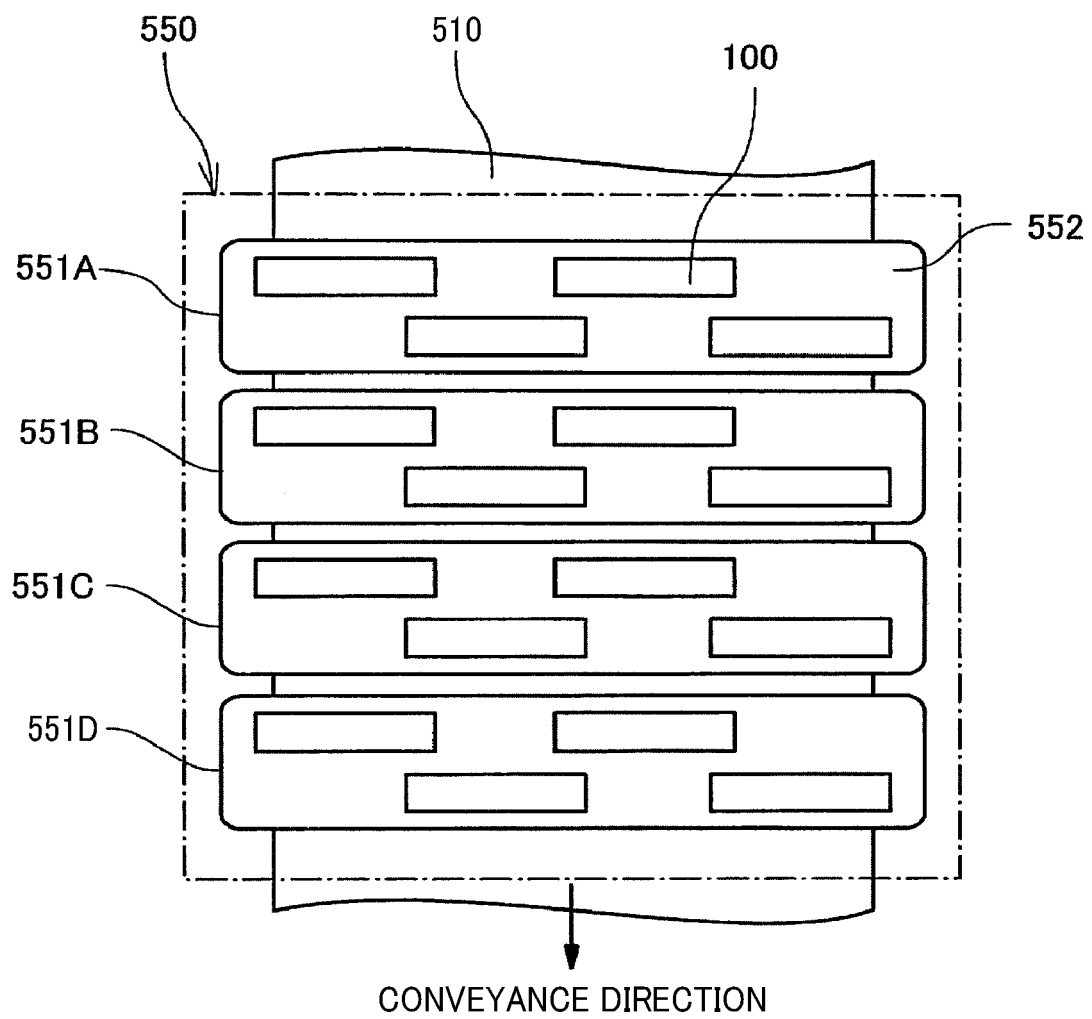


FIG. 14

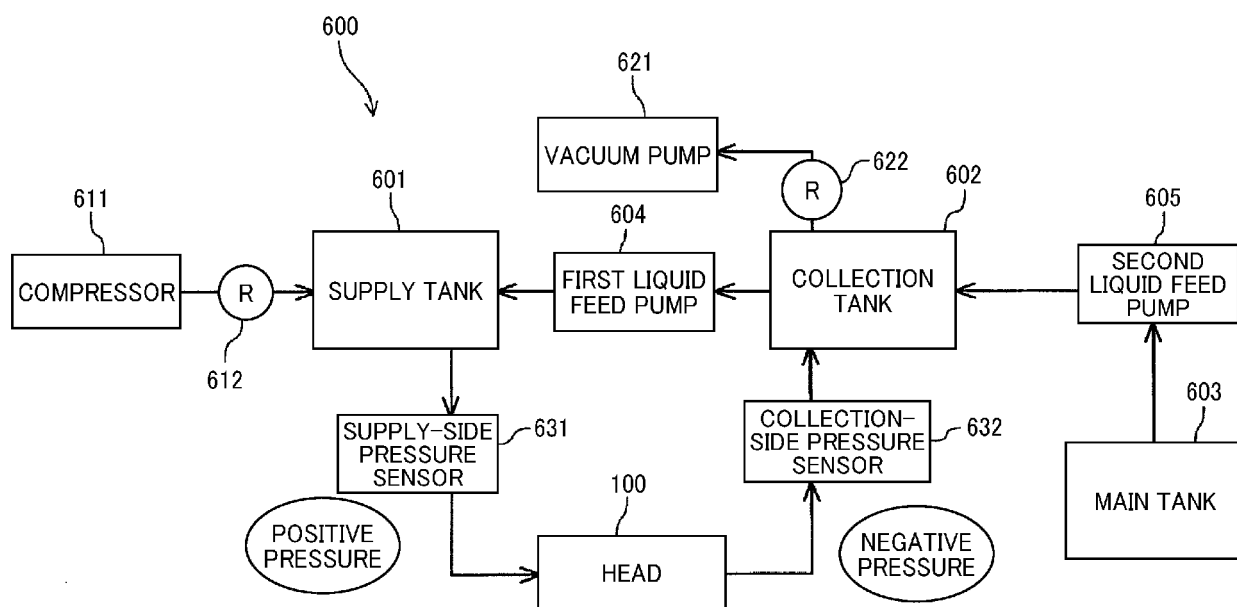


FIG. 15

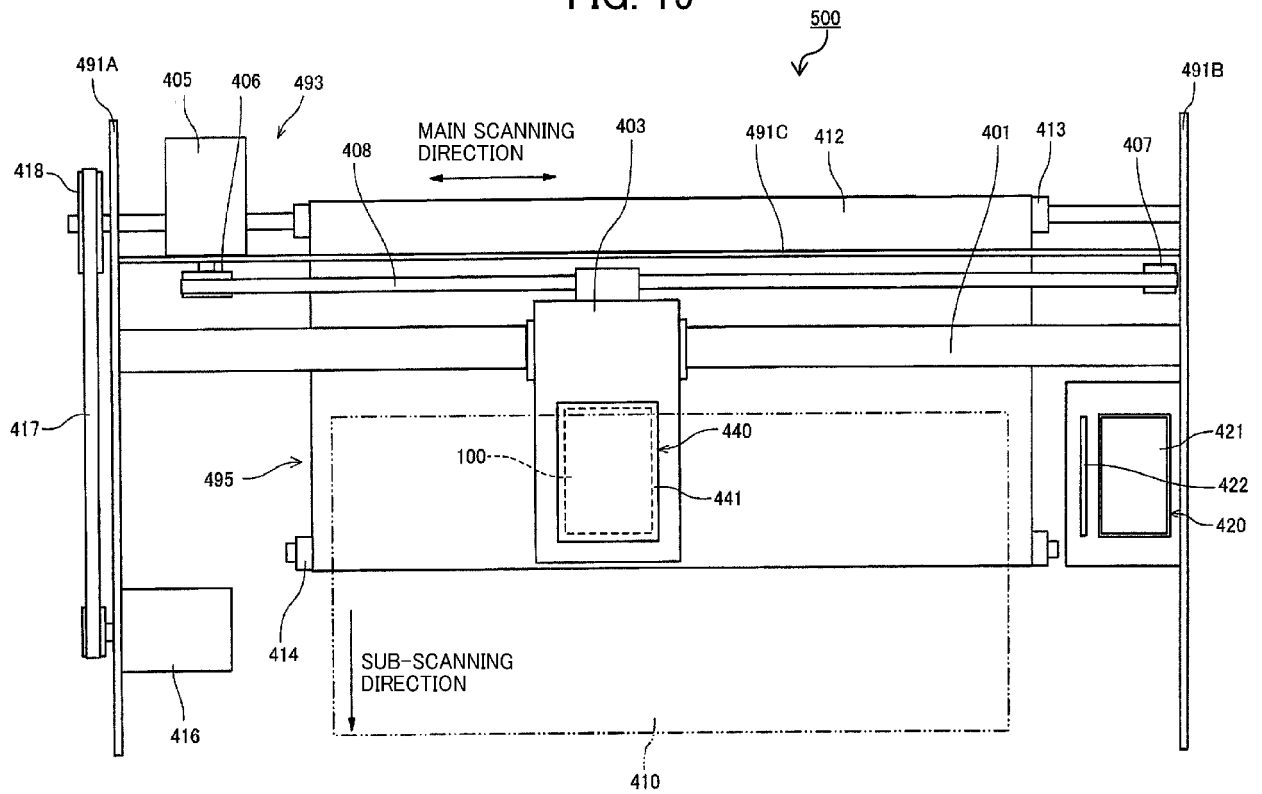


FIG. 16

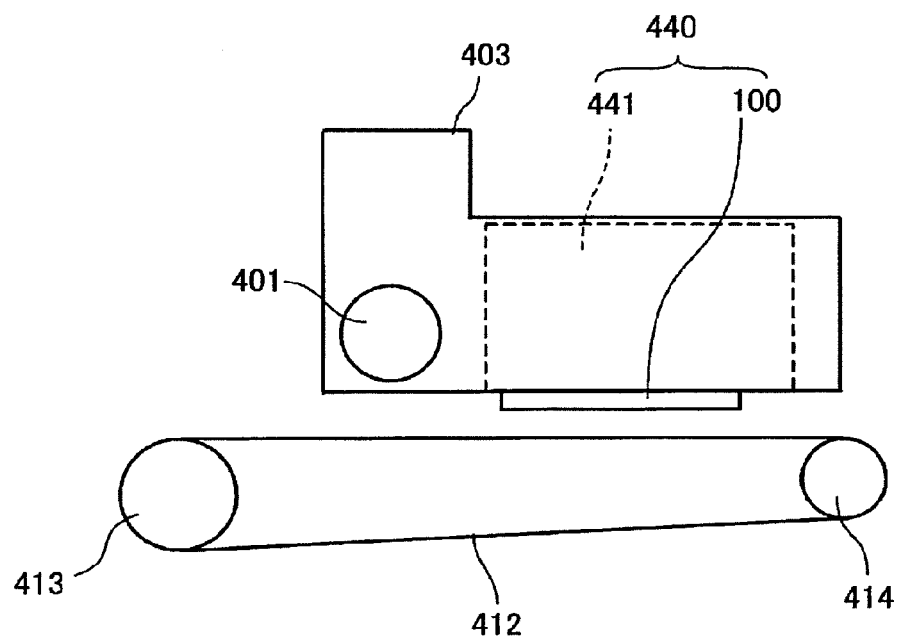


FIG. 17

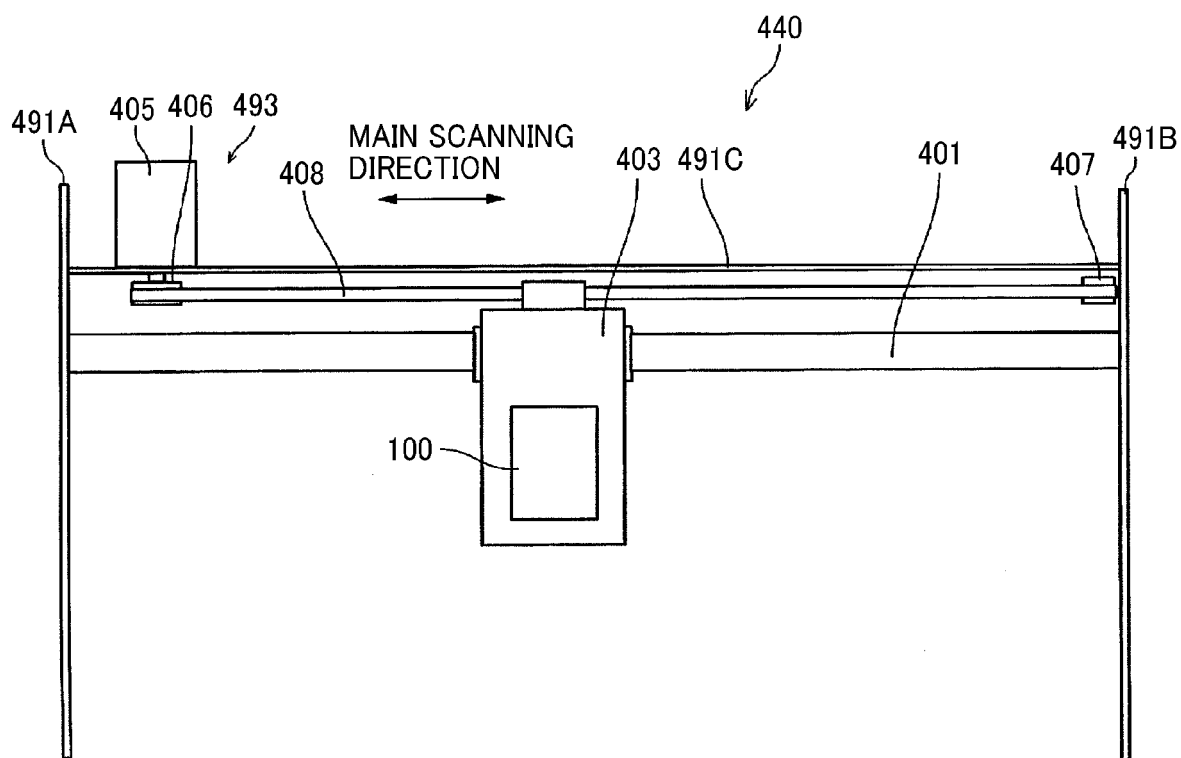
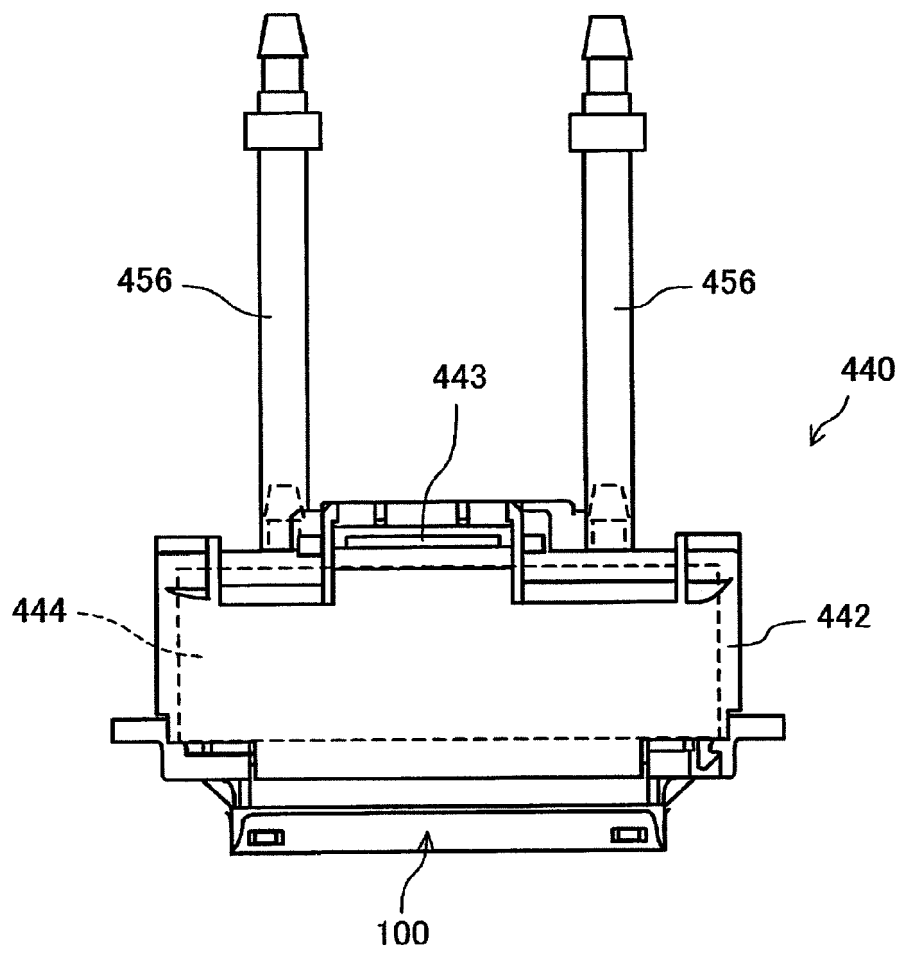


FIG. 18





EUROPEAN SEARCH REPORT

Application Number
EP 21 15 0875

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2006/059102 A1 (XAAR TECHNOLOGY LTD [GB]; TEMPLE STEVE [GB]; HARVEY ROBERT ALAN [GB]) 8 June 2006 (2006-06-08) * page 5, line 9 - page 7, line 10 * * figures *	1-3	INV. B41J2/14
X	US 2015/062254 A1 (KAWAKUBO TAKASHI [JP] ET AL) 5 March 2015 (2015-03-05) * paragraphs [0122] - [0127] * * figure 4 *	1-5	
A	EP 3 238 942 A1 (TOSHIBA TEC KK [JP]) 1 November 2017 (2017-11-01) * the whole document *	1-5	
A	EP 0 952 000 A2 (SEIKO EPSON CORP [JP]) 27 October 1999 (1999-10-27) * paragraphs [0027] - [0035] * * pages -; figures *	1-5	
			TECHNICAL FIELDS SEARCHED (IPC)
			B41J
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 8 June 2021	Examiner Didenot, Benjamin
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 21 15 0875

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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08-06-2021

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2006059102 A1	08-06-2006	NONE	
US 2015062254 A1	05-03-2015	JP 5771655 B2 JP 2015047726 A US 2015062254 A1	02-09-2015 16-03-2015 05-03-2015
EP 3238942 A1	01-11-2017	CN 107310273 A EP 3238942 A1 JP 2017196800 A US 2017313075 A1	03-11-2017 01-11-2017 02-11-2017 02-11-2017
EP 0952000 A2	27-10-1999	EP 0952000 A2 JP 4122564 B2 JP H11307833 A US 6411017 B1	27-10-1999 23-07-2008 05-11-1999 25-06-2002

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP H03065350 A [0003] [0004]
- JP 3427608 B [0004]
- JP H09226111 A [0004]