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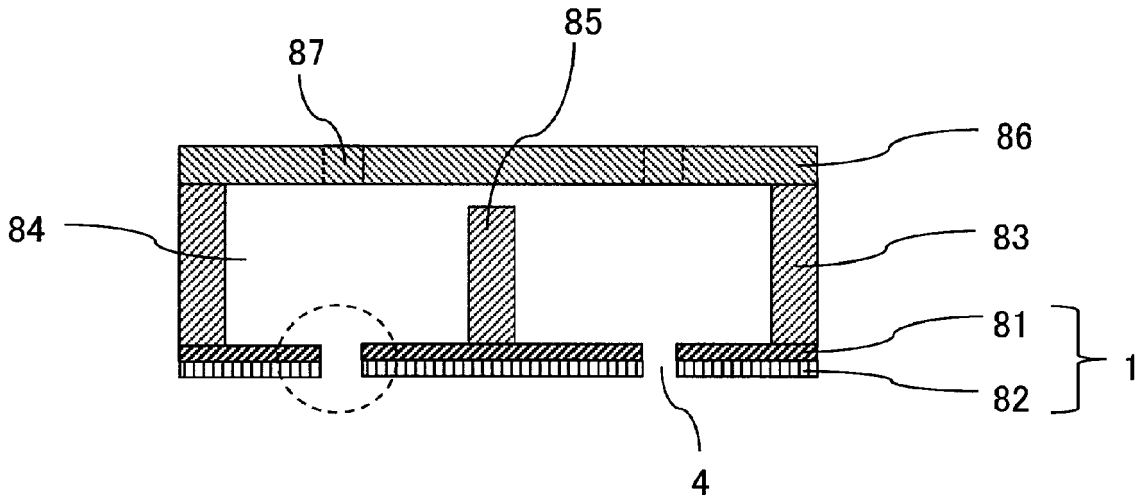
(54) **METHOD OF MANUFACTURING LIQUID DISCHARGE HEAD AND METHOD OF MANUFACTURING LIQUID DISCHARGE APPARATUS**

(57) There is provided a method of manufacturing a liquid discharge head (100) to vibrate a nozzle plate (1) including a substrate (81) and a piezoelectric body (82) to discharge liquid. The method includes forming the piezoelectric body (82) on the substrate (81) at 450°C to 600°C and forming a nozzle orifice (4) penetrating through the substrate (81) and the piezoelectric body (82).

FIG. 1



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Description

BACKGROUND

Technical Field

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

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, it is known that a large vibration is needed to discharge ink.

[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 such conventional techniques, sufficient vibration has not yet been ensured. On the other hand, in order to ensure sufficient vibration, for example, an attempt is conceivable to form a film of a piezoelectric body at a high temperature to increase the piezoelectric multiplier of the piezoelectric body and obtain a large displacement.

[0006] However, when a conventional method of manufacturing a thin-film piezoelectric body is applied to a liquid discharge head that vibrates a nozzle surface to discharge ink, a substrate may be warped due to a reason such as excessively high temperature. If nozzle orifices are formed on the substrate in such a warped state, there is a problem that variation may occur in the shape of nozzles in the substrate, thus causing variations in discharge characteristics.

SUMMARY

[0007] In light of the above-described problem, a purpose of the present invention is to restrain variations in discharge characteristics in a liquid discharge head that vibrates a nozzle plate to discharge liquid.

[0008] According to an aspect of the present disclosure, there is provided a method of manufacturing a liquid discharge head to vibrate a nozzle plate including a substrate and a piezoelectric body to discharge liquid. The method includes forming the piezoelectric body on the substrate at 450°C to 600°C and forming a nozzle orifice penetrating through the substrate and the piezoelectric body.

[0009] According to another aspect of the present disclosure, there is provided a method of manufacturing a liquid discharge apparatus including a liquid discharge head. The method includes manufacturing the liquid discharge head by the above-described method.

[0010] According to the present invention, variations in discharge characteristics can be restrained in a liquid discharge head that vibrates a nozzle plate to discharge liquid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] 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 cross-sectional 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;
FIG. 7 is a schematic cross-sectional view of a liquid discharge head according to an embodiment of the present invention;
FIG. 8 is another schematic cross-sectional view of the liquid discharge head of FIG. 7;
FIG. 9 is a schematic cross-sectional view of a liquid discharge head according to another embodiment of the present invention;
FIG. 10 is a schematic perspective view of the liquid discharge head of FIG. 9;
FIG. 11 is a schematic view of a liquid discharge apparatus according to an embodiment of the present invention;
FIG. 12 is a schematic view of an example of a head unit of the liquid discharge apparatus;
FIG. 13 is a block diagram of a liquid circulating apparatus according to an embodiment of the present invention;
FIG. 14 is a schematic plan view of a liquid discharge apparatus according to another embodiment of the present invention;
FIG. 15 is a schematic side view of the liquid discharge apparatus of FIG. 14;
FIG. 16 is a schematic view of an example of a liquid discharge device according to an embodiment of the present invention; and
FIG. 17 is a schematic view of a liquid discharge device according to another embodiment of the present invention.

[0012] 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

[0013] 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.

[0014] 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.

[0015] With reference to drawings, descriptions are given below of embodiments of the present disclosure. It is to be noted that elements (for example, mechanical parts and components) having the same functions and shapes are denoted by the same reference numerals throughout the specification and redundant descriptions are omitted.

[0016] Hereinafter, a method of manufacturing a liquid discharge head and a method of manufacturing a liquid discharge apparatus according to embodiments of the present invention are described with reference to the drawings. Note that the present invention is not to be considered limited to the following embodiments but can be changed within the range that can be conceived of by those skilled in the art, such as other embodiments, additions, modifications, deletions, and the scope of the present invention encompasses any aspect, as long as the aspect achieves the operation and advantageous effect of the present invention.

[0017] A method of manufacturing a liquid discharge head according to the present embodiment is a method of manufacturing a liquid discharge head that vibrates a nozzle plate having a substrate and a piezoelectric body to discharge liquid. The method includes a piezoelectric body forming step of forming the piezoelectric body on the substrate at 450°C to 600°C, and a nozzle orifice forming step of forming nozzle orifices that penetrate the substrate and the piezoelectric body.

[0018] FIG. 1 is a schematic cross-sectional view illustrating an example 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.

[0019] Liquid (for example, ink) is supplied to the common liquid chamber 84 in the common liquid chamber plate 83 (as a common liquid chamber substrate) 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.

[0020] 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. Although the number, arrangement, and shape of the nozzle orifices 4 can be appropriately changed, the nozzle orifices 4 are formed to penetrate through the substrate 81 and the piezoelectric body 82.

[0021] 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.

[0022] Next, a method of manufacturing the liquid discharge head according to the present embodiment is described. FIGS. 2A, 2B, and 2C are schematic cross-sectional views of the nozzle plate 1 illustrating steps of forming the nozzle plate 1. In FIGS. 2A, 2B, and 2C, a piezoelectric body forming step and a nozzle orifice forming step are performed.

[0023] FIG. 2A depicts the substrate 81. The substrate 81 can be appropriately changed, and for example, a Si substrate can be used. When the substrate 81 is a Si substrate, a film of oxide such as silicon dioxide (SiO_2) may be formed. The thickness of the substrate 81 is preferably, for example, 200 μm to 900 μm.

[0024] FIG. 2B is a diagram illustrating the piezoelectric body forming step. In the piezoelectric body forming step, the piezoelectric body 82 is formed on the substrate 81. The piezoelectric body 82 is preferably made of lead zirconate titanate (PZT). The thickness of the piezoelectric body 82 is preferably, for example, 1 μm to 6 μm.

[0025] In the piezoelectric body forming step, a temperature at which the piezoelectric body is formed (also referred to as a film forming temperature) is 450°C to 600°C. Setting the temperature within such a range can prevent the substrate 81 from being warped when the piezoelectric body is formed. When the film forming temperature is higher than 600°C, the temperature becomes too high, the substrate 81 is warped, and the shape of nozzle orifices formed in a later step varies in the liquid discharge head. When the film forming temperature is lower than 450°C, the formation of the piezoelectric body becomes insufficient, and sufficient discharge characteristics are not obtained.

[0026] The film forming temperature is preferably 450°C to 550°C. In such a case, warpage of the substrate 81 can be further restrained. Thus, variations in discharge characteristics within the liquid discharge head can be further restrained.

[0027] The piezoelectric body 82 can be formed by, for example, a sputtering method, a chemical vapor deposition (CVD) method, or a sol-gel method. In the case of the sol-gel method, after a precursor solution of the piezoelectric body is applied onto the substrate 81, the substrate 81 and the precursor solution of the piezoelectric body are heated at the film forming temperature.

[0028] FIG. 2C is a diagram illustrating the nozzle orifice forming step. In the nozzle orifice forming step, the nozzle orifices 4 penetrating the substrate 81 and the piezoelectric body 82 are formed. The method of forming the nozzle orifices 4 can be appropriately changed, and for example, dry etching can be used.

[0029] The method of manufacturing the liquid discharge head according to the present embodiment can prevent the substrate from warping when forming the piezoelectric body. Thus, variations in the shape of nozzles in the liquid discharge head can be restrained. For example, the method according to the present embodiment can prevent the shape of a nozzle orifice near the center of the nozzle plate 1 from differing from a nozzle orifice on an end side of the nozzle plate 1. The method according to the present embodiment can also prevent, for example, the shape of a nozzle orifice on one end side of the nozzle plate 1 from differing from the shape of a nozzle orifice on the other end side.

[0030] Accordingly, the method according to the present embodiment can restrain variations in discharge characteristics such as the droplet amount, the droplet speed (the speed of droplet), and the landing position accuracy of liquid discharged from each nozzle in the liquid discharge head. Thus, the quality of the image can be further enhanced.

[0031] FIGS. 3A, 3B, and 3C are schematic cross-sectional views of the nozzle plate 1 according to the present embodiment. FIG. 3A is a schematic view illustrating a state in which a nozzle orifice 4 is formed in the nozzle plate 1. Since the substrate 81 can be prevented from warping, the heights of the left side and the right side of the nozzle orifice 4 can be aligned. For example, as illustrated in FIG. 3A, the height of a nozzle surface 1b and the height of a nozzle surface 1c in the vicinity of the nozzle orifice 4 can be aligned to each other. Such a configuration can also uniform the shapes of the nozzle orifices in the liquid discharge head.

[0032] FIG. 3B 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 position of the nozzle surface 1b and the position of the nozzle surface 1c are aligned in the vicinity of the nozzle orifice 4, the shapes of meniscuses can be uniform on the left and right sides of a central axis of the nozzle orifice 4. Further, the shapes of the meniscuses can be uniform among the nozzle orifices in the liquid discharge head.

[0033] FIG. 3C 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. 3C schematically depicts a direction in which the liquid 88 is discharged. The liquid 88 can be discharged straight from the nozzle orifice 4. In addition, variations in the discharge direction can be restrained among the nozzle orifices 4 in the liquid discharge head.

[0034] Here, a description is given of a liquid discharge head according to a comparative example also described later. FIG. 5 is a schematic cross-sectional view of a liquid discharge head according to a comparative example. In the comparative example, a piezoelectric body 82a is formed at a temperature higher than the film forming temperature in the present embodiment, for example, a temperature of 800°C or lower and higher than 600°C. Accordingly, a substrate 81a has a warped shape, and a nozzle plate 1a has a warped shape.

[0035] When nozzle orifices 4a are formed in such a state, the left and right heights of the nozzle orifice are different. In addition, the shape of the nozzle, the volume in the nozzle, and the like are different for each nozzle. Accordingly, the discharge characteristics vary among the nozzle orifices in the liquid discharge head.

[0036] FIGS. 6A, 6B, and 6C are schematic enlarged cross-sectional views of a portion indicated by a broken line circle in FIG. 5, illustrating details of the comparative example. As illustrated in FIG. 6A, since the nozzle orifice 4a is formed in the warped nozzle plate 1a, the left and right heights of the nozzle orifice are different. For example, FIG. 6A schematically depicts that the height of the nozzle surface 1b is different from the height of the nozzle surface 1c.

[0037] When liquid is supplied to the nozzle orifice 4a in such a state, as illustrated in FIG. 6B, the left and right heights of a meniscus in the nozzle orifice 4a are different. In addition, the shape of the nozzle, the volume in the nozzle, and the like are different for each nozzle.

[0038] In such a case, as illustrated in FIG. 6C, in addition to the occurrence of discharge deviation, the amount of discharge deviation varies among nozzles. In addition, the droplet amount, the droplet speed (the speed of droplet), the landing position accuracy, and the like of liquid discharged from each nozzle also vary among the nozzles, and the discharge characteristics vary within the liquid discharge head. Accordingly, there occurs a failure that an image of good quality is not obtained.

[0039] Next, a description is given of a bonding step and the like in 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.

[0040] 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 (as a common liquid chamber substrate). 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.

[0041] 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. In the bonding step in the present embodiment, after the nozzle orifice forming step, the ceiling plate 86 is bonded to one side of the nozzle plate 1 that faces the substrate 81.

[0042] Further, according to the present embodiment, a method of manufacturing a liquid discharge apparatus is provided. The method of manufacturing a liquid discharge apparatus according to the present embodiment is a method of manufacturing a liquid discharge apparatus using the method of manufacturing a liquid discharge head according to the present embodiment.

[0043] Examples 1 and Comparative Example 1 In Example 1, as illustrated in FIGS. 2A to 4C, the liquid discharge head illustrated in FIG. 1 is manufactured. First, a 10 μm thick SiO_2 film was formed on a silicon 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 sputtering at a film forming temperature of 550°C 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 a nozzle orifice 4 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, as Comparative Example 1, the liquid discharge head illustrated in FIGS. 5 and 6A to 6C was produced in the same manner as in Example 1 except that the film forming temperature in Comparative Example 1 was set to 800°C.

[0046] Next, the discharge characteristics of the obtained liquid discharge head were evaluated by discharging ink onto a medium. The measurement conditions were as follows.

[Measurement Conditions]

[0047]

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

[0048] The results are presented in Table 1. In this example, it can be seen that variations in discharge characteristics can be restrained. In Table 1, the droplet amount (max-min) represents the difference between a droplet amount [pl] at which the amount of one droplet is maximum and a droplet amount [pl] at which the amount of one droplet is minimum

among the plurality of nozzle orifices in the liquid discharge head. In addition, in Table 1, the droplet speed (max-min) represents the difference between a droplet speed [m/sec] at which the discharge speed is maximum and a droplet speed [m/sec] at which the discharge speed is minimum among the plurality of nozzle orifices in the liquid discharge head. The deviation amount 3σ represents an average value in the liquid discharge head. In each of the above-described items, the smaller the value, the smaller the variation.

Table 1

	Example 1	Comparative Example 1
Droplet amount (max-min) [pl]	0.1	0.6
Droplet speed (max-min) [m/sec]	0.2	1.0
Deviation amount 3σ [μm]	3.1	12.2

[0049] Hereinafter, a liquid discharge head and a liquid discharge apparatus according to embodiments of the present invention are described. FIG. 7 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. 8 is a cross-sectional view of the liquid discharge head taken along the nozzle arrangement direction.

[0050] 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 member 3 may be further provided.

[0051] The nozzle plate 1 has a plurality of nozzles 4 that discharge liquid.

[0052] 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).

[0053] 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.

[0054] 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.

[0055] 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.

[0056] 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.

[0057] 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.

[0058] 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.

[0059] 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.

[0060] 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.

[0061] FIG. 9 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. 10 is a schematic perspective view of the liquid discharge head according to the present embodiment.

[0062] 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.

[0063] 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.

[0064] 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.

[0065] 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.

[0066] 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.

[0067] 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.

[0068] 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.

[0069] 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.

[0070] The common supply channel 10 communicates with supply ports 71. The common collection channel 50 communicates with collection ports 72.

[0071] 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.

[0072] 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.

[0073] 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.

[0074] 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.

[0075] Next, a liquid discharge apparatus according to an embodiment of the present invention is described with

reference to FIGS. 11 and 12. FIG. 11 is a schematic view of the liquid discharge apparatus according to the present embodiment. FIG. 12 is a plan view of an example of a head unit of the liquid discharge apparatus.

[0076] 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.

[0077] 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.

[0078] 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.

[0079] 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.

[0080] 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.

[0081] 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 disclosure are not limited to the arrangement and may be any other suitable head arrangement.

[0082] 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 apparatus using the liquid discharge head. An example of the liquid circulating apparatus is described with reference to FIG. 13. FIG. 13 is a block diagram of an example of the liquid circulating apparatus. Although only one head is illustrated in FIG. 13, 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.

[0083] A liquid circulating apparatus 600 illustrated in FIG. 13 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.

[0084] The compressor 611 and the vacuum pump 621 together generate a pressure difference between the supply tank 601 and the collection tank 602.

[0085] 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.

[0086] 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.

[0087] 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.

[0088] 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.

[0089] Thus, the negative pressure of the meniscus can be kept constant while the liquid is circulated through the head 100.

[0090] 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.

[0091] 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.

[0092] 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. 14 and 15. FIG. 14 is a plan view of a main part of the printing apparatus. FIG. 15 is a side view of the main part of the printing apparatus.

[0093] 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 a left side plate 491A and a right side plate 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.

[0094] 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.

[0095] The liquid discharge head 100 is connected to the liquid circulating apparatus 600 described above, and liquid of desired colors is circulated and supplied.

[0096] 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.

[0097] 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 can be attracted to the conveyance belt 412 by electrostatic attraction, air suction, or the like.

[0098] 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.

[0099] 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.

[0100] 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.

[0101] 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.

[0102] 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.

[0103] 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.

[0104] 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. 16. FIG. 16 is a plan view of a main part of the liquid discharge device according to the present embodiment.

[0105] 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.

[0106] 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.

[0107] Next, still another example of the liquid discharge device is described with reference to FIG. 17. FIG. 17 is a front view of the liquid discharge device according to the present embodiment.

[0108] 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.

[0109] 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.

[0110] In the present disclosure, 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. Examples of the liquid include a solution, a suspension, or an emulsion including, for example, a solvent, such as water or an organic solvent, a colorant, such as dye or pigment, a functional material, such as a polymerizable compound, a resin, or a surfactant, a biocompatible material, such as DNA, amino acid, protein, or calcium, and an edible material, such as a natural colorant. Such a solution, a suspension, or an emulsion can be used for, e.g., inkjet ink, surface

treatment solution, a liquid for forming components of electronic element or light-emitting element or a resist pattern of electronic circuit, or a material solution for three-dimensional fabrication.

[0111] 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 an electrothermal transducer element, such as a heat element, and an electrostatic actuator including a diaphragm and opposed electrodes.

[0112] 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.

[0113] Examples of integrating herein include, for example, securing of the liquid discharge head, functional component, and mechanism by fastening, bonding, or engaging, and holding of one so as to be movable with respect to the other. The liquid discharge head, functional component, and mechanism may also be detachably attached to one another.

[0114] 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.

[0115] In another example, the liquid discharge device may include a liquid discharge head integrated with a carriage as a single unit.

[0116] 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.

[0117] 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.

[0118] 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.

[0119] The main-scanning moving mechanism may be a guide only. The supply mechanism may be a tube(s) only or a loading unit only.

[0120] 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.

[0121] 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.

[0122] 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.

[0123] 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.

[0124] 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.

[0125] 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.

[0126] 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.

[0127] Examples of the "liquid discharge apparatus" further include a treatment liquid coating apparatus to discharge 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.

[0128] The terms "image formation", "recording", "printing", "image printing", and "fabricating" are herein used as synonyms.

Claims

1. A method of manufacturing a liquid discharge head (100) to vibrate a nozzle plate (1) including a substrate (81) and a piezoelectric body (82) to discharge liquid, the method comprising:

   forming the piezoelectric body (82) on the substrate (81) at 450°C to 600°C; and
   forming a nozzle orifice (4) penetrating through the substrate (81) and the piezoelectric body (82).

2. The method according to claim 1,
   wherein the piezoelectric body (82) is made of lead zirconate titanate (PZT).

3. The method according to claim 1 or 2,
   wherein the forming the piezoelectric body (82) includes forming the piezoelectric body at 450°C to 550°C.

4. The method according to any one of claims 1 to 3,
   wherein the forming the piezoelectric body (82) includes forming the piezoelectric body by a sputtering method or a chemical vapor deposition (CVD) method.

5. The method according to any one of claims 1 to 3,
   wherein the forming the piezoelectric body (82) includes forming the piezoelectric body by a sol-gel method, and
   wherein the forming the piezoelectric body (82) includes applying a precursor solution of the piezoelectric body (82) onto the substrate (81) and heating the precursor solution of the piezoelectric body (82) on the substrate.

6. The method according to any one of claims 1 to 5,
   wherein the forming the nozzle orifice includes forming the nozzle orifice by dry etching.

7. The method according to any one of claims 1 to 6, further comprising bonding a common liquid chamber substrate to the substrate (81) of the nozzle plate (1) after the nozzle orifice is formed.

8. A method of manufacturing a liquid discharge apparatus (500, 600) including a liquid discharge head, the method comprising:
   manufacturing the liquid discharge head by the method according to any one of claims 1 to 7.

FIG. 1

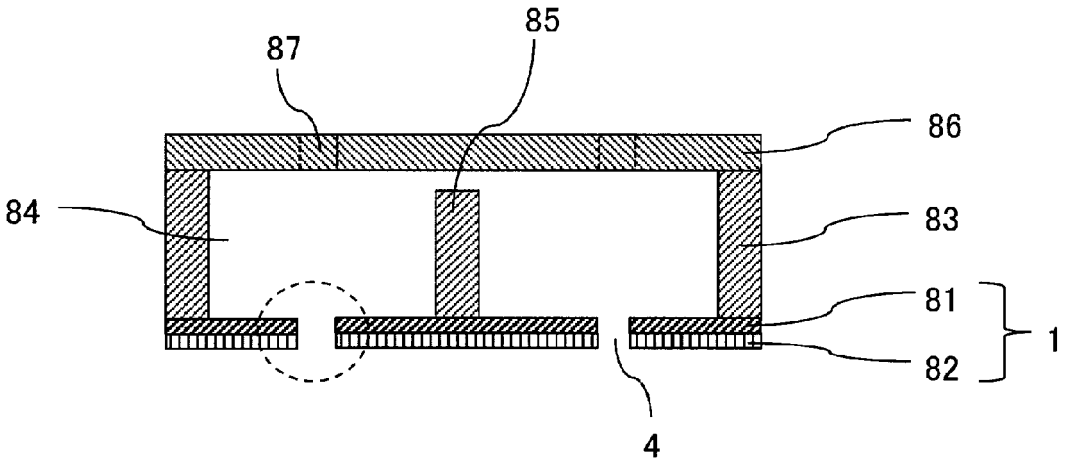


FIG. 2A

FIG. 2B

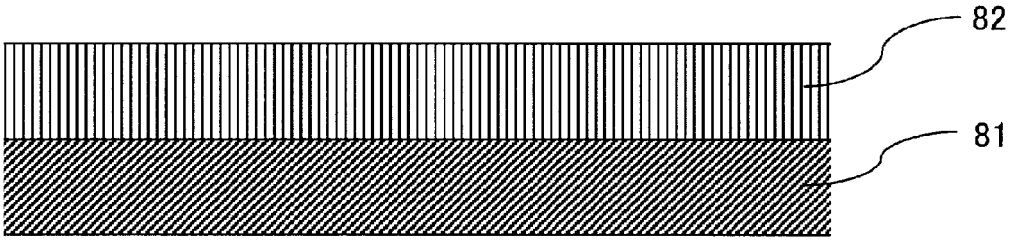


FIG. 2C

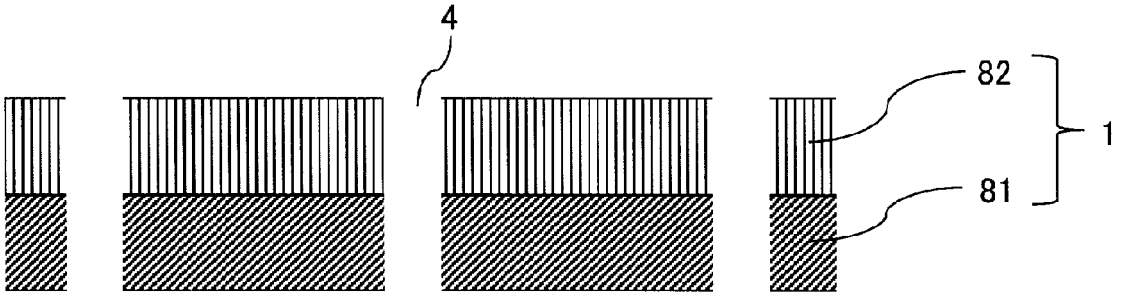


FIG. 3A

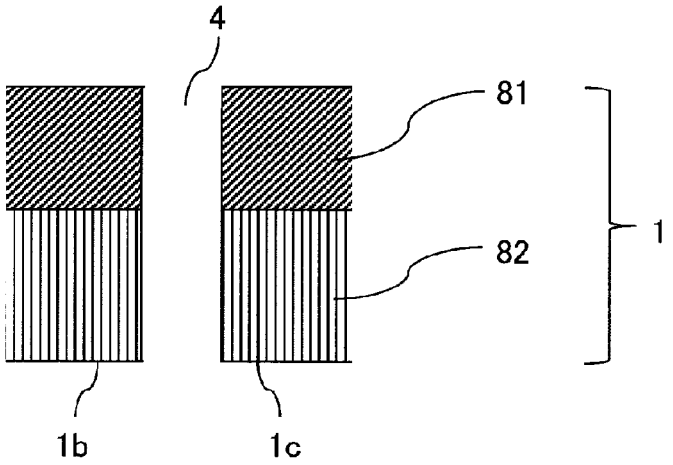


FIG. 3B

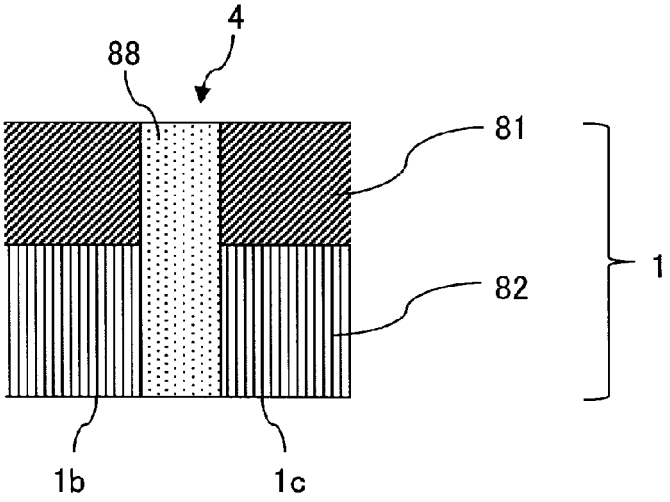


FIG. 3C

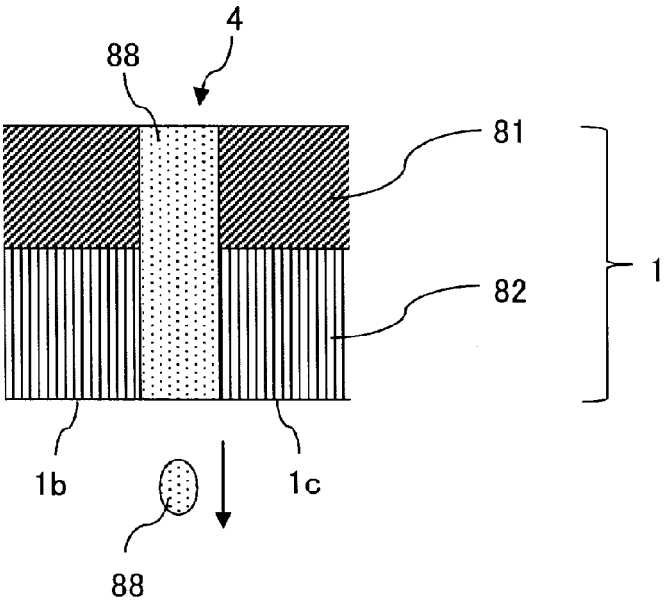


FIG. 4A

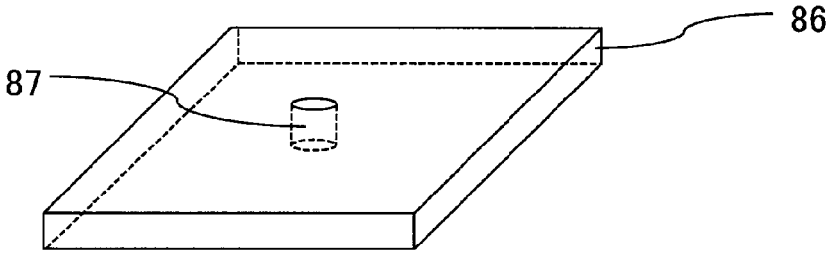


FIG. 4B

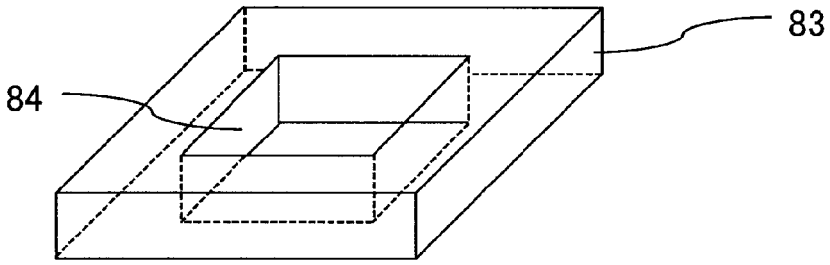


FIG. 4C

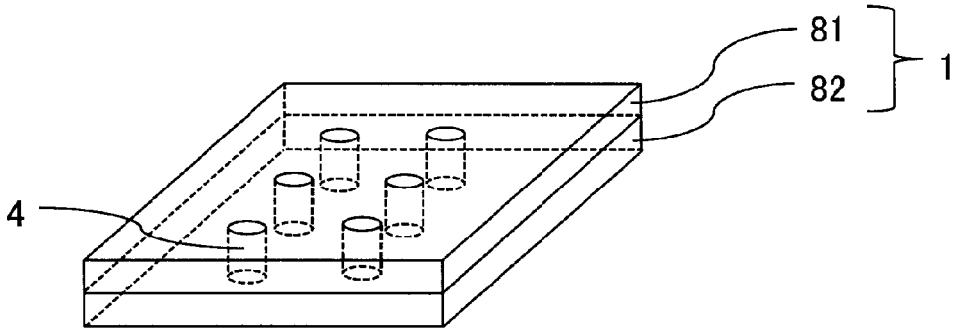


FIG. 5

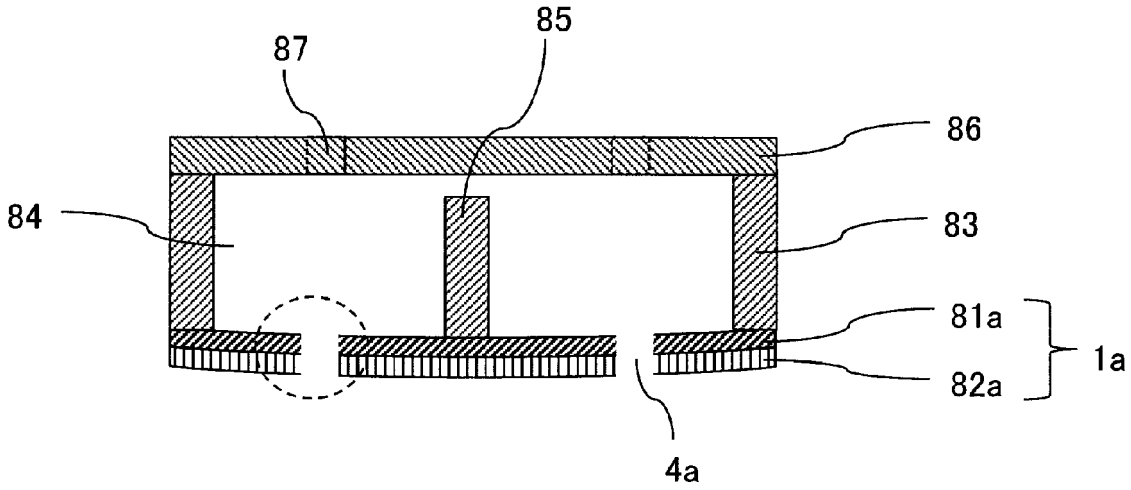


FIG. 6A

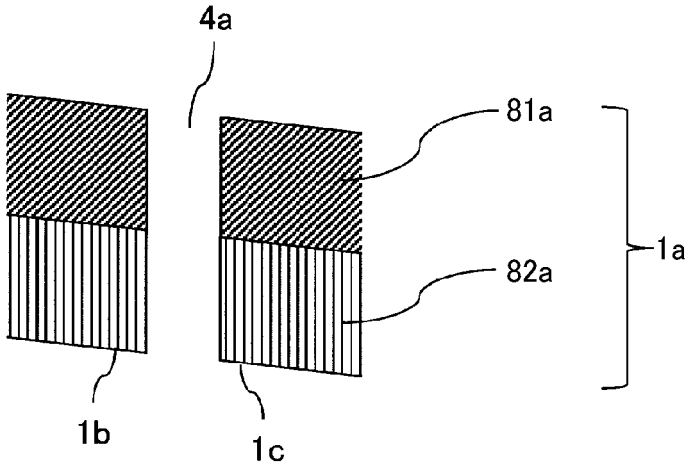


FIG. 6B

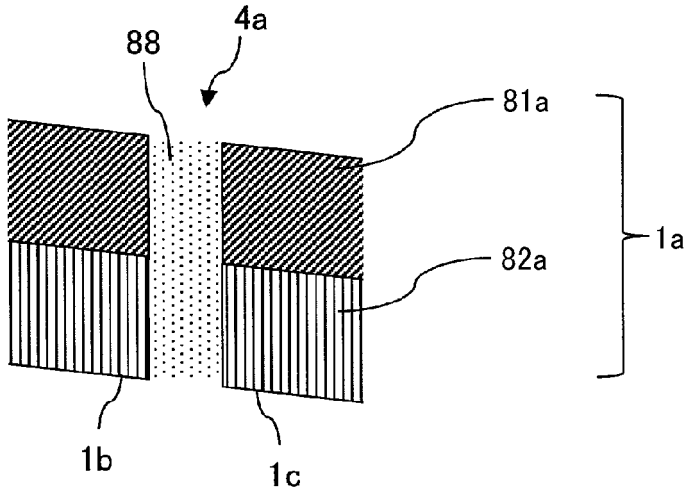


FIG. 6C

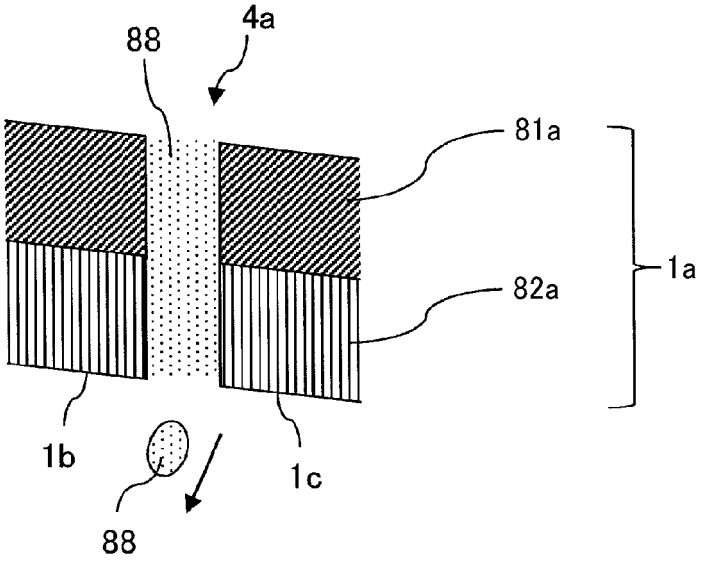


FIG. 7

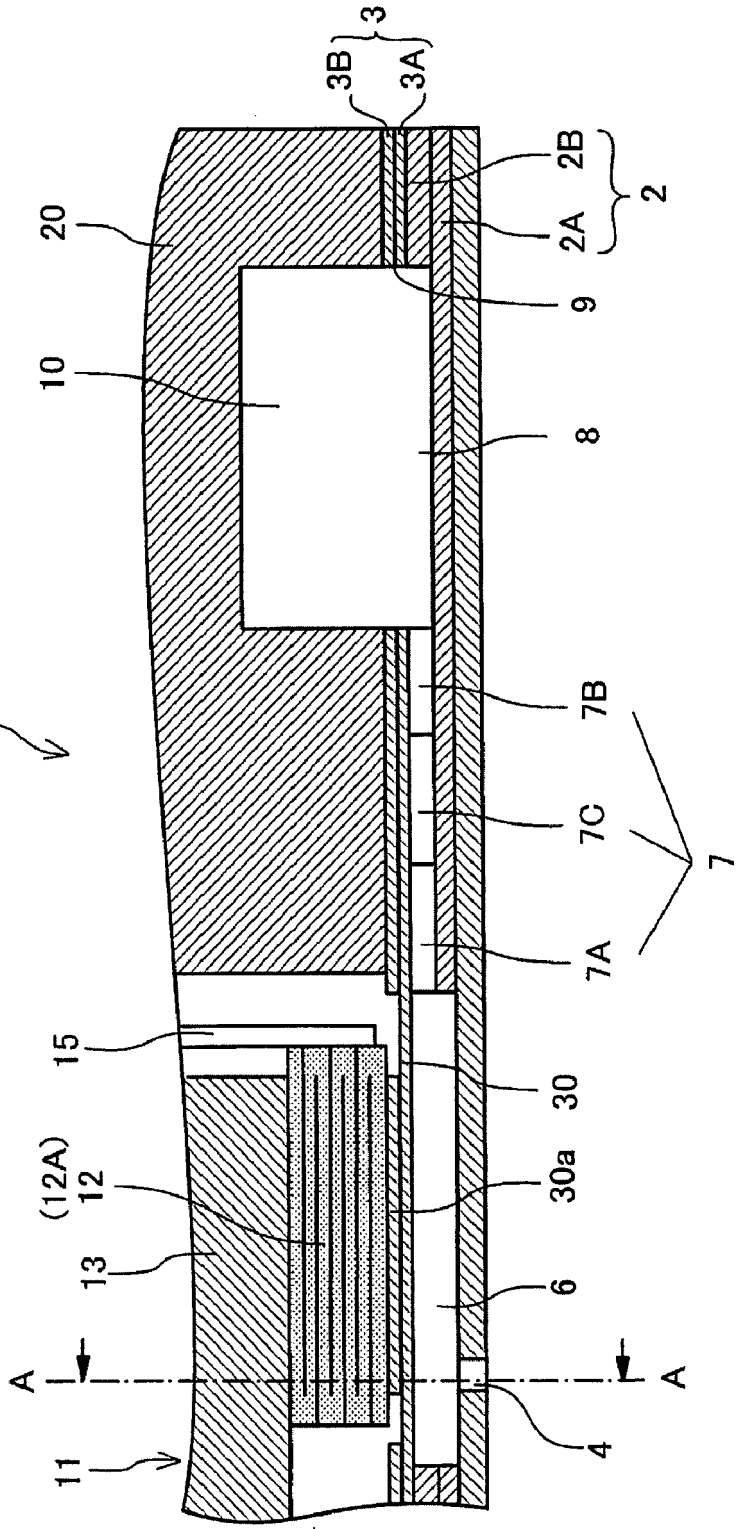


FIG. 8

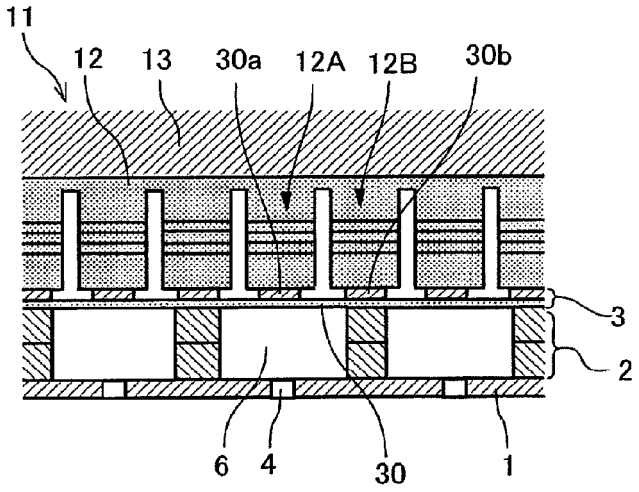

11
12
13
30a
12A
12B
30b
3
2
6
4
30
1

FIG. 9

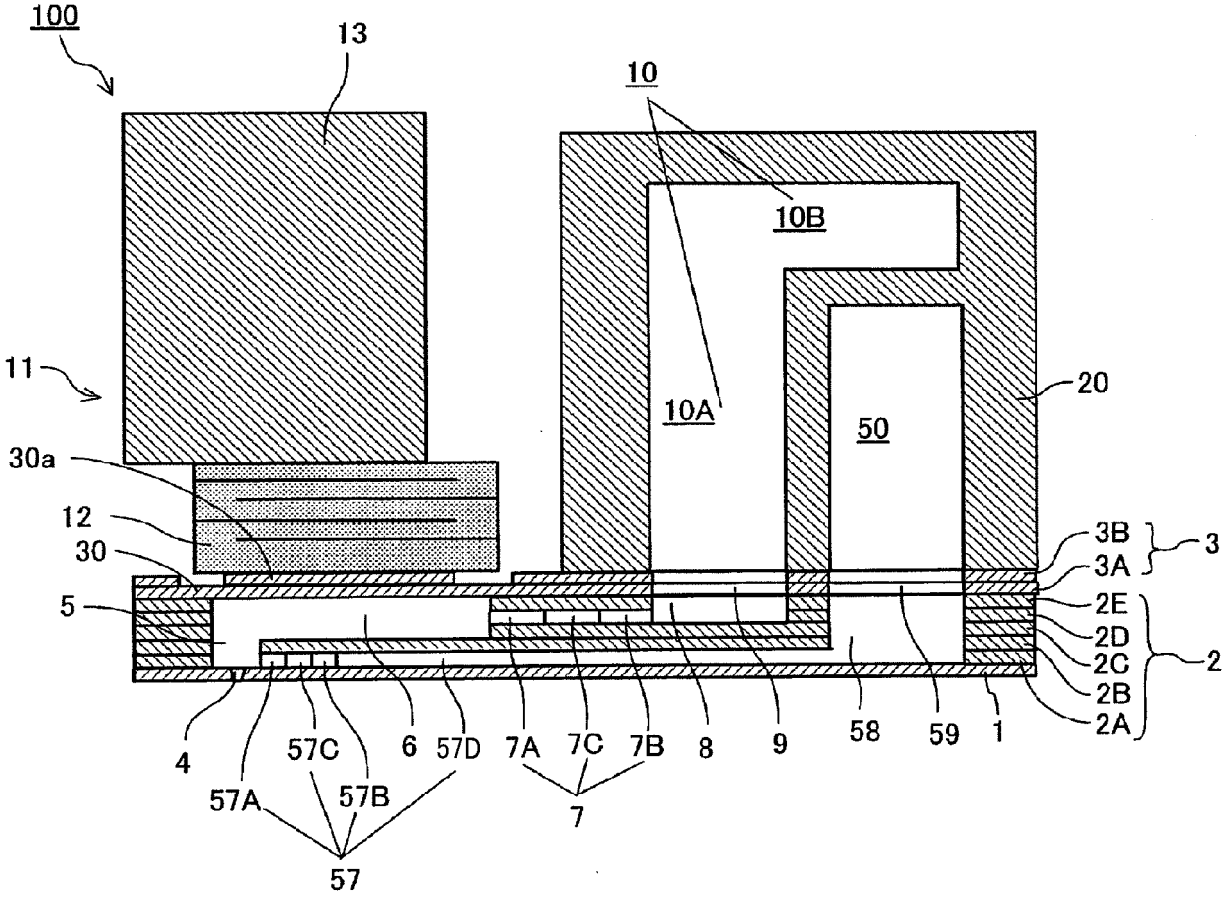

100
13
10
10B
11
10A
20
50
30a
12
30
3B
3A
3
5
2E
2D
2C
2
2B
2A
4
57C
6
57D
7A
7C
7B
8
9
58
59
1
57A
57B
7
57

FIG. 10

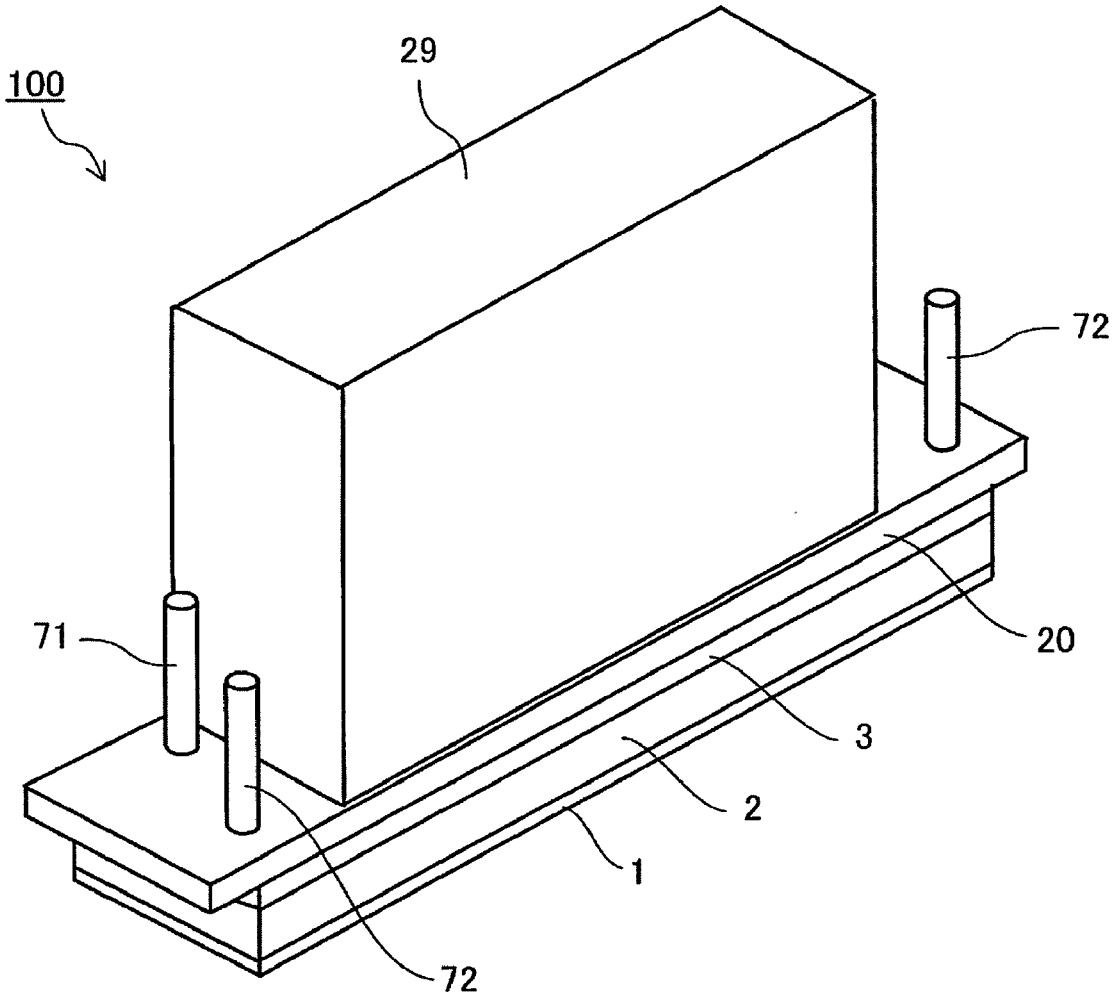


FIG. 11

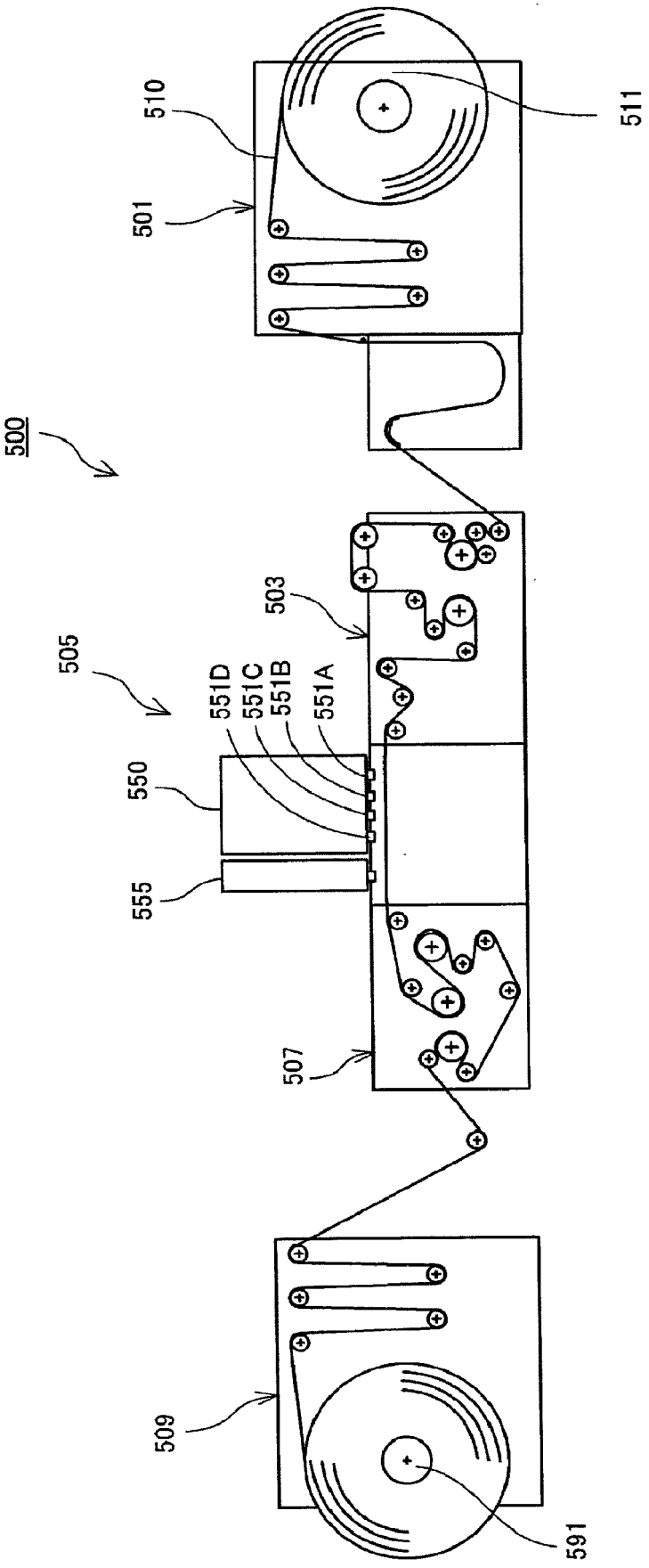


FIG. 12

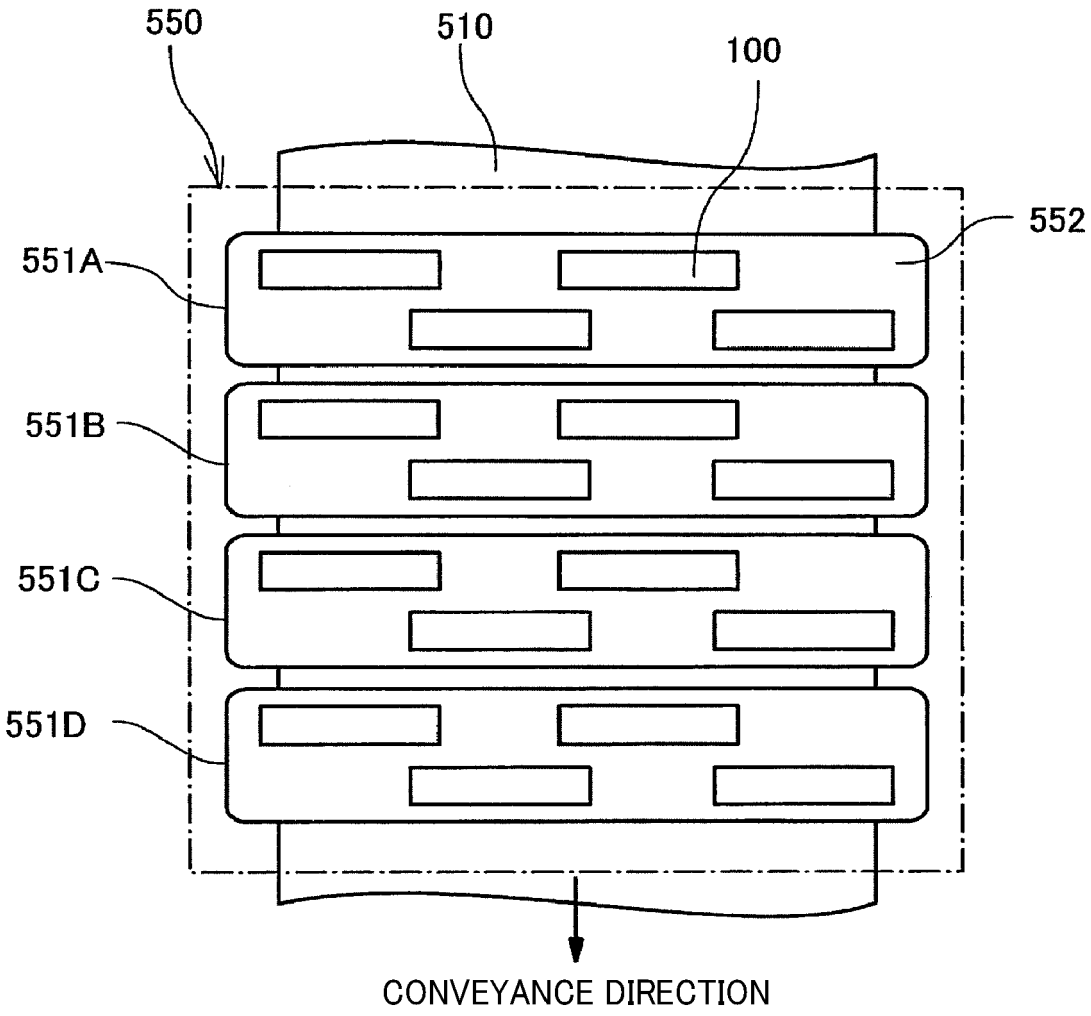


FIG. 13

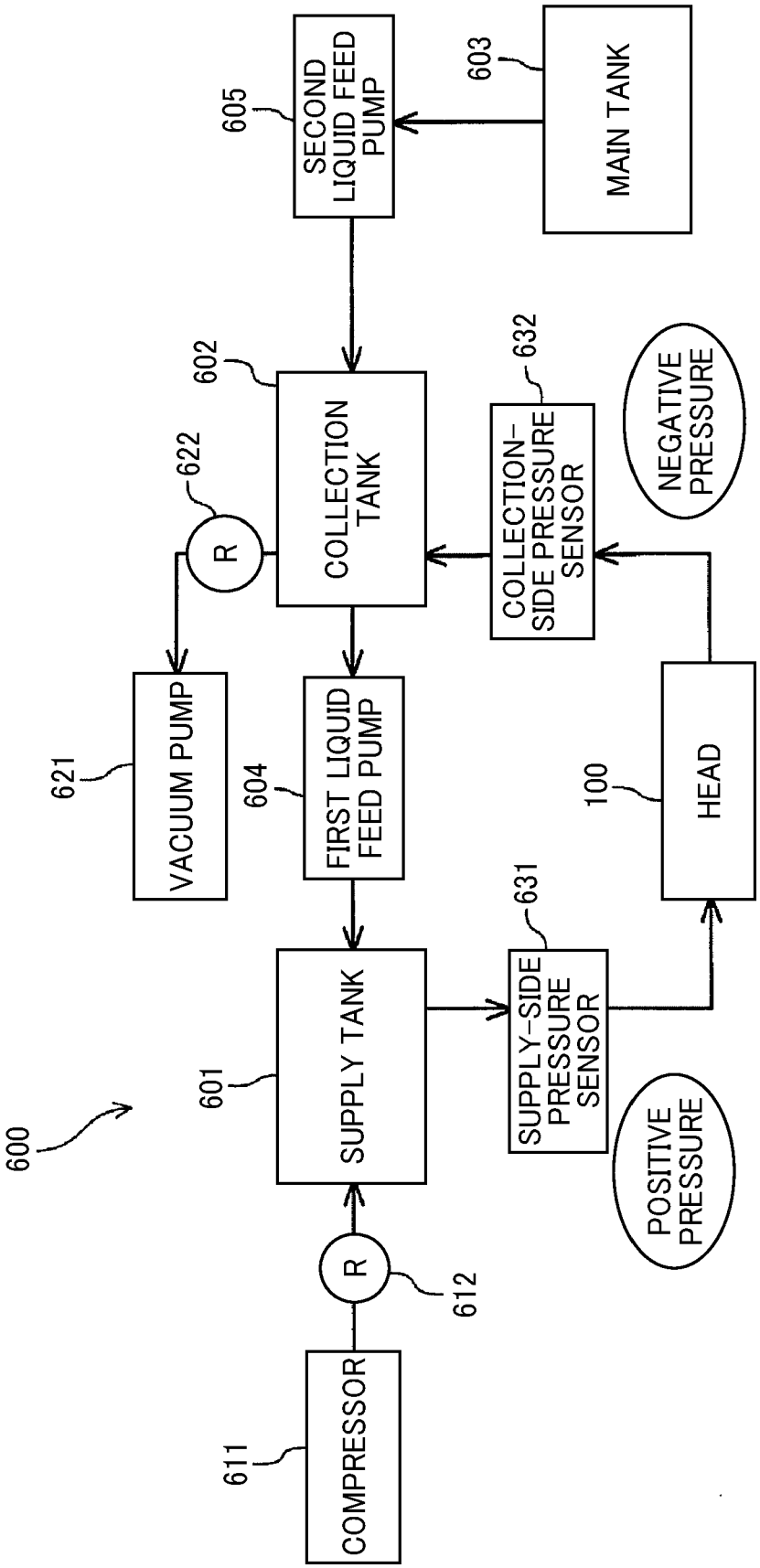

600
601
SUPPLY TANK
602
COLLECTION TANK
603
MAIN TANK
604
FIRST LIQUID FEED PUMP
605
SECOND LIQUID FEED PUMP
611
COMPRESSOR
612
R
621
VACUUM PUMP
622
R
631
SUPPLY-SIDE PRESSURE SENSOR
632
COLLECTION-SIDE PRESSURE SENSOR
100
HEAD
POSITIVE PRESSURE
NEGATIVE PRESSURE

FIG. 14

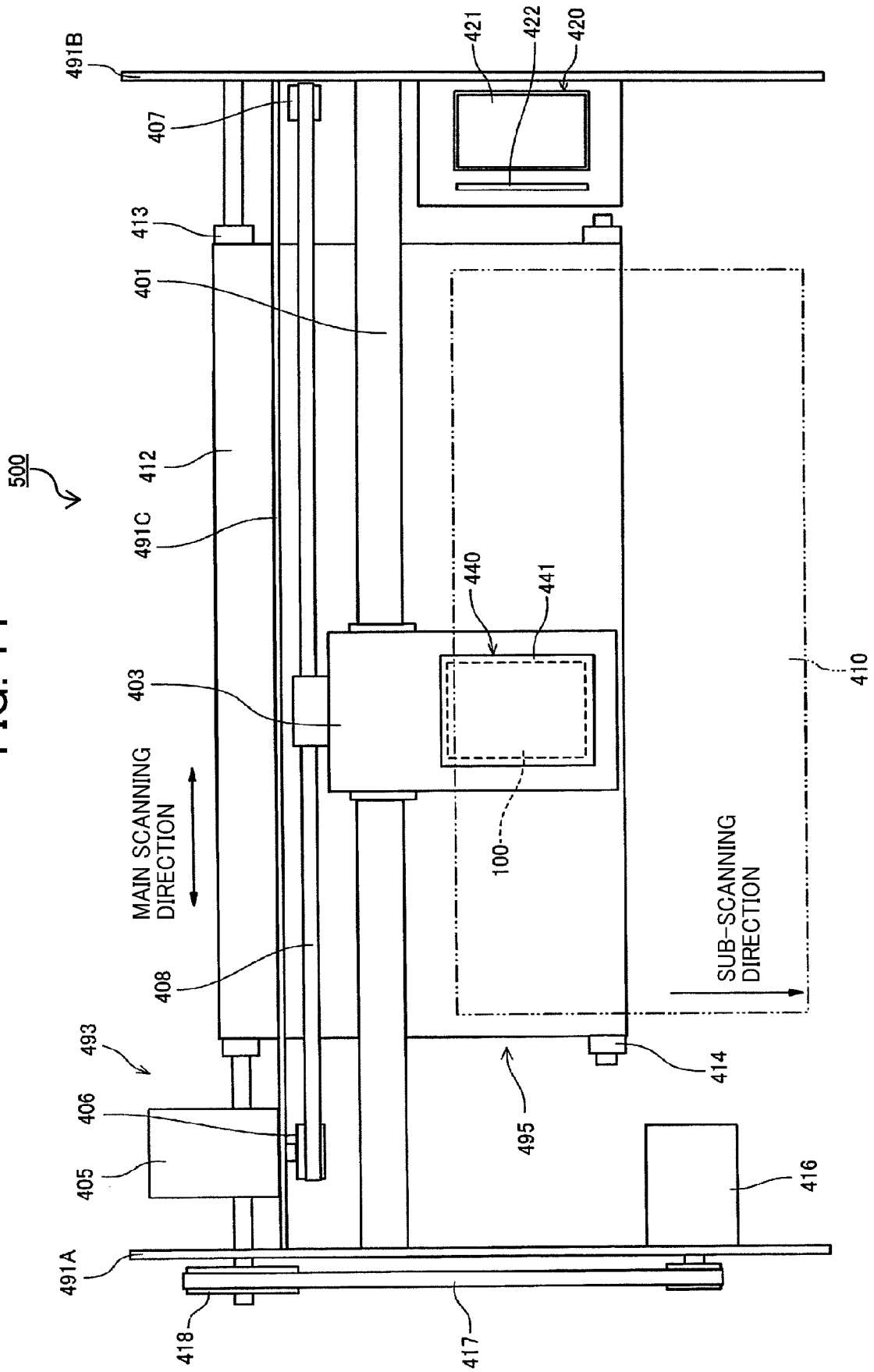
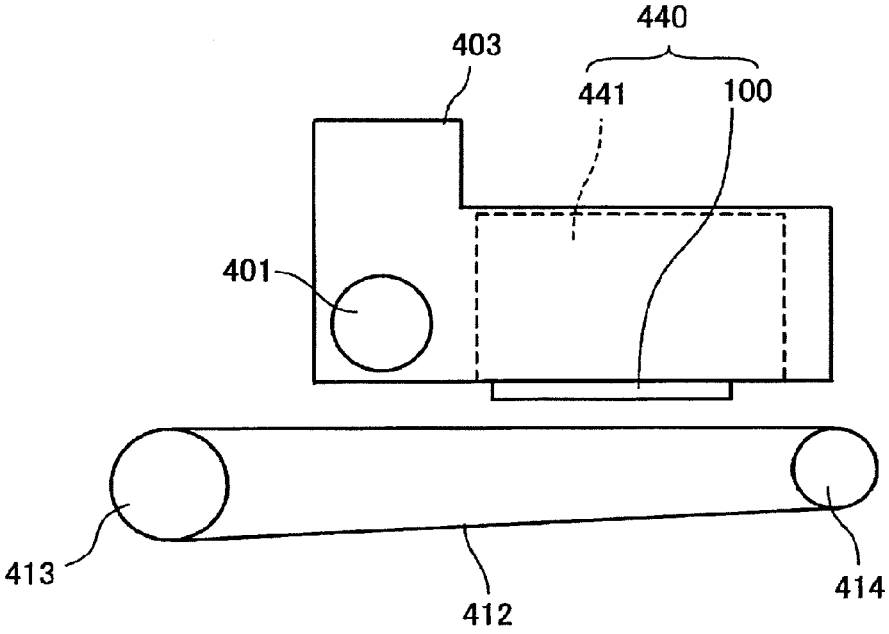

500
491B
421
422
420
407
413
401
412
491C
440
441
403
410
MAIN SCANNING DIRECTION
100
SUB-SCANNING DIRECTION
408
493
414
406
495
405
416
491A
418
417

FIG. 15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403
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100
401
413
412
414

FIG. 16

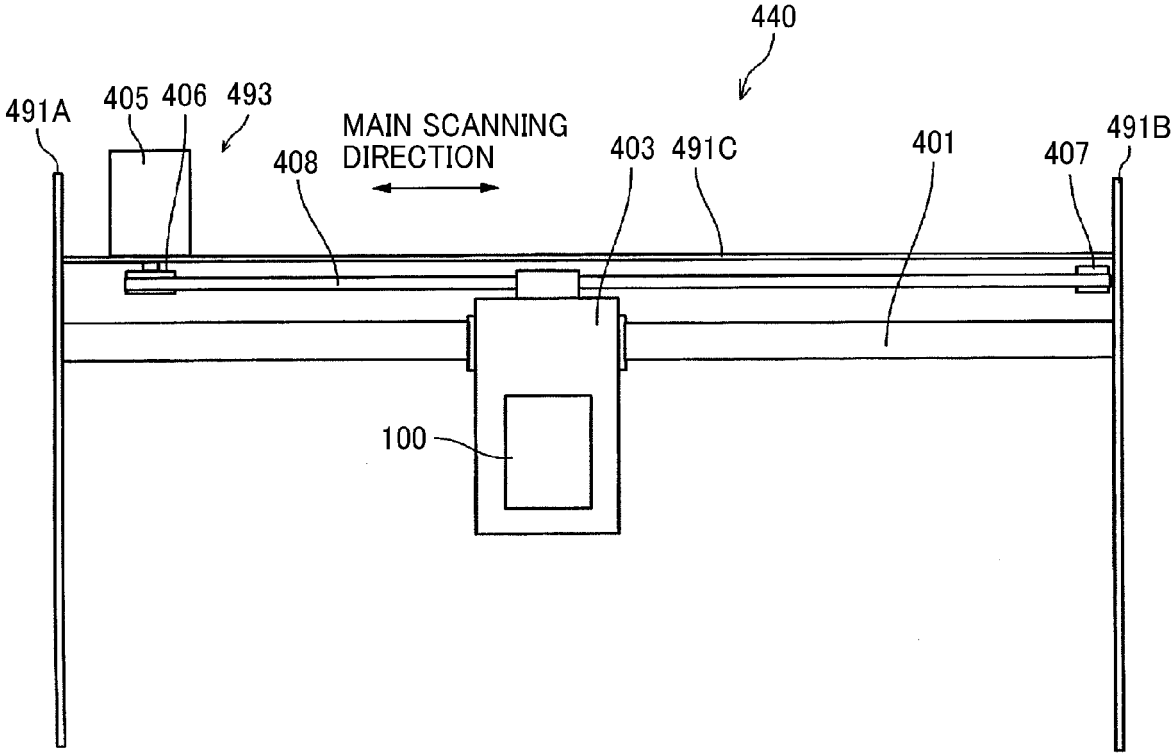
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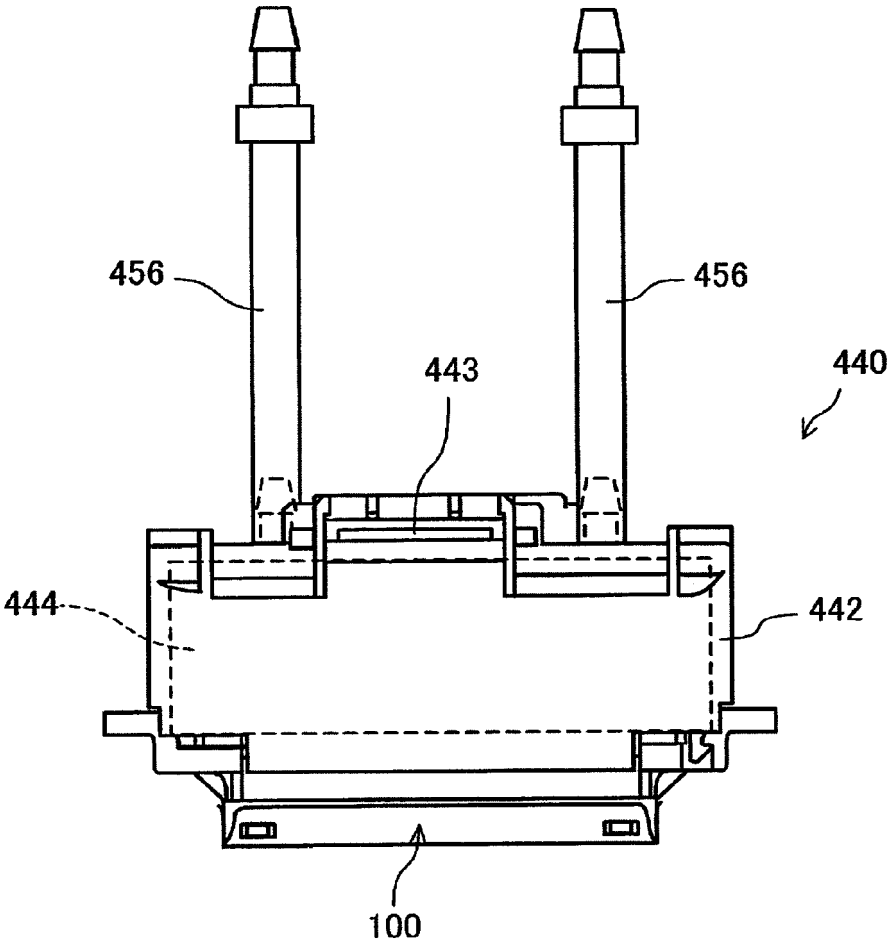
FIG. 17



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EUROPEAN SEARCH REPORT

Application Number
EP 20 21 6883

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	US 2014/267498 A1 (YOKOYAMA SHUHEI [JP] ET AL) 18 September 2014 (2014-09-18) * the whole document *	1-8	INV. B41J2/16
X	US 2014/253639 A1 (YOKOYAMA SHUHEI [JP] ET AL) 11 September 2014 (2014-09-11) * the whole document *	1-8	

TECHNICAL FIELDS SEARCHED (IPC)

B41J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	11 May 2021	Dewaele, Karl

CATEGORY OF CITED DOCUMENTS

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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 20 21 6883

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11-05-2021

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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- JP 3427608 B **[0004]**
- JP H09226111 A **[0004]**