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Liquid discharge head, liquid discharge device, liquid discharge apparatus, and method of manufacturing liquid discharge head

Abstract

A liquid discharge head includes a nozzle plate, a housing, a channel, and a positioning member. The nozzle plate has a nozzle hole and a first positioning hole penetrating through the nozzle plate in a thickness direction of the nozzle plate. The housing is bonded to the nozzle plate to form a single bonded body and has a second positioning hole extending in a thickness direction of the housing. A liquid flows through the channel between the nozzle plate and the housing to the nozzle hole. The positioning member fits into the first positioning hole and the second positioning hole to position the nozzle plate relative to the housing. A length of the positioning member is smaller than a sum of a length of the first positioning hole and a length of the second positioning hole in the thickness direction of the nozzle plate, and larger than the length of the second positioning hole.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

(1) This patent application is based on and claims priority pursuant to 35 U.S.C. § 119(a) to Japanese Patent Application Nos. 2022-083024, filed on May 20, 2022, and 2023-039858, filed on Mar. 14, 2023, in the Japan Patent Office, the entire disclosure of each of which is hereby incorporated by reference herein.

BACKGROUND

Technical Field

(2) Embodiments of the present disclosure relate to a liquid discharge head, a liquid discharge device, a liquid discharge apparatus, and a method of manufacturing a liquid discharge head.

Related Art

(3) In the related art, a liquid discharge apparatus includes a nozzle plate and a needle valve. The nozzle plate has a nozzle hole which is a fine hole. The needle valve has a valve body at a leading end thereof. The valve body of the needle valve contacts and moves away from the nozzle hole to discharge droplets of a highly pressurized liquid of several hundred kPa from the nozzle hole. A trailing end of the needle valve is coupled to a driver (actuator) such as a piezoelectric element. Such a liquid discharge apparatus is used in various fields, for example, to draw a figure on a body of an automobile with high image quality, to discharge droplets of a liquid resist or a DNA sample, or to discharge a constant amount of oil to a mechanical component.

SUMMARY

(4) Embodiments of the present disclosure describe an improved liquid discharge head that includes a nozzle plate, a housing, a channel, and a positioning member. The nozzle plate has a nozzle hole from which a liquid is discharged and a first positioning hole penetrating through the nozzle plate in a thickness direction of the nozzle plate. The housing is bonded to the nozzle plate to form a single bonded body and has a second positioning hole extending in a thickness direction of the housing. The channel is disposed between the nozzle plate and the housing. The liquid flows through the channel to the nozzle hole. The positioning member fits into the first positioning hole and the second positioning hole to position the nozzle plate relative to the housing. A length of the positioning member in the thickness direction of the nozzle plate is smaller than a sum of a length of the first positioning hole and a length of the second positioning hole in the thickness direction of the nozzle plate, and larger than the length of the second positioning hole in the thickness direction of the nozzle plate.

(5) According to another embodiment of the present disclosure, there is provided a method of manufacturing a liquid discharge head. The method includes forming a nozzle hole in a nozzle plate, forming a first positioning hole in the nozzle plate, forming a second positioning hole in a housing, fitting a positioning member into the first positioning hole and the second positioning hole to position the nozzle plate relative to the housing, and bonding the nozzle plate and the housing to each other to form a single bonded body. The first positioning hole penetrates through the nozzle plate in a thickness direction of the nozzle plate, and the second positioning hole extends in a thickness direction of the housing. A length of the positioning member in the thickness direction of the nozzle plate is smaller than a sum of a length of the first positioning hole and a length of the

second positioning hole in the thickness direction of the nozzle plate, and larger than the length of the second positioning hole in the thickness direction of the nozzle plate.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) 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:

(2) FIG. **1**A is a front view of a liquid discharge head according to embodiments of the present disclosure:

(3) FIG. **1**B is a perspective view of the liquid discharge head according to embodiments of the present disclosure;

(4) FIG. **2**A is a front view of the liquid discharge head from which a lower housing is removed:

(5) FIG. **2**B is an enlarged perspective view of a lower end of the liquid discharge head;

(6) FIG. **3** is a cross-sectional view of the liquid discharge head traversing a channel of the liquid discharge head:

(7) FIG. **4**A is a cross-sectional view of the liquid discharge head taken along the channel;

(8) FIG. **4**B is a plan view of the lower end of the liquid discharge head in a horizontal cross section;

(9) FIG. **5**A is a cross-sectional view of a housing of the liquid discharge head according to Embodiment 1 of the present disclosure:

(10) FIG. **5**B is a plan view of a nozzle plate of the liquid discharge head according to Embodiment 1;

(11) FIG. **5**C is a bottom view of the housing;

(12) FIG. **5**D is a cross-sectional view of the housing during diffusion bonding;

(13) FIG. **6** is a cross-sectional view of a laminated plate of the liquid discharge head set in a diffusion bonding apparatus;

(14) FIG. **7**A is a plan view of the nozzle plate according to Embodiment 2 of the present disclosure;

(15) FIG. **7**B is a cross-sectional view of the housing during the diffusion bonding according to Embodiment 2;

(16) FIG. **8**A is a plan view of the nozzle plate according to Embodiment 3 of the present disclosure;

(17) FIG. **8**B is an enlarged partial cross-sectional view of the housing during the diffusion bonding according to Embodiment 3;

(18) FIG. **9**A is a plan view of the nozzle plate according to Embodiment 4 of the present disclosure;

(19) FIG. **9**B is a plan view of a side of the housing on which the nozzle plate is disposed according to Embodiment 4:

(20) FIG. **10**A is a plan view of the nozzle plate according to Embodiment 5 of the present disclosure;

(21) FIG. **10**B is a plan view of a side of the housing on which the nozzle plate is disposed according to Embodiment 5;

(22) FIG. **11**A is a plan view of the nozzle plate according to Embodiment 6 of the present disclosure;

(23) FIG. **11**B is a plan view of a side of the housing on which the nozzle plate is disposed according to Embodiment 6:

(24) FIG. **12**A is a cross-sectional view of the housing during the diffusion bonding according to

Embodiments 1 to 4;
(25) FIG. **12**B is a cross-sectional view of the housing according to Comparative Example 1:
(26) FIGS. **13**A and **13**B are cross-sectional views of the housing illustrating thermal expansion of the housing during the diffusion bonding according to Comparative Example 1;
(27) FIG. **14** is a table illustrating a relation between a structure of the laminated plate and concentricity according to Embodiments 1 to 4 and Comparative Examples 1 and 2:
(28) FIG. **15** is a perspective view of a liquid discharge apparatus according to embodiments of the present disclosure; and
(29) FIG. **16** is a perspective view of a drive unit of the liquid discharge apparatus.
(30) The accompanying drawings are intended to depict embodiments of the present invention 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. Also, identical or similar reference numerals designate identical or similar components throughout the several views.
DETAILED DESCRIPTION
(31) 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.
(32) Referring now to the drawings, embodiments of the present disclosure are described below. 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.
(33) Liquid Discharge Head
(34) Embodiments of the present disclosure are described below with reference to the accompanying drawings. FIG. **1**A is a front view of a liquid discharge head **1**, and FIG. **1**B is a perspective view of the liquid discharge head **1** as viewed obliquely from below. Coordinate axes of an X-axis, a Y-axis, and a Z-axis illustrated in FIGS. **1**A and **1**B indicate the same directions as the coordinate axes in the other drawings below.
(35) The liquid discharge head **1** includes a housing **10** including an upper housing **10***a* and a lower housing **10***b*. The upper housing **10***a* and the lower housing **10***b* may be formed in a single body. A laminated plate, in which a plurality of plates is laminated one on another, are bonded to each other by diffusion bonding to construct the housing **10** in a single bonded body.
(36) The housing **10** has dimensions of, for example, 80 mm in length (X-axis direction)×25 mm in width (Y-axis direction)×15 mm in thickness (Z-axis direction). Examples of a material of the housing **10** include stainless steel such as steel use stainless (SUS) 430.
(37) A cover **20** is attached onto the upper housing **10***a*, and electrical components are disposed inside the cover **20**. A connector **2** connected to the electrical components is disposed at an upper end of the cover **20**.
(38) A nozzle plate **101** is disposed on a lower face of the lower housing **10***b*. The nozzle plate **101** is made of a corrosion-resistant material such as SUS430 (i.e., stainless steel), for example. The lower face of the lower housing **10***b* has a surface roughness Ra of 0.01 μm or less. The nozzle plate **101** is bonded to the lower face of the lower housing **10***b* so that the housing **10** supports the nozzle plate **101**.
(39) Droplets of liquid are discharged from nozzle holes **111** which are fine holes formed in the nozzle plate **101**. Hereinafter, the housing **10** and the nozzle plate **101** are collectively referred to as the laminated plate.
(40) A second nozzle plate may be interposed between the lower housing **10***b* and the nozzle plate **101**. Such a configuration increases a bonding strength around a positioning pin **140** (see FIG. **5**A) to reinforce the nozzle plate **101**, thereby reducing concentricity. That is, a nozzle plate may include a plurality of plates laminated one on another. In addition, a length of the nozzle hole **111**

can be extended to enhance a flying stability of the droplets of the liquid discharged from the nozzle holes **111**.

(41) As illustrated in FIG. **3**, a channel **112** of the liquid is formed between the nozzle plate **101** and the housing **10**, inside the lower housing **10***b*. One end of the channel **112** communicates with a supply port **11**, and the other end of the channel **112** communicates with a collection port **12** as illustrated in FIGS. **4**A and **4**B.

(42) The supply port **11** and the collection port **12** are connected to each other via a circulation passage L, and the liquid pressurized by a pump P in the circulation passage L is supplied to the supply port **11**. The pressurized liquid that has not been discharged from the nozzle holes **111** is collected from the collection port **12**, and is then supplied to the supply port **11** again via the circulation passage L and the pump P.

(43) In the liquid discharge head **1** according to the present embodiment, a peripheral portion of the nozzle plate **101** and the housing **10** are firmly bonded to each other, for example, by an adhesive to supply the liquid to the supply port **11** with a feed pressure of several hundred kPa.

(44) When the lower housing **10***b* is removed, as illustrated in FIGS. **2**A and **2**B, leading ends of needle valves **113** having a shaft shape are exposed from bearings **121** on a lower face of the upper housing **10***a*. The needle valves **113** are made of the corrosion-resistant material such as SUS (i.e., stainless steel). Each of the needle valves **113** is thin and has a diameter of 1 mm or less at a thin portion and a diameter of about 2 mm at a thick portion. The thin needle valves **113** are exposed from the bearings **121** on the upper housing **10***a* by a length of 1 to 20 mm, for example.

(45) The needle valve **113** includes a valve body **113***a* to open and close the nozzle hole **111** at the leading end of thereof. An O-ring **113***b* having elasticity as a seal and a washer **113***c* to secure the O-ring **113***b* to the needle valve **113** are disposed on a side (upper side in FIG. **2**B) of the valve body **113***a* in −Z direction in FIG. **2**B. The peripheral portion of the nozzle plate **101** may be bonded to the housing **10** by a thermosetting resin or the like.

(46) The nozzle holes **111** of the nozzle plate **101** are typically formed in one row. Currently, the nozzle holes may be formed in a plurality of rows such as two rows, or three rows or more in order to enhance image quality and downsize the liquid discharge head **1**. The nozzle holes **111** arranged in the plurality of rows in a staggered manner can achieve high image quality, downsize the liquid discharge head **1**, and increase coating area to enhance productivity without inclining the nozzle plate **101** with respect to a printing direction.

(47) Opening and Closing Operations of Needle Valve

(48) As illustrated in FIG. **3**, the needle valve **113** and a piezoelectric element **114** that drives the needle valve **113** are disposed in an axial direction **113***d* of the needle valve **113** in the upper housing **10***a*. The piezoelectric element **114** is held in a central space **115***a* of a holder **115**. The axial direction **113***d* of the needle valve **113** corresponds to a height direction (direction parallel to the Z-axis) of the liquid discharge head **1**, a longitudinal direction of the piezoelectric element **114**, and a direction in which the needle valve **13** moves to open and close the nozzle hole **111**.

(49) Spring portions are disposed at both ends (upper and lower end in FIG. **3**) of the holder **115**, and the piezoelectric element **114** is held in a compressed state in the axial direction **113***d* of the needle valve **113** by the spring portions. A front end **115***b* of the holder **115** and a trailing end of the needle valve **113** are coupled to each other so that the piezoelectric element **114** and the needle valve **113** are concentric (coaxial) with each other. With this configuration, when the piezoelectric element **114** contracts in the longitudinal direction, which is the axial direction **113***d*, the holder **115** also contracts in the longitudinal direction, and a biasing force in a direction (−Z direction) in which the needle valve **113** moves away from the nozzle hole **111** in the axial direction **113***d* acts on the needle valve **113**. The direction in which the needle valve **113** moves away from the nozzle hole **111** may be referred to as a direction in which the nozzle hole **111** is opened, and both directions indicate the same direction (i.e., −Z direction illustrated in FIG. **3**).

(50) When a voltage is applied to the piezoelectric element **114** by a voltage application unit, the

piezoelectric element **114** is operated in a d31 mode to drive the needle valve **113** in the direction (−Z direction) in which the nozzle hole **111** is opened. In the d31 mode, the piezoelectric element **114** contracts when the voltage is applied. That is, the needle valve **113** is driven (moved) in the direction (−Z direction) in which the nozzle hole **111** is opened by the voltage applied to the piezoelectric element **114**.
(51) The needle valve **113** closes the nozzle hole **111** when no voltage is applied to the piezoelectric element **114**. Thus, even when the pressurized liquid is supplied to the channel **112**, the liquid is not discharged from the nozzle hole **111**.
(52) The voltage is applied to the piezoelectric element **114** to cause the piezoelectric element **114** to contract, thereby pulling the needle valve **113** via the holder **115**. As a result, the valve body **113***a* of the needle valve **113** is moved away from the nozzle hole **111** to open the nozzle hole **111**. Accordingly, the pressurized liquid supplied to the channel **112** is discharged from the nozzle hole **111** as droplets of the liquid.
(53) The piezoelectric element **114** may be operated in a d33 mode. In the d33 mode, the piezoelectric element **114** expands in a direction (+Z direction) in which the needle valve **113** is moved toward the nozzle hole **111** in the axial direction **113***d* when the voltage is applied, that is, in a direction in which the nozzle hole **111** is closed. When the piezoelectric element **114** is operated in the d33 mode, the valve body **113***a* of the needle valve **113** is pressed against the nozzle hole **111** to close the nozzle hole **111** while the voltage is applied.
(54) When the droplets of the liquid are discharged, the application of the voltage to the piezoelectric element **114** is stopped or the voltage is lowered to move the valve body **113***a* of the needle valve **113** in the direction (−Z direction) in which the nozzle hole **111** is opened to open the nozzle hole **111**. In the d33 mode, the piezoelectric element **114** has a high responsiveness and a large displacement amount. Accordingly, the d33 mode is suitable to increase the responsiveness of opening and closing operations of the needle valve **113** and reduce variations in a speed and a volume of the droplets of the liquid discharged from the nozzle hole **111**.
(55) Movement of Needle Valve
(56) The holder **115** is disposed in the upper housing **10***a*, and a position of the holder **115** is adjustable in the top and bottom direction in FIG. **3**. A rear end **115***c* of the holder **115** is positioned and secured to the upper housing **10***a* by a fixing screw **124**. A female screw hole **115***d* is disposed in the rear end **115***c* of the holder **115** in a direction perpendicular to the axial direction **113***d*, and a leading end of the fixing screw **124** is screwed into the female screw hole **115***d*.
(57) As illustrated in FIG. **3**, an elongated hole **30** elongated in the axial direction **113***d* is disposed in the upper portion of the upper housing **10***a*, and the fixing screw **124** is inserted into the elongated hole **30**. When the fixing screw **124** is loosened, the holder **115** can be moved up and down in FIG. **3**.
(58) As illustrated in FIG. **3**, the fixing screw **124** is fastened to secure the holder **115** relative to the elongated hole **30** at a position where a predetermined clearance δ is formed between the valve body **113***a* and the nozzle hole **111**. The liquid discharge head **1** in this state is delivered as a product.
(59) Nozzle Plate
(60) As illustrated in FIG. **1**B and FIGS. **4**A and **4**B, the nozzle holes **111** are disposed in the nozzle plate **101** along the channel **112** extending from the supply port **11** to the collection port **12**. The nozzle holes **111** can be formed by pressing, etching, or the like.
(61) In FIG. **4**B, the nozzle holes **111** are arranged in two rows, for example. Four nozzle holes **111** are arranged in each row. Each of these nozzle holes **111** is opened and closed by the valve body **113***a* disposed at the leading end of the needle valve **113**. In FIG. **4**A, lead wires **2***a* and **2***b* of the connector **2** are connected to the piezoelectric element **114**.
(62) In FIG. **4**B, the eight nozzle holes **111** are arranged in two rows (four in each row) in the staggered manner in the longitudinal direction of the channel **112**. The longitudinal direction (X-

axis direction) of the channel **112** is a direction in which the liquid flows from the supply port **11** toward the collection port **12**. The liquid to be discharged from the nozzle holes **111** flows from the supply port **11** to the collection port **12** in the channel **112** in a direction indicated by arrows illustrated in FIG. **4**B.

(63) The nozzle plate **101** and the housing **10** are made of a material that is resistant to corrosion by the highly pressurized liquid and has sufficient strength to withstand the pressure of the highly pressurized liquid. The materials of the nozzle plate **101** and the housing **10** are not particularly limited and can be appropriately selected according to the intended purpose.

(64) Examples of the materials of the nozzle plate **101** and the housing **10** includes stainless steel, Al, Bi, Cr, InSn, indium tin oxide (ITO), Nb, Nb.sub.2O.sub.5, NiCr, Si, SiO.sub.2, Sn, Ta.sub.2O.sub.5, Ti, W, ZAO (aluminum-doped zinc oxide, ZnO+Al.sub.2O.sub.3), Zn, or the like. Each of these materials can be used alone or in combination with others. Among these materials, stainless steel is preferable for rust prevention.

(65) Embodiments 1 to 6 of the nozzle plate **101** are described below.

Embodiment 1

(66) FIGS. **5**A to **5**D illustrate Embodiment 1. FIG. **5**A is a cross-sectional view of the housing **10**, FIG. **5**B is a plan view of the nozzle plate **101**. FIG. **5**C is a bottom view of the housing **10**, and FIG. **5**D is a cross-sectional view of the housing **10** during the diffusion bonding.

(67) The nozzle plate **101** and the housing **10** are made of stainless steel (e.g., SUS430), for example. The nozzle plate **101** and the housing **10** made of the same material can reduce strain due to a difference in thermal expansion coefficient. The nozzle plate **101** is a rectangular flat plate and have, for example, a length of 80 mm, a width of 25 mm, a thickness of 0.2 mm, and the surface roughness Ra of 0.01 μm or less.

(68) As illustrated in FIG. **5**A, a pair of left and right positioning pins **140** are implanted in positioning holes **131***a* and **131***b* of the housing **10**. The positioning holes **131***a* and **131***b* extend in a direction (Z-axis direction) perpendicular to the lower face of the housing **10** on which the nozzle plate **101** is disposed (i.e., a thickness direction of the housing **10**). The direction perpendicular to the lower face of the housing **10** corresponds to a thickness direction of the nozzle plate **101**, which is the same as the thickness direction of the housing **10**. The positioning pin **140** is made of stainless steel (e.g., SUS430). The positioning pin **140** has a length of 2.4 mm and a diameter of 0.99 mm, for example.

(69) Through holes **132** into which the needle valves **113** are inserted are disposed between the pair of left and right positioning pins **140** in the housing **10**. The through hole **132** can be formed by drilling and has an inner diameter of 2.7 mm, for example.

(70) As illustrated in FIG. **5**D, the positioning pin **140** has the length so as to fits into each of positioning holes **130***a* and **130***b* of the nozzle plate **101** and so as not to project outward from the positioning holes **130***a* and **130***b*. In detail, the positioning holes **131***a* and **131***b* of the housing **10** have an effective depth of 2.3 mm, for example. The nozzle plate **101** has the thickness of 0.2 mm as described above.

(71) Accordingly, the positioning holes **130***a* and **130***b* of the nozzle plate **101**, which are described later, extending (i.e., penetrating through the nozzle plate **101**) in the thickness direction have a depth of 0.2 mm, and the sum of the depth of 0.2 mm and the effective depth of 2.3 mm equals the total depth of 2.5 mm. Since the length of the positioning pin **140** is 2.4 mm, an end of the positioning pin **140** is set back inside the positioning holes **130***a* and **130***b* of the nozzle plate **101** by a depth D of 0.1 mm and does not project outside the positioning holes **130***a* and **130***b*.

(72) The positioning pin **140** may has the length of 2.5 mm at maximum so as not to project outward from the positioning holes **130***a* and **130***b*. In this case, the end of the positioning pin **140** is at the same height as outer edges of the positioning holes **130***a* and **130***b*, and does not interfere with a pressure plate during diffusion bonding.

(73) At least two positioning pins **140** are used to position the nozzle plate **101** relative to the

housing **10**. As the number of the positioning pins **140** increases, the bonding strength of the nozzle plate **101** can be increased as described later.
(74) Conventionally, the positioning pin **140** is removable in order to avoid interference between the positioning pin **140** and the pressure plate during the diffusion bonding. In the present embodiment, since the positioning pin **140** is left in place during the diffusion bonding, and is not removed after the diffusion bonding.
(75) The nozzle plate **101** illustrated in FIG. **5**B is directly mounted on the lower face of the housing **10** on which the positioning pins **140** are disposed. The nozzle plate **101** is the rectangular flat plate, and eight nozzle holes **111** are arranged in a row at equal intervals in the longitudinal direction (X-axis direction) of the nozzle plate **101** as illustrated in FIG. **5**B. The nozzle holes **111** may be arranged in two rows as illustrated in FIG. **4**B, or in three or more rows.
(76) The positioning holes **130***a* and **130***b* are spaced outboard of the nozzle holes **111** and the through holes **132** at both the extreme ends in the longitudinal direction. The positioning holes **130***a* and **130***b* are formed at both end portions of the nozzle plate **101** in the longitudinal direction (X-axis direction). In the present embodiment, both the end portions of the nozzle plate **101** in the longitudinal direction correspond to regions outside the nozzle holes **111** at both the extreme ends in the longitudinal direction (X-axis direction) of the nozzle plate **101**. Both the positioning holes **130***a* and **130***b* are round holes having a diameter of 1.01 mm, and extend in the thickness direction (Z-axis direction) of the nozzle plate **101**. The positioning holes **130***a* and **130***b* can be formed by drilling or the like.
(77) The housing **10** and the nozzle plate **101** illustrated in FIG. **5**D are set between a pair of upper and lower pressure plates **201** of a diffusion bonding apparatus as illustrated in FIG. **6**, and a top ram **202** is slid downward to press and bond the housing **10** and the nozzle plate **101** to each other. For example, a vacuum hot press (FVHP-R-750 FRET-300) can be used as the diffusion bonding apparatus. The pressure plates **201** are made of ceramics.
(78) In the diffusion bonding, the pressure plates **201** press the housing **10** and the nozzle plate **101** against each other with a load of 40 kN or more to apply a pressure of 20 MPa or more to an interface between the housing **10** and the nozzle plate **101**. In this state, the temperature is raised to in a range of 800 to 1000° C. at a degree of vacuum of 1.0×10.sup.−4 Pa, and then the temperature is held for 10 minutes to 1 hour to perform the diffusion bonding. After the diffusion bonding, the laminated plate in which the housing **10** and the nozzle plate **101** are bonded to each other and the pressure plates **201** are cooled by Ar gas, the pressure of the pressure plate **201** is released, and then the laminated plate (the housing **10** and the nozzle plate **101** bonded in the single bonded body) is taken out of the diffusion bonding apparatus.
(79) Since the positioning pin **140** has an outer diameter of 0.99 mm, a positional deviation of the nozzle plate **101** relative to the housing **10** due to the diffusion bonding is 20 μm at maximum. A positional tolerance of the nozzle plate **101** can be set to, for example, 25 μm, which is described later. Accordingly, the positional deviation of the nozzle plate **101** of 20 μm is within an allowable range, for example.
Embodiment 2
(80) FIG. **7**A is a plan view of a second nozzle plate **102** according to Embodiment 2 of the present disclosure, and FIG. **7**B is a cross-sectional view of the housing **10** during the diffusion bonding according to Embodiment 2. In Embodiment 2, as illustrated in FIG. **7**B, the second nozzle plate **102** having the same size as the nozzle plate **101** is interposed between the nozzle plate **101** and the housing **10** described in Embodiment 1. In the present embodiment, the nozzle plate **101** may be referred to as an outer nozzle plate **101** so as to be distinguished from the second nozzle plate **102**.
(81) The second nozzle plate **102** is a rectangular flat plate and have, for example, a length of 80 mm, a width of 25 mm, a thickness of 0.3 mm, and the surface roughness Ra of 0.01 μm or less. The second nozzle plate **102** laminated over the nozzle plate **101** can increase the bonding strength around the positioning pin **140** to reinforce the nozzle plate **101**, thereby reducing the concentricity.

In addition, a length of the nozzle hole **111** can be substantially extended to enhance the flying stability of the droplets of the liquid discharged from the nozzle holes **111**.

(82) Nozzle holes **103** of the second nozzle plate **102** are larger than the nozzle holes **111** of the outer nozzle plate **101**. Other than that, the second nozzle plate **102** is the same as the outer nozzle plate **101** except that the thickness of the second nozzle plate is 0.3 mm. Thus, the positional deviation between the outer nozzle plate **101** and the second nozzle plate **102** is 20 μm at maximum, which is within the allowable range.

(83) Since the nozzle holes **103** of the second nozzle plate **102** are larger than the nozzle holes **111** of the outer nozzle plate **101**, the flow of the pressurized liquid in the nozzle holes **111** and **103** can be rectified, and a discharge direction of the droplets of the liquid discharged from the nozzle holes **111** can be stabilized. Further, even when the diameter of the nozzle hole **111** is small, the large nozzle holes **103** of the second nozzle plate **102** larger than the nozzle holes **111** can adjust the volume of the pressurized liquid in the nozzle holes **111** and **103**, thereby adjusting the volume of the droplets of the liquid discharged from the nozzle holes **111** with high accuracy.

(84) Positioning holes **104***a* and **104***b* are formed at both end portions of the second nozzle plate **102** in the longitudinal direction (X-axis direction). The positioning holes **104***a* and **104***b* correspond to the positioning holes **131***a* and **131***b* of the housing **10**. Both the positioning holes **104***a* and **104***b* are round holes having a diameter of 1.01 mm.

(85) The positioning holes **104***a* and **104***b* are the round holes extending in the thickness direction of the nozzle plate **101**.

(86) In the present embodiment, both the end portions of the second nozzle plate **102** in the longitudinal direction correspond to regions outside the nozzle holes **111** at both the extreme ends in the longitudinal direction (X-axis direction) of the nozzle plate **101**.

(87) The housing **10** used in Embodiment 2 has the same configuration as that in Embodiment 1 illustrated in FIGS. **5**A and **5**C. As illustrated in FIG. **7**B, the pair of left and right positioning pins **140** are implanted in the positioning holes **131***a* and **131***b* of the housing **10**. The positioning holes **131***a* and **131***b* extend in the direction (Z-axis direction) perpendicular to the lower face of the housing **10** on which the second nozzle plate **102** is disposed. The direction perpendicular to the lower face of the housing **10** on which the second nozzle plate **102** is disposed corresponds to the thickness direction of the nozzle plate **101**. The positioning pin **140** is made of stainless steel (e.g., SUS430). The positioning pin **140** has a length of 2.7 mm and a diameter of 0.99 mm, for example.

(88) The nozzle plate **101** used in Embodiment 2 has the same configuration as that in Embodiment 1 illustrated in FIG. **5**B. The nozzle plate **101** is the rectangular flat plate and have, for example, a length of 80 mm, a width of 25 mm, a thickness of 0.2 mm, and the surface roughness Ra of 0.01 μm or less. The positioning holes **130***a* and **130***b* are spaced outboard of the nozzle holes **111** and the through holes **132** at both the extreme ends in the longitudinal direction. Both the positioning holes **130***a* and **130***b* are the round holes having the diameter of 1.01 mm. That is, the positioning holes **130***a* and **130***b* are the round holes extending in the thickness direction of the nozzle plate **101**.

(89) The positioning pin **140** used in Embodiment 2 is the same as that in Embodiment 1 except that the length of the positioning pin **140** is 2.7 mm. When the positioning holes **131***a* and **131***b* of the housing **10** has an effective depth of 2.3 mm, since the sum of the thicknesses of the nozzle plates **101** and the second nozzle plate **102** is 0.5 mm, the total effective depth of the positioning holes into which the positioning pin **140** fits equals 2.8 mm. Since the length of the positioning pin **140** is 2.7 mm, which is shorter than 2.8 mm, the end of the positioning pin **140** does not project outward from the positioning holes **130***a* and **130***b*.

Embodiment 3

(90) FIG. **8**A is a plan view of the nozzle plate **101** according to Embodiment 3 of the present disclosure, and FIG. **8**B is an enlarged cross-sectional view of the positioning pin **140** as a positioning member that positions the nozzle plate **101** relative to the housing **10** during the

diffusion bonding and the surrounding thereof according to Embodiment 3. One positioning hole **130***a* (on the left end portion of the nozzle plate **101** in FIG. **8**A) is a round hole having a diameter of 1.01 mm, and the other positioning hole **130***b* (on the right end portion of the nozzle plate **101** in FIG. **8**A) is a slotted hole having a width of 1.01 mm and a length of 1.05 mm. The other configurations are the same as in Embodiment 1. FIG. **8**B is an enlarged cross-sectional view of the positioning pin **140** (on the right side in FIG. **8**A) in the positioning hole **130***b* of the nozzle plate **101** and the positioning hole **131***b* of the housing **10**, and the surrounding thereof.
(91) Also in Embodiment 3, since the positioning hole **130***a* on one side, which is the round hole, is used as a reference position, the positional deviation of the nozzle plate **101** is 20 μm at maximum. In Embodiment 3 illustrated in FIGS. **8**A and **8**B, since the positioning hole **130***b* on the other side is the slotted hole elongated in the longitudinal direction of the nozzle plate **101**, the positioning hole **130***b* allows the nozzle plate **101** to deform and expand in the longitudinal direction due to heating during the diffusion bonding, thereby reducing the strain of the nozzle plate **101**.
Embodiment 4
(92) FIG. **9**A is a plan view of the nozzle plate **101** according to Embodiment 4 of the present disclosure, and FIG. **9**B is a plan view of the lower face of the housing **10** on which the nozzle plate **101** is disposed according to Embodiment 4. In Embodiment 4, three positioning holes **130***a*, **130***b*, and **130***c* are disposed at both end portions and a center portion in the longitudinal direction of the nozzle plate **101** as illustrated in FIG. **9**A.
(93) The positioning holes **130***a* and **130***b* at both the end portions in the longitudinal direction of the nozzle plate **101** are slotted holes having a width of 1.01 mm and a length of 1.05 mm. The positioning holes **130***a* and **130***b*, which are the slotted holes, is elongated in the longitudinal direction of the nozzle plate **101**.
(94) In the present embodiment, both the end portions of the nozzle plate **101** in the longitudinal direction correspond to regions outside the nozzle holes **111** at both the extreme ends in the longitudinal direction (X-axis direction) of the nozzle plate **101**. In addition, in the present embodiment, the center portion in the longitudinal direction is disposed between the nozzle holes **111** at both the extreme ends of the nozzle row in the longitudinal direction (X-axis direction) of the nozzle plate **101**, and is preferably disposed at a substantially middle position between the nozzle holes **111** at both the extreme ends.
(95) The positioning hole **130***c* at the center portion in the longitudinal direction (X-axis direction) of the nozzle plate **101** is a round hole having a diameter of 1.01 mm. The positioning hole **130***c* is disposed at a position away from the positions of the nozzle holes **111** and the through holes **132** of the housing **10** toward one side (+Y direction) in a transverse direction of the nozzle plate **101**.
(96) In the housing **10** illustrated in FIG. **9**B, the positioning holes **131***a*, **131***b*, and **131***c* are disposed at positions corresponding to the positioning holes **130***a*. **130***b*, and **130***c* of the nozzle plate **101** illustrated in FIG. **9**A, respectively. The same positioning pin **140** as that in Embodiment 1 is implanted in each of the positioning holes **131***a*, **131***b*, and **131***c* of the housing **10**.
(97) The positioning hole **130***c* at the center portion of the nozzle plate **101** serves as a reference hole in the Y-axis direction and the X-axis direction, i.e., the longitudinal direction and the transverse direction of the nozzle plate **101** (the top and bottom direction and the lateral direction in FIG. **9**A). The positioning holes **130***a* and **130***b* at both the end portions position the nozzle plate **101** in the Y-axis direction, i.e., the transverse direction of the nozzle plate **101** (the top and bottom direction in FIG. **9**A). The other configurations are the same as in Embodiment 1.
(98) In Embodiment 4, since the positioning holes **130***a* and **130***b* at both the end portions are the slotted holes, similarly to Embodiment 3, the positioning holes **130***a* and **130***b* allow the nozzle plate **101** to deform and expand in the longitudinal direction due to the heating during the diffusion bonding, thereby reducing the strain of the nozzle plate **101**. Further, the positioning hole **130***c* at the center portion of the nozzle plate **101** positions the nozzle plate **101** in the Y-axis direction and the X-axis direction, i.e., the longitudinal direction and the transverse direction of the nozzle plate

101 (the top and bottom direction and the lateral direction in FIG. **9**A) with high accuracy.

Embodiment 5

(99) FIG. **10**A is a plan view of the nozzle plate **101** according to Embodiment 5 of the present disclosure, and FIG. **10**B is a plan view of the lower face of the housing **10** on which the nozzle plate **101** is disposed according to Embodiment 5. In Embodiment 5, three positioning holes **130***a*, **130***b*, and **130***d* are disposed at both end portions and a center portion in the longitudinal direction of the nozzle plate **101** as illustrated in FIG. **10**A.

(100) The nozzle plate **101** according to Embodiment 5 is the same as that in Embodiment 4 except that the positioning hole **130***d* in the center portion is disposed in the row of the nozzle holes **111**. In the present embodiment, both the end portions of the nozzle plate **101** in the longitudinal direction correspond to regions outside the nozzle holes **111** at both the extreme ends in the longitudinal direction (X-axis direction) of the nozzle plate **101**. In addition, in the present embodiment, the center portion in the longitudinal direction is disposed between the nozzle holes **111** at both the extreme ends of the nozzle row in the longitudinal direction (X-axis direction) of the nozzle plate **101**, and is preferably disposed at a substantially middle position between the nozzle holes **111** at both the extreme ends.

(101) The positioning holes **130***a* and **130***b* at both the end portions in the longitudinal direction of the nozzle plate **101** are slotted holes having a width of 1.01 mm and a length of 1.05 mm. The positioning holes **130***a* and **130***b*, which are the slotted holes, is elongated in the longitudinal direction of the nozzle plate **101**.

(102) The positioning hole **130***d* at the center portion in the longitudinal direction of the nozzle plate **101** is a round hole having a diameter of 1.01 mm. This positioning hole **130***d* is disposed in the middle between the fourth and fifth nozzle holes **111** from the left in FIG. **10**A.

(103) In the housing **10** illustrated in FIG. **10**B, the positioning holes **131***a*. **131***b*, and **131***d* are disposed at positions corresponding to the positioning holes **130***a*, **130***b*, and **130***d* of the nozzle plate **101** illustrated in FIG. **10**A, respectively. The same positioning pin **140** as that in Embodiment 1 is implanted in each of the positioning holes **131***a*, **131***b*, and **131***d* of the housing **10**. The housing **10** according to Embodiment 5 is the same as that in Embodiment 4 except that the positioning hole **131***d* in the center portion is disposed in the row of the through holes **132**.

(104) In the nozzle plate **101** according to the present embodiment, the positioning hole **130***d* between the nozzle holes **111** serves as a reference position for expansion deformation of the nozzle plate **101** in the longitudinal direction due to the heating during the diffusion bonding, thereby advantageously reducing the positional deviation of each nozzle hole **111**.

Embodiment 6

(105) FIG. **11**A is a plan view of the nozzle plate **101** according to Embodiment 6 of the present disclosure, and FIG. **11**B is a plan view of the lower face of the housing **10** on which the nozzle plate **101** is disposed according to Embodiment 6. In Embodiment 6, a positioning hole **130***a* is disposed at one end portion and two positioning holes **130***c* and **130***e* are disposed at a center portion, three in total, in the longitudinal direction of the nozzle plate **101** as illustrated in FIG. **11**A.

(106) In the present embodiment, the one end portion of the nozzle plate **101** in the longitudinal direction correspond to a region outside the nozzle holes **111** at one of both the extreme ends in the longitudinal direction (X-axis direction) of the nozzle plate **101**. In addition, in the present embodiment, the center portion in the longitudinal direction is disposed between the nozzle holes **111** at both the extreme ends of the nozzle row in the longitudinal direction (X-axis direction) of the nozzle plate **101**, and is preferably disposed at a substantially middle position between the nozzle holes **111** at both the extreme ends.

(107) The positioning hole **130***a* at the one end portion in the longitudinal direction is a round hole having a diameter of 1.01 mm. The two positioning holes **130***c* and **130***e* at the center portion in the longitudinal direction of the nozzle plate **101** are slotted holes having a width of 1.01 mm and a

length of 1.05 mm.

(108) A direction of a major axis of the slotted hole is the longitudinal direction of the nozzle plate **101** (the X-axis direction which is the lateral direction in FIG. **11**A). The positioning holes **130***c* and **130***e* are disposed at positions away from the positions of the nozzle holes **111** and the through holes **132** of the housing **10** toward both sides in the transverse direction of the nozzle plate **101** (the Y-axis direction which is the top and bottom direction in FIG. **11**A).

(109) In the housing **10** illustrated in FIG. **11**B, the positioning holes **131***a*, **131***c*, and **131***e* are disposed at positions corresponding to the positioning holes **130***a*, **130***c*, and **130***e* of the nozzle plate **101** illustrated in FIG. **11**A, respectively. The positioning holes **131***a*, **131***c*, and **131***e* are spaced apart from the through holes **132**. The same positioning pin **140** as that in Embodiment 1 is implanted in each of the positioning holes **131***a*, **131***c*, and **131***e* of the housing **10**.

(110) In Embodiment 6, the positioning hole **130***a* at the one end portion in the longitudinal direction serves as a reference hole in the X-axis direction and the Y-axis direction (the top and bottom direction and the lateral direction in FIG. **11**A). Since the two positioning holes **130***c* and **130***e* at the center portion are the slotted holes, the positioning holes **130***c* and **130***e* allow the nozzle plate **101** to deform and expand in the longitudinal direction (the X-axis direction which is the lateral direction in FIG. **11**A) due to the heating during the diffusion bonding, thereby reducing the strain of the nozzle plate **101**.

(111) Bonding State Around Positioning Pin

(112) FIGS. **12**A and **12**B illustrate a bonding state around the positioning pin **140**. FIG. **12**A illustrates the bonding state according to the present embodiment in which the positioning pins **140** are left in place of the positioning holes **130***a*, **131***a*, **130***b*, and **131***b* during the diffusion bonding. FIG. **12**B illustrates the bonding state according to a comparative example (e.g., Comparative Example 1) in which the positioning pins **140** are pulled out from the positioning holes **130***a*, **131***a*, **130***b*, and **131***b* before the diffusion bonding.

(113) As indicated by thick lines in FIGS. **12**A and **12**B, a bonding area in the present embodiment is larger than a bonding area in the comparative example around the positioning pin **140** by an outer circumferential surface (interface in the Z-axis direction) and an end surface (X-Y interface) of the positioning pins **140**, thereby increasing the bonding strength. Since the ends of the positioning pins **140** do not project outward from the positioning holes **130***a* and **130***b* of the nozzle plate **101**, the positioning pins **140** do not interfere with the pressure plate **201** during the diffusion bonding.

(114) As described later with reference to FIGS. **15** and **16**, when the liquid discharge head **1** is used in a liquid discharge apparatus **500**, the liquid discharge head **1** can be moved close to an object **700** on which an image is printed or an object to be coated. Further, the positioning pins **140** do not hinder a blade or cloth from wiping the liquid discharge head **1** to clean the surface of the liquid discharge head **1**, thereby maintaining a performance of the liquid discharge head **1**.

(115) Deviation of Nozzle Plate Due to Thermal Expansion

(116) FIGS. **13**A and **13**B are cross-sectional views of the housing **10** illustrating thermal expansion of the nozzle plate **101** during the diffusion bonding according to Comparative Example 1. FIG. **13**A illustrates a state immediately after the nozzle plate **101** is positioned relative to the housing **10** by the positioning pins **140** and then the positioning pins **140** are pulled out from the positioning holes **130***a*, **131***a*. **130***b*, and **131***b*.

(117) FIG. **13**B illustrates a state after the housing **10** and the nozzle plate **101** are bonded to each other by the diffusion bonding. Central axes of the nozzle holes **111** and the through holes **132** coincide with each other in the state immediately after positioning as illustrated in FIG. **13**A. However, the nozzle plate **101** thermally expands and the central axes of the nozzle holes **111** and the through holes **132** deviate from each other without the positioning pins **140** during the diffusion bonding as illustrated in FIG. **13**B (i.e., a deviation due to thermal expansion).

(118) In the present embodiment, the positioning pins **140** are left in place in the housing **10** and

the nozzle plate **101** during the diffusion bonding, thereby preventing the housing **10** and the nozzle plate **101** from being deviated from each other due to the heating during the diffusion bonding. In addition, it is unnecessary to remove the positioning pins **140** immediately before the diffusion bonding.

Comparison Among Embodiments 1 to 4 and Comparative Examples 1 and 2

(119) FIG. **14** is a table illustrating the concentricity of the laminated plate according to Embodiments 1 to 4 and Comparative Examples 1 and 2. According to Comparative Example 2, in Comparative Example 1, the housing **10** and the nozzle plate **101** are temporarily fixed to each other by spot welding before the positioning pins **140** are pulled out.

(120) In the spot welding, a pressing force between the housing **10** and the nozzle plate **101** was 0.5 to 3 kN, a pressing time was 0.1 to 5 sec. a heating temperature of the surface of the nozzle plate **101** was 1000 to 1500° C., and a weld diameter was 1 to 10 mm. The housing **10** and the nozzle plate **101** were bonded to each other in the single bonded body by the diffusion bonding, similarly to Embodiment 1 except that the positioning pins **140** were removed after the temporary fixing and before the diffusion bonding. The above-described vacuum hot press (FVHP-R-750 FRET-300) was used as the diffusion bonding apparatus.

(121) A CNC VISION MEASURING SYSTEM (QV HYPER 606) was used to evaluate the concentricity. The procedure for evaluating the concentricity is as follows. In a first step, the laminated plate is turned upside down after the diffusion bonding, and a bottom surface of the housing **10** is used as a measurement surface. Center points of circles of the eight through hole **132** on the bottom surface of the housing **10** is acquired.

(122) In a second step, center points of circles of the eight nozzle holes **111** on the bonded interface between the nozzle plate **101** and the housing **10** are acquired. When the nozzle plates **101**, the second nozzle plate **102**, and the housing **10** are bonded one on another as in Embodiment 2, center points of circles of the eight nozzle holes **111** and the eight nozzle holes **103** at a bonded interface between the nozzle plate **101** and the second nozzle plate **102** are also acquired.

(123) In a third step, a deviation between the acquired center points of circle of the through hole **132** and the nozzle hole **111** at the same position is calculated. In a fourth step, deviations at all the eight positions are calculated, and the maximum deviation is defined as the concentricity.

(124) As illustrated in FIG. **14**, the concentricity between the nozzle hole **111** and the through hole **132** was 25 μm or less in Embodiments 1 and 2, and the concentricity between the nozzle hole **111** and the through hole **132** was 15 μm or less in Embodiments 3 and 4. Thus, according to the present embodiments, the liquid discharge head **1** has a good concentricity. When the deviation of the concentricity is about 25 μm, an acceptable image quality can be obtained in practical use.

(125) On the other hand, in Comparative Example 1, the concentricity of the nozzle hole **111** was 70 μm, which exceeded 25 μm. This is because, in Comparative Example 1, the nozzle plate **101** and the housing **10** are largely deviated from each other due to thermal expansion during the diffusion bonding without a restricted point by the positioning pin **140**.

(126) When the concentricity is more than 25 μm, the droplets of the liquid (e.g., ink) is discharged in an oblique flying direction, causing coating unevenness on the object **700** illustrated in FIG. **15**. When the nozzle plate **101** has a length of 80 mm, a linear thermal expansion coefficient of SUS430 is 12.4×10.sup.−6/° C., and the laminated plate is heated at 1000° C., the nozzle plate **101** and the housing **10** may be thermally expanded and displaced in opposite directions, resulting in the concentricity of about 2 mm at maximum.

(127) In Comparative Example 2, the liquid (e.g., ink) leaks from the liquid discharge head **1** due to defective bonding. The defective bonding may be caused by the strain or cracks in the housing **10** or the nozzle plate **101** due to the temporary fixing by spot welding.

(128) Liquid Discharge Apparatus

(129) The liquid discharge apparatus **500** using the liquid discharge head **1** illustrated in FIGS. **1**A and **1**B according to the present embodiment is described with reference to FIGS. **15** and **16**. FIG.

15 is a perspective view of the liquid discharge apparatus **500**, and FIG. **16** is a perspective view of a drive unit of the liquid discharge apparatus **500**.

(130) The liquid discharge apparatus **500** includes a movable frame unit **802** installed to face the object **700** having a curved surface such as a hood of a vehicle. The frame unit **802** includes a left frame **810**, a right frame **811**, and a movable part **813**. The movable part **813** is attached to the left frame **810** and the right frame **811** so that the movable part **813** is bridged between the left frame **810** and the right frame **811**. The movable part **813** is vertically movable in the X-axis direction.

(131) A drive unit **803** including a built-in motor and a liquid discharge device **501** attached to the drive unit **803** are mounted on the movable part **813**. The drive unit **803** is reciprocally movable in the horizontal direction (Y-axis direction) on the movable part **813**. The liquid discharge device **501** discharges a liquid toward the object **700**.

(132) Further, the liquid discharge apparatus **500** includes a controller **805** and a data processing device **806**. The controller **805** controls a liquid discharge from liquid discharge device **501**, a reciprocal movement of the drive unit **803**, and a vertical movement of the movable part **813**. The data processing device **806** such as a personal computer (PC) sends instructions to the controller **805**. The data processing device **806** is connected to a database (DB) unit **807** that records and stores data related to the object **700** such as a shape and a size of the object **700**.

(133) The frame unit **802** further includes an upper frame **808** and a lower frame **809** in addition to the left frame **810** and the right frame **811** that form a vertical and horizontal outline of the frame unit **802**. The upper frame **808**, the lower frame **809**, the left frame **810**, and the right frame **811** are formed of metal pipes or the like. The frame unit **802** further includes a left leg **812***a* and a right leg **812***b* attached to both ends of the lower frame **809** to make the frame unit **802** to be freestanding. The left leg **812***a* and the right leg **812***b* are perpendicularly and horizontally attached to both the ends of the lower frame **809**. The movable part **813** bridged between the left frame **810** and the right frame **811** is vertically movable while supporting the drive unit **803**. That is, the movable part **813** functions as a drive mechanism of the liquid discharge device **501** to move the liquid discharge device **501** in the X-axis direction.

(134) A surface of the object **700** is perpendicular to the direction of the liquid discharge (Z-axis direction). Thus, the surface of the object **700** faces a plane formed by the upper frame **808**, the lower frame **80**), the left frame **810**, and the right frame **811** of the frame unit **802**. In this case, in order to arrange the object **700** at a predetermined position at which printing is to be performed, a back side of a printing area of the object **700** is sucked and held by a chuck attached to a leading end of a robot arm of a multi-articulated robot, for example. By using the multi-articulated robot, the object **700** can be accurately arranged at a printing position, and the posture of the object **700** can be appropriately changed.

(135) As illustrated in FIGS. **15** and **16**, the drive unit **803** is reciprocally movable in the horizontal direction (Y-axis direction) along the movable part **813**. The movable part **813** includes a rail **830**, a rack gear **831**, a linear guide **832**, a pinion gear **833**, a motor **834**, and a rotary encoder **835**. The rail **830** is horizontally disposed to bridge between the left frame **810** and the right frame **811** of the frame unit **802**. The rack gear **831** is parallel to the rail **830**. The linear guide **832** is fitted on a part of the rail **830** and slidably moves along the rail **830**. A pinion gear **833** is coupled to the linear guide **832** and meshes with the rack gear **831**. The motor **834** includes a decelerator **836** and drives the pinion gear **833** to rotate. The rotary encoder **835** detects a position of a printing point.

(136) The motor **834** is forwardly or reversely driven to move the liquid discharge device **501** rightward or leftward along the movable part **813** in FIGS. **15** and **16**. Further, the drive unit **803** functions as the drive mechanism of the liquid discharge device **501** to move the liquid discharge device **501** in the Y-axis direction. The decelerator **836** includes limit switches **837***a* and **837***b* attached to both sides of a case of the decelerator **836**.

(137) The liquid discharge device **501** includes, for example, at least one of the multiple liquid discharge heads **1** that discharge liquids of different colors of black, cyan, magenta, yellow, and

white, or the liquid discharge head **1** having a plurality of nozzle arrays to discharge the liquids of such different colors. The liquid of each color is supplied under pressure from a liquid tank to each liquid discharge head **1** of the liquid discharge device **501** or each nozzle array of the liquid discharge head **1**.

(138) In the liquid discharge apparatus **500**, the movable part **813** is moved in the X-axis direction and the liquid discharge device **501** is moved in the Y-axis direction to print a desired image on the object **700**. 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, a film of paint, or the like, or an apparatus that fabricates three-dimensional images.

(139) Although some embodiments of the present disclosure have been described above, embodiments of the present disclosure are not limited to the embodiments described above, and a variety of modifications can be made within the scope of the present disclosure. For example, arrangements of the positioning holes **130***a* to **130***d* according to Embodiments 1 to 6 can be combined in any combination of the multiple arrangements. The nozzle plate **101** and the housing **10** can be bonded to each other in the single bonded body by a method other than the diffusion bonding, for example, can be bonded by an adhesive or the like.

(140) The channel **112** is not necessarily connected to the circulation passage L. and the present disclosure is also applicable to a liquid discharge head of a type in which all the supplied liquid is discharged from the nozzle holes **111** without the collection port **12**. The piezoelectric element **114** is replaceable with another driver that can expand and contract in the longitudinal direction. For example, a piston that expands and contracts in the longitudinal direction by an electromagnetic solenoid may be used instead of the piezoelectric element **114**.

(141) Hereinafter, each of aspects of the present disclosure is additionally described.

(142) Aspect 1

(143) According to Aspect 1, a liquid discharge head includes a nozzle plate, a housing, a channel, and a positioning member. The nozzle plate has a nozzle hole from which a liquid is discharged and a first positioning hole penetrating through the nozzle plate in a thickness direction of the nozzle plate. The housing is bonded to the nozzle plate to form a single bonded body and has a second positioning hole extending in a thickness direction of the housing. The channel is disposed between the nozzle plate and the housing. The liquid flows through the channel to the nozzle hole. The positioning member fits into the first positioning hole and the second positioning hole to position the nozzle plate relative to the housing. A length of the positioning member in the thickness direction of the nozzle plate is smaller than a sum of a length of the first positioning hole and a length of the second positioning hole in the thickness direction of the nozzle plate, and larger than the length of the second positioning hole in the thickness direction of the nozzle plate.

(144) Aspect 2

(145) According to Aspect 2, in Aspect 1, the liquid discharge head further includes a needle valve to open and close the nozzle hole. The housing further has a through hole through which the needle valve is slidable. The nozzle plate and the housing are bonded to each other to form the single bonded body with the through hole and the nozzle hole concentric with each other

(146) Aspect 3

(147) According to Aspect 3, in Aspect 1 or 2, the nozzle plate, the housing, and the positioning member are made of stainless steel.

(148) Aspect 4

(149) According to Aspect 4, in any one of Aspects 1 to 3, the nozzle plate and the housing are directly bonded to each other in the single bonded body.

(150) Aspect 5

(151) According to Aspect 5, in any one of Aspects 1 to 4, the nozzle plate includes multiple plates laminated one on another.

(152) Aspect 6
(153) According to Aspect 6, in any one of Aspects 1 to 5, the liquid discharge head further includes multiple nozzle holes including the nozzle hole and multiple first positioning holes including the first positioning hole. The multiple nozzle holes are arranged in a longitudinal direction of the nozzle plate in a row. The multiple first positioning holes are disposed at both end portions of the row of the multiple nozzle holes in the longitudinal direction.
(154) Aspect 7
(155) According to Aspect 7, in any one of Aspects 1 or 5, the liquid discharge head further includes multiple nozzle holes including the nozzle hole and multiple first positioning holes including the first positioning hole. The multiple nozzle holes are arranged in a longitudinal direction of the nozzle plate in a row. The multiple first positioning holes are disposed at both end portions of the row of the multiple nozzle holes and a center portion of the nozzle plate in the longitudinal direction. The center portion is shifted from the row in a direction orthogonal to the longitudinal direction.
(156) Aspect 8
(157) According to Aspect 8, in Aspect 6 or 7, each of the multiple first positioning holes is a round hole.
(158) Aspect 9
(159) According to Aspect 9, in Aspect 6 or 7, one of the multiple first positioning holes at one of the both end portions in the longitudinal direction is a round hole, and another of the multiple first positioning holes at another of the both end portions in the longitudinal direction is a slotted hole elongated in the longitudinal direction.
(160) Aspect 10
(161) According to Aspect 10, in Aspect 7, two of the multiple first positioning holes at the both end portions in the longitudinal direction are slotted holes elongated in the longitudinal direction, and one of the multiple first positioning holes at the center portion in the longitudinal direction is a round hole.
(162) Aspect 11
(163) According to Aspect 11, in any one of Aspects 1 to 10, the positioning member is a pin and is diffusion bonded to the first positioning hole and the second positioning hole.
(164) Aspect 12
(165) According to Aspect 12, a liquid discharge device includes the liquid discharge head according to any one of Aspects 1 or 11 to discharge the liquid to an object.
(166) Aspect 13
(167) According to Aspect 13, a liquid discharge apparatus includes the liquid discharge device according to Aspect 12 and a drive mechanism to move the liquid discharge device relative to the object.
(168) Aspect 14
(169) According to Aspect 14, a method of manufacturing a liquid discharge head includes forming a nozzle hole in a nozzle plate, forming a first positioning hole in the nozzle plate, forming a second positioning hole in a housing, fitting a positioning member into the first positioning hole and the second positioning hole to position the nozzle plate relative to the housing, and bonding the nozzle plate and the housing to each other to form a single bonded body. The first positioning hole penetrates through the nozzle plate in a thickness direction of the nozzle plate, and the second positioning hole extends in a thickness direction of the housing. A length of the positioning member in the thickness direction of the nozzle plate is smaller than a sum of a length of the first positioning hole and a length of the second positioning hole in the thickness direction of the nozzle plate, and larger than the length of the second positioning hole in the thickness direction of the nozzle plate.
(170) As described above, according to the present disclosure, the nozzle plate can be bonded to the

housing in the single bonded body with the positioning member left in place to position the nozzle plate relative to the housing.
(171) The above-described embodiments are illustrative and do not limit the present invention. Thus, numerous additional modifications and variations are possible in light of the above teachings. For example, elements and/or features of different illustrative embodiments may be combined with each other and/or substituted for each other within the scope of the present invention.
(172) Any one of the above-described operations may be performed in various other ways, for example, in an order different from the one described above.

Claims

1. A liquid discharge head comprising: a nozzle plate having: a nozzle hole from which a liquid is discharged; and a first positioning hole penetrating through the nozzle plate in a thickness direction of the nozzle plate; a housing bonded to the nozzle plate to form a single bonded body, the housing having a second positioning hole extending in a thickness direction of the housing; a channel between the nozzle plate and the housing, the liquid flowing through the channel to the nozzle hole; and a positioning member fitting into the first positioning hole and the second positioning hole to position the nozzle plate relative to the housing, wherein a length of the positioning member in the thickness direction of the nozzle plate is: smaller than a sum of a length of the first positioning hole and a length of the second positioning hole in the thickness direction of the nozzle plate; and larger than the length of the second positioning hole in the thickness direction of the nozzle plate.
2. The liquid discharge head according to claim 1, further comprising a needle valve configured to open and close the nozzle hole, wherein the housing further has a through hole through which the needle valve is slidable, and the nozzle plate and the housing are bonded to each other to form the single bonded body with the through hole and the nozzle hole concentric with each other.
3. The liquid discharge head according to claim 1, wherein the nozzle plate, the housing, and the positioning member are made of stainless steel.
4. The liquid discharge head according to claim 1, wherein the nozzle plate and the housing are directly bonded to each other in the single bonded body.
5. The liquid discharge head according to claim 1, wherein the nozzle plate includes multiple plates laminated one on another.
6. The liquid discharge head according to claim 1, further comprising multiple nozzle holes including the nozzle hole; and multiple first positioning holes including the first positioning hole, wherein the multiple nozzle holes are arranged in a longitudinal direction of the nozzle plate in a row, and the multiple first positioning holes are disposed at both end portions of the row of the multiple nozzle holes in the longitudinal direction.
7. The liquid discharge head according to claim 6, wherein each of the multiple first positioning holes is a round hole.
8. The liquid discharge head according to claim 6, wherein one of the multiple first positioning holes at one of the both end portions in the longitudinal direction is a round hole, and another of the multiple first positioning holes at another of the both end portions in the longitudinal direction is a slotted hole elongated in the longitudinal direction.
9. The liquid discharge head according to claim 1, further comprising: multiple nozzle holes including the nozzle hole; and multiple first positioning holes including the first positioning hole, wherein the multiple nozzle holes are arranged in a longitudinal direction of the nozzle plate in a row, and the multiple first positioning holes are disposed at: both end portions of the row of the multiple nozzle holes in the longitudinal direction; and a center portion of the nozzle plate in the longitudinal direction, the center portion shifted from the row in a direction orthogonal to the longitudinal direction.
10. The liquid discharge head according to claim 9, wherein two of the multiple first positioning

holes at the both end portions in the longitudinal direction are slotted holes elongated in the longitudinal direction, and one of the multiple first positioning holes at the center portion in the longitudinal direction is a round hole.

11. The liquid discharge head according to claim 1, wherein the positioning member is a pin and is diffusion bonded to the first positioning hole and the second positioning hole.

12. A liquid discharge device comprising: the liquid discharge head according to claim 1, configured to discharge the liquid to an object.

13. A liquid discharge apparatus comprising: the liquid discharge device according to claim 12; and a drive mechanism configured to move the liquid discharge device relative to the object.

14. The liquid discharge head according to claim 1, wherein the positioning member is a pin and is implanted in the first positioning hole and the second positioning hole.

15. A method of manufacturing a liquid discharge head comprising: forming a nozzle hole in a nozzle plate; forming a first positioning hole in the nozzle plate, the first positioning hole penetrating through the nozzle plate in a thickness direction of the nozzle plate; forming a second positioning hole in a housing, the second positioning hole extending in a thickness direction of the housing; fitting a positioning member into the first positioning hole and the second positioning hole to position the nozzle plate relative to the housing; and bonding the nozzle plate and the housing to each other to form a single bonded body, wherein a length of the positioning member in the thickness direction of the nozzle plate is: smaller than a sum of a length of the first positioning hole and a length of the second positioning hole in the thickness direction of the nozzle plate; and larger than the length of the second positioning hole in the thickness direction of the nozzle plate.

16. The method according to claim 15, wherein the positioning member is a pin and is implanted in the first positioning hole and the second positioning hole.