



FLUID EJECTION DEVICE AND PRODUCTION METHOD THEREOF

FIELD OF THE INVENTION

The present invention relates to a fluid ejection device to be used in a
5 printhead of an ink jet printer for ejecting fluid such as ink in a well-controlled manner,
and production method thereof.

BACKGROUND OF THE INVENTION

With the development of a computerized society in recent years, demand for
10 office automation or OA devices has been growing rapidly. Under such circumstances,
demand for various kinds of printers has become increasingly stronger, not only with
respect to their performance as a recording means but for higher-speed printing and
improved picture quality.

In widely used ink jet printers, the ink jet printhead of the on-demand
15 system which enables a high-speed ejection of the ink at the user's will, is critical for the
performance of the printer. The ink jet printhead, in general, comprises an ink channel, a
pressure chamber where ink is pressurized, a pressurizing means for the ink such as an
actuator, and an ink outlet through which the ink is ejected. To realize an on-demand ink
jet printer system, a pressurizing means with high controllability is required. However,
20 most of the conventional systems employ a bubble ejecting method whereby the ink is
heated to produce bubbles, which eventually eject the ink (heating method), or a
piezoelectric method in which ink is directly pressurized by a deformation of piezoelectric
ceramics and the like.

Fig 11 is a sectional perspective view showing an example of the
25 construction of a conventional ink jet printhead. The conventional ink jet printhead consists



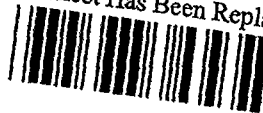
of a piezoelectric member 111, a pressure chamber 112, an ink channel 113, an ink outlet 114, a fluid (ink) inlet 115, a structure member A 116, a structure member B 117, a structure member C 118, a diaphragm 119 and individual electrodes 120 (120a, 120b).

On a first side of the piezoelectric member 111 individual electrodes 120 are formed thereon. On a second side thereof electrodes are also formed in the same manner (not depicted). The piezoelectric member 111 is bonded to the diaphragm 119 via the electrode on the second side.

The diaphragm 119 and the structure member A 116, the structure member B 117 and the structure member C 118 are bonded by an adhesive or similar material thereby forming a laminated structure. There is a cavity in the structure member A 116, where the pressure chamber 112 and the ink channel 113 are to be formed. In general, a plurality sets of the pressure chambers 112, the ink channel 113 and individual electrodes 120 are formed and disposed such that each set is separated from the other sets. The structure member B 117 is formed in the same manner with the ink inlet 115 being mounted additionally. On the structure member C 118, corresponding to the position of the pressure chamber 112, the ink outlet 114 is mounted. The ink is supplied through the ink inlet 115, and the ink channel 113 and the pressure chamber 112 are filled with ink.

The diaphragm 119 is made of a conductive material and has conductivity with the electrodes mounted on the bonded surface of the piezoelectric member 111. Thus, if an electric voltage is applied between the diaphragm 119 and the individual electrodes 120, the laminated section of the piezoelectric member 111 and the diaphragm 119 is deformed. At this time, an arbitrary location of the piezoelectric member 111, in other words, the location corresponding to an arbitrary pressure chamber 112 can be deformed by selecting an electrode to be applied with an electric voltage. The deformation pressurizes ink in the pressure chamber 112, and the amount of ink responsive to the pressure is

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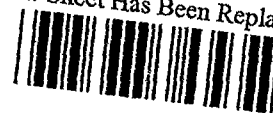


ejected from the ink outlet 114. The amount of deformation depends on the electric voltage applied to the piezoelectric member 111. Therefore, by controlling the magnitude of the electric voltage and the location on which the electric voltage is applied, amount and location of the ink ejection can be arbitrarily changed.

5 The conventional thermal ink jet printhead, in general, is inferior to the piezoelectric method in terms of the response speed. On the other hand, in the case of the piezoelectric ink jet printhead, the displacement of the piezoelectric member and the diaphragm is restricted by the thickness of the piezoelectric member. If the piezoelectric member is too thick, a sufficient displacement can not be gained due to the rigidity of the piezoelectric member itself. If the area of the piezoelectric member is increased to effect a
10 sufficient displacement, the ink jet printhead will become bigger making harder to achieve a higher density of the nozzle. As a result, material cost will increase. When the area of the piezoelectric member can not be increased, a higher driving voltage is required for a sufficient deformation.

15 A piezoelectric member with thickness of about 20 μ m have become available now by techniques of the thick film forming and the integrated firing, however, a higher density in the nozzle is still required for an improved picture quality. In order to reduce the area of the piezoelectric member to achieve a higher density of the nozzle, reduction of the thickness of the piezoelectric member is essential. However, conventional
20 methods have limitations in this regard.

 A cavity must be provided within the structures made of stainless steel or the like in order to form an ink channel, and for precise and complex ink channels, increased number of layers are required. Adhesive used on the bonded section is subjected to fluid for a long time, therefore, reliability of such material has always required close
25 attention.



An object of the present invention is to provide a fluid ejection device such as an ink jet printhead with higher picture quality, higher reliability and lower cost.

SUMMARY OF THE INVENTION

5 A fluid ejection device of the present invention includes at least one chamber divided independently from other chambers, an ink channel communicating with the chamber, an ink outlet communicating with the chamber, and a pressure generating section having a laminated body made of a piezoelectric material of a thickness of not more than $7\mu\text{m}$ and an elastic body, the section covering one face of the chamber.

10 A production method of a fluid ejection device of the present invention includes the steps of: a process of forming a through-hole for the pressure chamber and a through-hole for the ink inlet on a first substrate; a process of bonding the first substrate and a second substrate; a process of bonding the second substrate and a third substrate; and a process of forming a pressure generating section comprising a laminated body including
15 piezoelectric material and an elastic material such that the pressure generating section covers the through-hole for the pressure chamber.

According to the present invention, a thin film material of PZT related material deposited by sputtering method is used as a piezoelectric material.

20 According to the present invention, silicon and glass substrates are used as structure members which are etched and processed by sand-blasting.

The structures are directly bonded by processing the surfaces and heating without the use of resin or other adhesives.

The configuration discussed above allows the piezoelectric member to be thinner with ease, which contributes to a higher density of the nozzle. A plurality of silicon
25 and glass substrates are simultaneously processed finely by etching and sand-blasting,



thereby improving processing precision for products and reducing a number of production processes. The silicon and glass substrates can be directly bonded, therefore, long-term reliability against inflow of fluid is secured. Meanwhile, the substrates can be bonded at a time, which contributes to streamlining of the production processes.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a sectional perspective view of a fluid ejection device in accordance with the first exemplary embodiment of the present invention.

10 Figs. 2A-2D show a manufacturing process of a piezoelectric thin film of the first exemplary embodiment as set forth in Fig. 1.

Figs. 3A-3E show a manufacturing process of a silicon substrate of the first exemplary embodiment as set forth in Fig. 1.

Figs. 4A-4E show a manufacturing process of an ink outlet of the first exemplary embodiment as set forth in Fig. 1.

15 Figs. 5A-5D show a manufacturing process of the fluid ejection device of the first exemplary embodiment as set forth in Fig. 1.

Figs. 6A-6F show an alternative manufacturing process of a silicon substrate.

Figs. 7A-7D show an alternative manufacturing process of an ink outlet.

20 Fig. 8 shows a sectional perspective view of a fluid ejection device in accordance with the second exemplary embodiment of the present invention.

Figs. 9A-9E show a manufacturing process of a silicon substrate of the second exemplary embodiment as set forth in Fig. 8.

25 Figs. 10A-10F show a manufacturing process of the fluid ejection device of the second exemplary embodiment as set forth in Fig. 8.



Fig. 11 shows a sectional perspective view of a fluid ejection device of the prior art.

Fig. 12 shows a plan view of the processed silicon substrate in accordance with the first exemplary embodiment of the present invention.

Fig. 13A-13E show a manufacturing process chart illustrating processing steps of the silicon and glass substrates.

Fig. 14A-14E show a manufacturing process chart illustrating another processing steps of the silicon and glass substrates.

Fig. 15A and 16B show processed condition of a silicon substrate in accordance with the second exemplary example of the present invention.

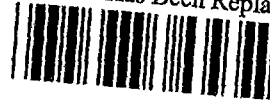
DESCRIPTION OF THE PREFERRED EMBODIMENTS

First exemplary embodiment

Fig. 1 is a perspective cross sectional view illustrating an example of a fluid ejection device comprising silicon, glass and piezoelectric thin films.

As shown in Fig. 1, a fluid ejection device in accordance with the first exemplary embodiment comprises the following elements; a piezoelectric thin film 11, a pressure chamber 12, an ink channel 13, an ink outlet 14, a through-hole 15, an ink inlet 16, a first silicon substrate 17, a glass substrate 18, a second silicon substrate 19, an elastic body 20 and individual electrodes 21(21a, 21b...). More specifically, the fluid ejection device of this embodiment comprises a laminated body made of the first silicon substrate 17, the glass substrate 18 and the second silicon substrate 19, the piezoelectric thin film 11, the elastic body 20 and the individual electrodes 21 mounted on the piezoelectric thin film 11.

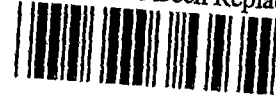
The first silicon substrate 17 is provided with such elements as the pressure



chamber 12 formed as an individual through-section at the position corresponding to the individual electrodes 21, the ink channel 13 formed up to the midway in the direction of the thickness of the silicon substrate 17 in such a manner that it communicates with the pressure chamber 12, and the ink inlet 16, a through-section communicating with the ink channel 13. The opening area of the ink channel 13 starts to expand outwardly as it goes away from the pressure chamber 12 (illustrated as dotted lines in Fig. 1). Fig. 1 shows a single set of the individual electrodes, the pressure chamber, and the ink outlet and so on. A fluid ejection device generally has a plurality of units constructed in a similar manner including the individual electrodes, the pressure chamber and the ink outlet. Fig. 1 shows two sets of the individual electrodes 21 (21a and 21b).

Next, the first silicon substrate 17 and the glass substrate 18 are bonded, whereby the pressure chamber 12 and the ink channel 13 are sealed except for some portion. The glass substrate 18 is provided with a through-hole 15 on the position corresponding to the pressure chamber 12. Corresponding to the center of the through-hole 15, an ink outlet 14 with an area smaller than the opening portion of the through-hole 15 is formed on the second silicon substrate 19. The glass substrate 18 and the second silicon substrate 19 are bonded. The piezoelectric thin film 11 is bonded through the elastic body 20 on the face of the pressure chamber 12 opposite the through-hole 15. The piezoelectric thin film 11 has the individual electrode 21a formed on front surface thereof, and other individual electrode on the back surface (not shown in the drawing).

The fluid which has flowed in from the ink inlet 16 fills the ink channel 13, pressure chamber 12 and the through-hole 15, and stays around the ink outlet 14. If an electric voltage is applied between the electrodes on both sides of the piezoelectric thin film 11, the laminated body of the piezoelectric thin film 11 and the elastic body 20 will be deformed. Providing the elastic body 20 is made of a conductive material, it will conduct



with the electrode mounted on the back face of the piezoelectric thin film, and deformation occurs when voltage is applied between the elastic body 20 and individual electrodes 21. The exact position of the laminated body to be deformed can be changed freely by selecting the portion of the individual electrode 21 to be applied with voltage. The deformation of the laminated body comprising the piezoelectric thin film 11 and the elastic body 20 brings the fluid in the pressure chamber 12 under pressure, and the fluid is ejected from the ink outlet 14 in a volume responsive to the strength of the pressure.

In general, a piezoelectric thin film 11 is made of material with high piezoelectric constant such as $\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$ or other PZT related material. A thin film made of such material is manufactured, under certain condition, by depositing a film on a MgO substrate for the piezoelectric thin film by the sputtering method. The MgO substrate for the piezoelectric thin film is etched in phosphate or in a similar chemical whereby a thin film consisting of the piezoelectric thin film 11 is easily obtained.

The shape of the ink outlet 14 affects ejection speed and the area of the ejected fluid, as such it is a key element determining the printing performance of an ink jet printer. A smaller opening area of the ink outlet 14 enables finer printing, however, an excessive difference in area from the pressure chamber would result in a large loss, thus desirable ejection can not be expected. This loss can be reduced when the glass substrate 18 is provided with the through-hole 15 of which a cross-sectional area tapers from the pressure chamber toward the ink outlet. Moreover, this construction makes the shape of the ink outlet more controllable than a construction having a tapered hole alone, resulting in the ink outlet 14 with finer and more uniform shape.

When pressure is applied, the pressure is not kept within the ink outlet 14 but transmitted to the ink channel 13 which may trigger a back flow of the fluid. To solve this problem, the ink channel 13 is shaped in a manner that its opening space (illustrated as



dotted lines in Fig. 1) tapers toward the pressure chamber 12 thereby resistance against the back flow increases, and even a better ink ejection is achieved. The same effect can be obtained by providing a narrower section in the ink channel 13. When the area of the narrower section in the ink channel 13 is about 0.5 to 1.5 times as large as the area of the ink outlet 14, good ejection is secured by preventing the back flow.

The piezoelectric thin film 11 of several μm in thickness can easily be obtained using the sputtering method. It is thinner when compared with conventional films. When the piezoelectric thin film 11 becomes thinner, its own rigidity is reduced, thus a larger deformation is more easily obtained. When the magnitude of deformation is the same, strain is smaller with the thinner film, therefore, reliability for repeated loading can be improved. As it has been described, the thinner piezoelectric material not only contributes to a reduced size of the actuator and its surrounding area and the area of the ink outlet 14, but also contributes to a higher density and in turn, a higher picture quality.

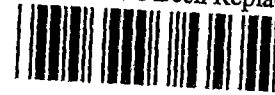
Regarding the thickness of the piezoelectric thin film 11, if it is too thin, a poor driving force would result, conversely, manufacturing thicker material by the thin film technique is inefficient since it requires a longer sputtering time. Therefore, a reasonable thickness of a piezoelectric thin film is not more than $7\mu\text{m}$ in terms of a secure driving force and film making cost. Since the actuator is not deformed when it is only made of the piezoelectric thin film 11, it must form a laminated structure with the elastic body 20. In order for the elastic body 20 to actually function as the elastic body 20 while maintaining conductivity, stainless steel or other metallic material is used. However, the thickness of and the rigidity determined by nature of the material of each layer affect the position of the neutral plane during deformation. The further the neutral plane moves away from the boundary surface, the more the stress generated at the boundary surface increases, increasing the risk of delamination. Conversely, when the neutral plane is formed inside

the piezoelectric member, driving efficiency declines. Therefore, in order to secure the neutral point in the vicinity of the boundary surface, the thickness of the elastic body made of metallic material must be the same or smaller than the thickness of the piezoelectric member.

5 Each piezoelectric material has to function only for each pressure chamber, therefore, the piezoelectric material is not needed in the partitions of adjacent pressure chambers. Rather, when the piezoelectric material is separated by every pressure, interference between adjacent piezoelectric members and stress imposed on the piezoelectric material during the bonding process and actual driving can be avoided, so that
10 cracking in the piezoelectric material is prevented.

Fig. 2 shows sectional views illustrating an example of the production method for dividing the piezoelectric material.

First, as shown in Fig. 2A, a material for the individual electrode 23 and a piezoelectric thin film 22 are deposited on a MgO substrate for the piezoelectric thin film
15 24 by the sputtering method. Second, the material for the individual electrode 23 and the piezoelectric thin film 22 are selectively etched away and divided into individual electrodes 23a, 23b and 23c, and piezoelectric thin films 22a, 22b and 22c respectively (Fig. 2B). Third, an elastic body 28 made of chromium or other metallic material is formed with a resin material 25 such as polyimide coated thereon (Fig. 2C). Then, a silicon
20 substrate 27 is bonded to the dividing portion or the portion where the material for the individual electrode 23 and the piezoelectric thin film 22 are etched away selectively, in a manner that only pressure chambers 26a, 26b and 26c are correspondingly in contact with the piezoelectric thin films 22a, 22b and 22c. Finally, the MgO substrate for the piezoelectric thin film is immersed in a phosphate solution and removed (Fig. 2D). As a
25 result, the dividing portions are strengthened by the resin material 25. Moreover, since the



rigidity of the resin material 25 is low, it does not seriously affect the driving.

The construction discussed above realizes a fluid ejection device which ejects fluid from an arbitrarily selected ink outlet in a plane of a substrate.

Following is an example of a manufacturing process. Figs. 3A-3E, Figs. 4A-4E and Figs. 5A-5D show sectional views illustrating the manufacturing process of the fluid ejection device of the present invention.

Figs. 3A-3E show an example of the processing of the first silicon substrate 31. Both sides of a first silicon substrate 31 as shown in Fig. 3A are coated with resists 32a and 32b, and the patterning is carried out by the photolithography technique (Fig. 3B). In this process, patterns are formed corresponding to the position and shape of each pressure chamber 34 and ink channel 33.

Next, silicon is etched from the side coated with the resist 32b by the reactive ion etching method (RIE). The etching stops at the predetermined depth in the direction of the thickness of the substrate with an opening being formed on only one side, forming an ink channel 33 (Fig. 3C). Then, etching is performed from the resist 32a side forming a through-section communicating with the ink channel 33. By this process, a pressure chamber 34 and an ink inlet 35 are formed (Fig. 3D). Finally, the resists 32a and 32b are removed to conclude the manufacturing process of the first silicon substrate 31 (Fig. 3E).

Figs. 4A-4E show an example of a manufacturing process of a glass substrate 41 and a second silicon substrate 44.

First, both sides of the glass substrate 41 are coated with resists 42a and 42b. Then, a pattern is formed only on the resist 42a side at a place corresponding to the pressure chamber (Fig. 4A). Next, abrasive grains are sprayed by the sand-blasting method from the resist 42a side, and then a through-hole 43 is formed by processing the glass



substrate 41. (Fig. 4B). In this process, the through-hole 43 is formed in a manner that it tapers from the side being sprayed with the abrasive grains toward the other opening. The resist 42b protects the other face from damage caused by the abrasive grains.

Then, after the resists 42a and 42b are removed, the second silicon substrate
5 44 and the glass substrate 41 are directly bonded by direct bonding technique. Patterning of a resist 45 coated on the second silicon substrate 44 is processed so as to form an ink outlet 46 in corresponding positions to each pressure chamber (Fig. 4C).

The direct bonding technique is a method to bond substrates by washing the substrates and heating them without using any inclusions such as resin or applying a high
10 electric voltage as it is the case with the anodic bonding method. In the direct bonding, for example, glass and silicon with a smooth surface are washed in peroxomonosulfuric acid, peroxodisulfuric or the like and stacked after drying.

When the substrates are pressed, certain bonding is gained, and the stacked body is heated at several hundreds °C to increase bonding strength. This method can lead
15 to an extremely strong bonding when optimum substrate material and washing and heating conditions are provided. For example, one delamination test revealed that in the bonding of glass substrates, bonding strength was so high that, in some mode, damage was caused not on the bonded surfaces but inside the substrate itself. The direct bonding realizes high reliability free from degradation in the bonded layers occurring with the lapse of time or in
20 contact with fluid as it is the case with the bonding using resin or similar material. Furthermore, the manufacturing process is very simple requiring only washing and heating processes. Following the bonding process, the second silicon substrate 44 is etched by RIE (Fig. 4D) and the resist 45 is removed to complete the process (Fig. 4E).

As described above, with the method illustrated in Figs. 4A-4E, aligning of
25 both through-holes can be done easily. Moreover, the substrates can be handled more easily



as the total thickness of the stacked substrates is increased by bonding. As a result, a thinner second substrate can be used, and a through-hole for the ink outlet on the second silicon substrate, which has a strong influence on the ejection performance, can be formed precisely and uniformly.

5 Figs. 5A-5D show sectional views illustrating the bonding process of a laminated body comprising a processed first silicon substrate 56, a glass substrate 57 and a second silicon substrate 58 and a piezoelectric thin film 59 (including elastic body).

First, the first silicon substrate 56 already processed in a manner illustrated in Figs. 3A-3E and the laminated body of the second silicon substrate 58 and the glass
10 substrate 57 processed in a manner illustrated in Figs. 4A-4E (Fig. 5A) are directly bonded by the same method described above (Fig. 5B). Before this process, a pressure chamber 51 and a through-hole 54 are aligned. Next, the piezoelectric thin film 59 (including an elastic body) formed on a substrate 60 made of MgO or the like for the piezoelectric thin film 60 is bonded onto the top of the pressure chamber 51 (Fig. 5C). Finally, the MgO substrate 60
15 for the piezoelectric thin film is removed to complete the process (Fig. 5D). When the substrate 60 for the piezoelectric thin film is made of MgO, it can be removed by immersing it in a phosphate solution and the like.

With the aforementioned method, a micro-fabrication technique can be adopted to realize a high-precision and high-efficiency processing. Moreover, bonding
20 process is simple and the end product is highly reliable. When the sand-blasting is used, fragile material such as glass can be processed rapidly with the through-hole automatically given an even tapering shape making itself suitable for ejecting the ink. The technique described above has a potential of processing a variety of shapes by pattern designing and is applicable to a wide range of designs.

25 The ink channel forming method of the aforementioned processing method

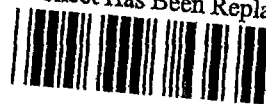


for the first silicon substrate 56 forms a groove with a predetermined depth in the direction of the thickness of the substrate, however, an alternative method for forming a through-section as the ink channel is also available. The method is described below.

5 Figs. 6A-6F are sectional views illustrating processing and assembly methods of a first silicon substrate 61.

The first silicon substrate 61 is coated with a first resist 62, and the patterning is carried out in predetermined positions (Fig. 6B) so as to allow an ink channel 63, a pressure chamber 64 and an ink inlet 65 to be processed. Next, the ink channel 63, the pressure chamber 64 and the ink inlet 65 are formed by RIE or similar technique in a manner that each of the three elements mentioned above forms a through-section extending through the thickness direction of the silicon substrate 61 (Fig. 6C). After the first resist 62 is removed, the first silicon substrate 61 is directly bonded to a sealing glass substrate 66, coated with a second resist 67 and patterning is carried out (Fig. 6D). Following this process, portions corresponding to the pressure chamber 64 and the ink inlet 65 are processed by the sand-blasting forming a first glass through-hole 68 and a second glass through-hole 69 respectively communicating with the pressure chamber 64 and the ink inlet 65 (Fig. 6E). If the first silicon substrate 61 has to be protected from the sand-blasting, it can be coated with resists on both sides. Alternatively, processing by the sand-blasting can be stopped immediately before penetration, to form a glass through-hole by etching the remaining glass by ammonium fluoride and the like. Finally, the second resist 67 is removed to complete the process (Fig. 6F).

Fig. 12 shows a schematic view illustrating the shape of the first silicon substrate already processed by the aforementioned method, looked from the surface of the substrate. The ink channel 63 which communicates with the pressure chamber 64 and ink inlet 65, is shaped in a manner that it tapers toward the pressure chamber, as is illustrated.



The purpose of this design is to effect a good ejection by increasing resistance against the back flow of fluid as described already.

With the aforementioned method, the processing of the first silicon substrate 61 is efficient since it does not require additional processing, as set forth in Figs. 3A-3E. In addition, the ink channel 63 can be shaped evenly as it is determined by the thickness of the first silicon substrate 61. Moreover, the cavity in the pressure chamber can be expanded by the thickness of the sealing glass substrate 66 whereby more fluid can be injected into the pressure chamber, contributing to easily realize an optimum ejection condition. If a silicon substrate itself is thick, the formation of a through-hole becomes difficult. This method is very effective in this regard as well.

One end of the ink channel 63 is sealed in the process described in Fig. 6, therefore, bonding to other elements is also possible, as was the case with the other examples shown in Fig. 5. In Fig. 6, the glass substrate was processed after being bonded directly to the silicon substrate. However, this method is also applicable to the other processes.

Alternative method for forming an ink channel is given below as an example, referring to Fig. 13. The glass substrate 57 already given the through-hole 54 by the sand-blasting (Fig. 13A) is directly bonded to the first silicon substrate 61 (Fig. 13B). Next, the first silicon substrate 61 is coated with the resist 62 and patterning is carried out (Fig. 13C). The resist here is patterned as shown in Fig. 12, a plan view. Then, through-holes 64, 65 and an through-hole for ink channel 63 corresponding to the pressure chamber and the ink inlet are processed at a time (Fig. 13D) and the resist 62 is removed to complete the process (Fig. 13E).

With this method, the total thickness of the substrate becomes larger thereby intensifying the strength, thus, damages occurring during the processing can be prevented.



In addition, the direct bonding which is easily influenced by dust and dirt is conducted at first, therefore, concerns over the influence of such elements can be eliminated in subsequent processes. Since the substrates are bonded directly, erosion into the boundary surfaces during etching is not such a serious source of concern, unlike bonding using resin or other similar material. Furthermore, because the processing on the first silicon substrate is conducted after the bonding of the glass substrate and the first silicon substrate, aligning of through-holes are easy. Increased effective thickness of the substrate by lamination reduces the incident of cracking. In addition, etching on the first silicon substrate is stopped at the bonding plane with the glass substrate, shape of grooves can be uniformly controlled, whereby highly uniformed channels are formed.

The following processing methods are applicable to the other methods of this embodiment described earlier (Fig. 3A-Fig. 5D). The first silicon substrate 31 is coated with the resist 32a and 32b, and patterning is carried out (Fig. 14A). The silicon substrate 31 is processed by RIE up to the certain depth in the direction of the thickness to form the ink channel 33 (Fig. 14B). Next, the first silicon substrate 31 is bonded directly to the glass substrate 57 on which the through-hole 54 is already formed by the sand-blasting (Fig. 14C). The first silicon substrate 31 is coated with a resist 32c and patterning is carried out (Fig. 14D). Then, through-holes 34, 35 corresponding to the pressure chamber and the ink inlet are processed on the first silicon substrate 31 by RIE (Fig. 14E). This method can facilitate positioning and controlling of the size of the through-hole 34 to be processed on the first silicon substrate 31 precisely since it can be conducted by referring to the through-hole 54 of the glass substrate 57. Etching speeds are different between the bonded surfaces of the first silicon substrate 31 and the glass substrate 57 as the characteristics of these materials are different. As a result, processing of the through-hole 54 is precisely stopped thereby forming the through-holes uniformly.



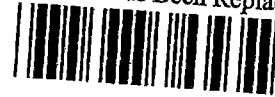
The same method can be applied to the bonding process of the glass substrate 71 and the second silicon substrate 72 as shown in Fig. 7A-7D. In this case as well, a through-hole can be formed after bonding them directly.

In addition, by making a second silicon substrate 72 thinner by lapping, a
5 finer and more precise processing can be expected..

Figs. 7A-7D show sectional views illustrating an example of the process for thinning the second silicon substrate 72 by lapping.

A glass substrate 71 and a second silicon substrate 72 are directly bonded as set forth in the foregoing example (Fig. 7A). After this process, the second silicon substrate
10 72 is lapped to reduce its thickness (Fig. 7B) and subsequently, a through-hole 73 and an ink outlet 74 are formed by the sand-blasting and RIE (Figs. 7C and 7D). If the second silicon substrate 72 is thick, processing takes time and tends to be uneven, which makes difficult to form uniform holes. Moreover, a very small and deep through-hole is difficult to form.

15 Therefore, the second silicon substrate 72 is preferably thin. However, in the case of a single silicon plate, there is a limitation in terms of the handling during the manufacturing process and the yield of the processing. The direct bonding with the glass substrate increases rigidity, and thus the substrate can be lapped with ease. After the lapping the silicon substrate can be sent as it is to the next process. In order to realize a
20 fluid ejection device with a higher ejection density, diameter of the ink outlet must be as narrow as less than tens of μm , and if the silicon plate too is thinned to around $50\mu\text{m}$ or less, a more compact ink outlet, higher in density and uniform in shape can be formed. Since the through-holes on the glass substrate and the second silicon substrate are processed after the substrates are bonded, there is no need for aligning in bonding.
25 Moreover, as the substrates are bonded prior to the processing, there is no risk of damage



on the bonded surfaces during processing, or gathering of dirt, thereby effecting a good bonding.

If there is no problem with the lapping, the direct bonding and lapping will be carried out after a through-hole is formed in the glass substrate. Needless to say, the method can also produce a similar effect when the first silicon substrate is excessively thick.

The through-hole processed by the sand-blasting has a shape tapering from the opening exposed to the spraying of the abrasive grain toward the other end. Therefore, although it is slightly affected by the size of the abrasive grain and speed to spray, if the thickness of the glass plate and the diameter of the opening exposed to the spray of the abrasive grains (opening area of the resist) are uniformly set, the diameter of the opening on the through-side is naturally set as well. Thus, by setting the thickness of the glass plate and the diameter of the opening on the spray side so that the diameter of the opening on the through-hole side is slightly larger than the diameter of the ink outlet, an optimum shape is uniquely processed. In order to deal with the ink outlet with the diameter tens of μm or less, in the case of the glass substrate having a thickness of 0.8mm or less, the following condition is applied to the thickness of glass substrate: approx. 1.2 to $1.9 \times (rg-rs)$, where "rg" is the diameter of the spray side, and "rs" is the diameter of the through-hole side.

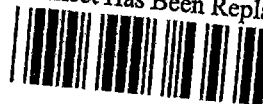
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Second exemplary embodiment

Fig. 8 shows a sectional perspective view illustrating a fluid ejection device according to the second exemplary embodiment of the present invention.

In Fig. 8, a silicon substrate 86, a first glass substrate 87 and a second glass substrate 88 are directly bonded as described in the first exemplary embodiment, forming a laminated body. The silicon substrate 86 has ink outlets 84(84a, 84b) having openings

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formed on the edge of the substrate, a pressure chamber 82 penetrating and communicating with the ink outlets 84, and a through-hole which partially forms an ink inlet 85, each of them formed by RIE or similar method. The first glass substrate 87 also has a through-section. A part of the through section communicates with the pressure chamber 82 and
5 forms an ink channel 83 while another part is partially forming the ink inlet 85.

A laminated body comprising a piezoelectric thin film 81 having individual electrodes 90(90a, 90b) mounted thereon and an elastic body 89 is bonded right on the pressure chamber 82. Each pressure chamber 82 and the ink channel 83 are separated from each other and are independent. The individual electrodes 90a, 90b are disposed
10 corresponding to each pressure chamber 82. The second glass substrate 88 seals one end of the through-section of the first glass substrate 87, forming a part of the ink channel 83. The fluid, supplied from the ink inlet 85, fills the pressure chamber 82 via the ink channel 83, and is brought under pressure by the displacement of the piezoelectric thin film 81 which occurs when applied with an electric voltage, and ejected from the ink outlets 84a and 84b.

15 Following is the description of a manufacturing method.

Figs. 9A-9E show sectional views illustrating the processing method of a silicon substrate.

First, both faces of a silicon substrate 91 as shown in Fig. 9A are coated with resists 92a and 92b, and patterning is carried out (Fig. 9B). Next, one side of the
20 silicon substrate 91 is shallowly etched by RIE and an ink outlet 93 is formed (Fig. 9C). Then, a through-section is formed from the other face to form a pressure chamber 94 and an ink inlet 95 in a manner that the pressure chamber 94 partially communicate with the ink outlet 93 (Fig. 9D). Finally, the resists are removed from both sides to complete the process (Fig. 9E).

25 Figs. 10A-10F show sectional views illustrating assembly method of the



whole device.

A first glass substrate 105 of which a through-section is already processed by the sand-blasting with an ink channel 106 being formed therein, is directly bonded to a silicon substrate 101(Fig. 10B) which is already processed by the method shown in Fig. 9A-9E (Fig. 10A). In this bonding, the ink channel 106 is set to conduct with a pressure chamber 103 and an ink inlet 104, and the direct bonding is carried out on the face with an ink outlet 102. Next, a second glass substrate 107 and the first glass substrate 105 are directly bonded to seal one side of the ink channel 106 (Fig. 10C).

As shown in the description of the first exemplary embodiment, a piezoelectric thin film 108 and an elastic body 109 disposed on a MgO substrate 110 are bonded (Fig. 10D), and the MgO substrate 110 is removed by soaking in a phosphate solution (Fig. 10E). Finally, when the laminate body made of the three substrates are divided, it is diced at right angles to the longitudinal direction of the ink outlet 102 so that the opening of the ink outlet 102 can face outside (Fig. 10F).

The shape of the ink outlet 102 is an important factor as it determines the fluid ejection capability. When the ink outlet 102 is very fine in shape, however, it might be chipped and the shape is damaged during the dicing process discussed above. One of the methods to avoid such damage is to cut the silicon substrate at the point where an ink outlet is to be formed prior to forming the ink outlet by etching the silicon substrate. This eliminates the processing after the ink outlet is formed. When the cutting causes problems in the processing of the wafer, another method can be adopted in which the portion where the ink outlet is to be formed is cut into up to a certain point rather than cut completely. For example, as shown in Fig. 15A and Fig. 15B, respectively illustrating sectional view of the silicon substrate 101 and a plan view of the same looked from below, a recessed portion 130 is formed on the silicon substrate 101. An ink outlet groove 102 is formed transversely



of the recessed portion 130. When dividing the whole substrate, it is cut along a cutting-plane line 140 by a blade narrower than the recessed portion 130, so that the ink outlet is not processed on cutting. Figs. 15A and 15B, numeral 103 represents pressure chamber, and numeral 104 an ink inlet. With the above-mentioned method, the ink outlets are formed
5 completely at the same time when the grooves are engraved on the silicon substrate, leaving no need for processing afterwards. Thus, the shape of ink outlets are maintained uniformly and ink ejecting capability is not damaged.

With all the embodiments of the present invention, everything is formed by laminating plane members, therefore, fine processing is easy and structure can become
10 finer. Further, the following efficient process can be adopted. At first a number of unit structures as shown in Fig. 9 or Fig. 15 are embedded like a matrix on a large silicon substrate as well as first and second glass substrates. Then the substrates are bonded by a method shown in Fig. 10, and cut into individual units. In this manner, a great number of fluid ejection devices are produced at a time, making the process very efficient.

15 According to the exemplary embodiments discussed above, the effect of the fine processing, direct bonding and piezoelectric thin film as shown in the first exemplary embodiment, is obtained at a time. In addition, a fluid ejection device with a different ejection mode in which fluid is ejected from an edge of a substrate can be produced. With this method, an ink outlet is designed freely by patterning resist, which greatly contributes
20 to the optimization of the shape. An easy, uniform and fine controlling of the ink outlet area is possible just by adjusting width and depth of the groove. If an ink channel of the first glass substrate is formed by etching up to the midway of the substrate rather than penetration, the second glass substrate is not necessary, therefore, only one direct bonding is required to complete the process. Thus, needless to say, further reduction in
25 manufacturing steps can be expected.



As described so far, according to the present invention, a fluid ejection device with a smaller and higher density of ink outlets can be formed by employing micro-fabrication technique of silicon and glass substrates and employing a piezoelectric thin film. As processing and lamination are conducted from the direction perpendicular to the
5 plane of the substrate, a plurality of units are produced, thus productivity and design freedom are high. As substrates are directly bonded to each other, adhesive materials are not needed, whereby process management is simplified, and the factor which deteriorates the long-term reliability in sealing capability of fluid can be eliminated.

As a result, an ink jet printhead of on-demand system for an ink jet printer
10 with higher density, higher reliability and lower cost can be achieved.

**What is claimed is:**

1. A fluid ejection device comprising;
at least one chamber divided independently from other chambers;
an ink channel communicating with said chamber;
5 an ink outlet communicating with said chamber; and
a pressure generating section comprising a laminated body made of a piezoelectric material of a thickness of not more than $7\mu\text{m}$ and an elastic body, said section covering one face of said chamber.
- 10 2. The fluid ejection device according to claim 1, wherein said elastic body is made of a metallic material with a thickness of the same or less than said piezoelectric material.
- 15 3. The fluid ejection device according to claim 1, wherein said piezoelectric material is divided corresponding to each chamber, and a layer of resin is disposed at least on the dividing sections of said piezoelectric material.
- 20 4. The fluid ejection device according to claim 1, wherein said chamber, said ink channel and said ink outlet are formed by laminating a plane member of a silicon plate and a glass plate.
- 25 5. The fluid ejection device according to claim 1, wherein chief ingredient of said piezoelectric material is $\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$.
6. The fluid ejection device according to claim 4, wherein said silicon plate



and glass plate are directly bonded by direct bonding technique.



7. A production method of a fluid ejection device comprising the steps of:
a process A1 of forming a through-hole for the pressure chamber and a
5 through-hole for the ink inlet on a first substrate;
a process B of bonding the first substrate and a second substrate;
a process C of bonding the second substrate and a third substrate; and
a process D of forming a pressure generating section comprising a
laminated body including piezoelectric material and an elastic material such that the
10 pressure generating section covers the through-hole for the pressure chamber.

8. The production method of a fluid ejection device according to claim 7
further comprising the steps of:
a process A2 of forming a groove for ink channel partially communicating
15 with the through-holes for the pressure chamber and the ink inlet on the first substrate;
a process E of forming a through-hole tapering from the end in contact with
the first substrate on the second substrate; and
a process F of forming a through-hole for the ink outlet on the third
substrate.

20

9. The production method of a fluid ejection device according to claim 8,
wherein said process A1 is carried out after said process A2 and said process B.

10. The production method of a fluid ejection device according to claim 7
25 further comprising the steps of; _____

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a process A3 of forming a through-hole for ink channel on the first substrate;

a process E of forming a through-hole tapering from the end in contact with the first substrate on the second substrate;

5 a process F of forming a through-hole for the ink outlet on the third substrate;

a process G of forming a through-hole for the pressure chamber on a fourth substrate; and

a process H of forming a groove for ink channel by bonding the first and
10 fourth substrates.

11. The production method of a fluid ejection device according to claim 10, wherein said process A1 and said process A3 are conducted after said process E and said process B.

15

12. The production method of a fluid ejection device according to claim 8 or 10, wherein said process F is conducted after said process E and said process C.

13. The production method of a fluid ejection device according to claim 8 or
20 10, wherein said process E and said process F are conducted after said process C.

14. The production method of a fluid ejection device according to claim 8 or 10, wherein said process C is conducted after said process E and said process F, or after said process E, and said method further comprising a step for thinning at least a section of
25 the third substrate by lapping, the section corresponding to the through-hole formed on the





second substrate.

15. The production method of a fluid ejection device according to claim 8 or 10, wherein thickness of the third substrate is not more than 50 μ m.

5

16. The production method of a fluid ejection device according to claim 8 or 10, wherein:

a diameter of the through-hole for the ink outlet formed on the third substrate is smaller than a diameter of tapered end of the through-hole on the second substrate in said process F; and

10

the through-hole for the ink outlet on the third substrate is aligned to approximately a center of the diameter of the narrower end of the through-hole on the second substrate in said process C.

15

17. The production method of a fluid ejection device according to claim 15, wherein, in the case that the second substrate is 0.8mm or less in thickness, the following condition is applied to the thickness of the second substrate:

$1.2x(rg-rs)$ to $1.9x(rg-rs)$,

where "rg" is the diameter of the larger end of the tapering through-hole formed on the second substrate and "rs" is the diameter of the through-hole for the ink outlet formed on the third substrate.

20

18. The production method of a fluid ejection device according to claim 7, further comprising the steps of:

25

a process A4 of forming a groove for the ink outlet partially communicating

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with the through-hole for the pressure chamber on the first substrate; and

a process I of forming a through-section for the ink channel on the second substrate.

5 19. The production method of a fluid ejection device according to claim 18, wherein the opening of the through-hole for the pressure chamber and the through-hole for the ink inlet on the first substrate and the through-section for the ink channel on the second substrate are aligned and bonded to partially communicate with each other and form an ink channel.

10

20. The production method of a fluid ejection device according to claim 18, wherein the groove for the ink outlet is formed on an edge of the first substrate in said process A4.

15

21. The production method of a fluid ejection device claim 18, wherein:
a recessed section is formed on the first substrate;
the groove for the ink outlet is formed transversely of the recessed portion;
an opening section is formed at a right angle to the longitudinal direction of the groove for the ink outlet; and

20

a process of cutting the first substrate along the recessed portion without contacting the opening section.

25

22. The production method of a fluid ejection device according to claim 17, further comprising a process of cutting the first substrate at a right angle to the longitudinal direction of the groove for the ink outlet formed on the first substrate.



23. The production method of a fluid ejection device according to one of claim 8, claim 10, and claim 18, wherein the ink channel is formed with an area 0.5 to 1.5 times as large as that of the ink outlet.

5

24. The production method of a fluid ejection device according to one of claim 8, claim 10, and claim 18, wherein the ink channel is formed in said processes A2, A3 or I in a manner that its area tapers towards the ink outlet.

10

25. The production method of a fluid ejection device according to one of claim 8, claim 10, and claim 18, wherein the first substrate is a silicon single-crystal substrate; the second substrate, a glass substrate; and each of the third and fourth substrates, one of glass and silicon single-crystal substrates.

15

26. The production method of a fluid ejection device according to one of claim 8, claim 10, and claim 18, wherein bonding method conducted in said process B, C and H is the direct bonding.

20

27. The production method of a fluid ejection device according to claim 25, wherein a silicon substrate is etched by reactive ion etching, and a glass substrate is processed by the sand-blasting.

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**ABSTRACT OF THE DISCLOSURE**

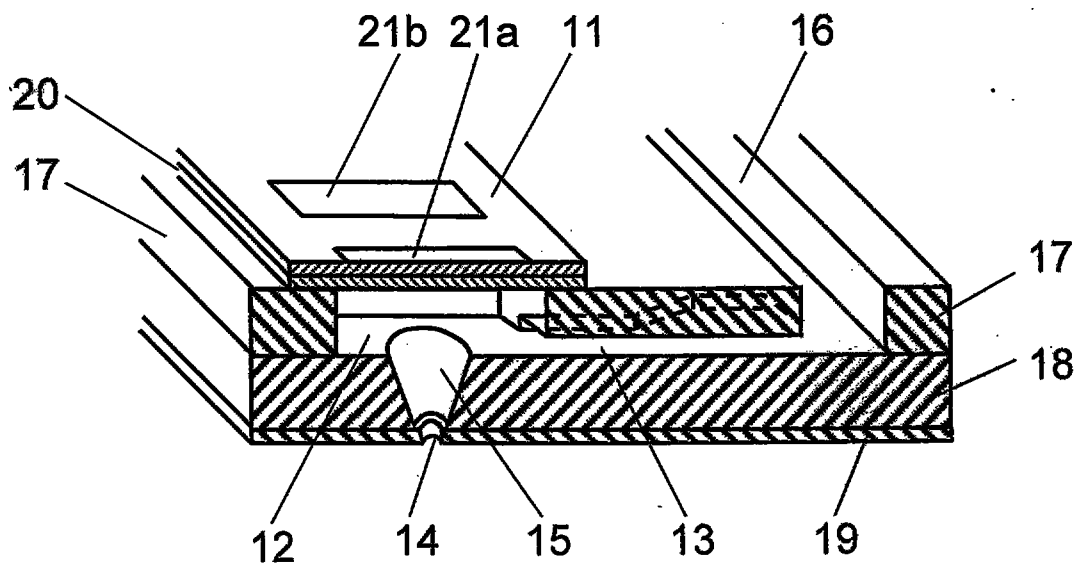
A fluid ejection device and production method thereof for an ink jet printer and the like for heightening density of a nozzle and improving efficiency of the production process. The through-hole 15 is provided to the glass substrate 18 to which the second
5 silicon substrate 19 is directly bonded to form the ink outlet 14. The first silicon substrate 17 is etched to form the pressure chamber 12, the ink channel 13 and the ink inlet 16, and bonded directly to the glass substrate 18. Subsequently, the piezoelectric thin film 11 having the elastic body 20 is bonded to right on the pressure chamber 12.

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FIG. 1



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FIG. 2A

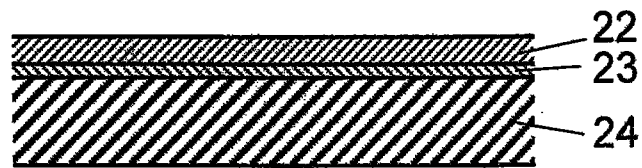


FIG. 2B

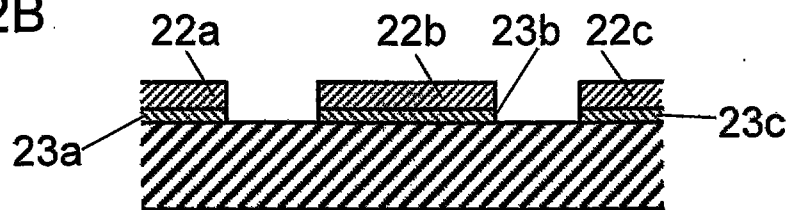


FIG. 2C

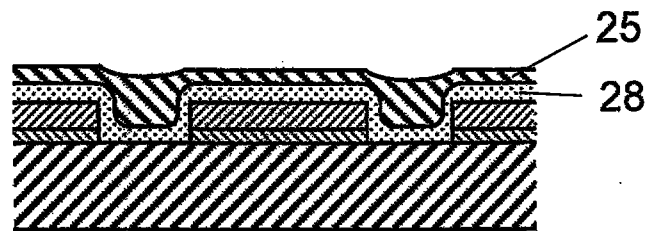


FIG. 2D

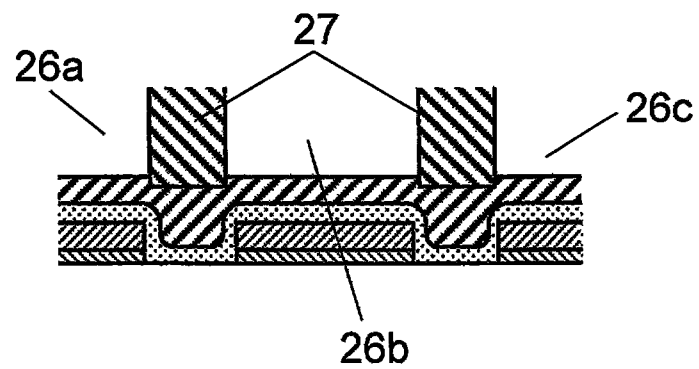


FIG. 3A

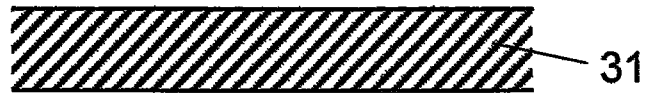


FIG. 3B

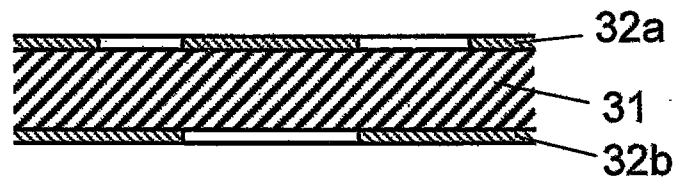


FIG. 3C

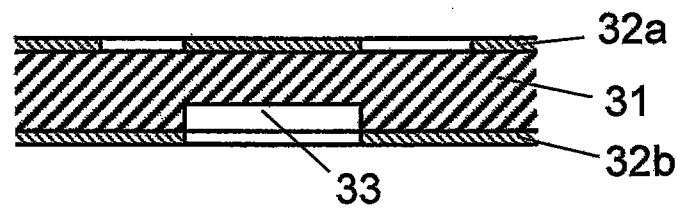


FIG. 3D

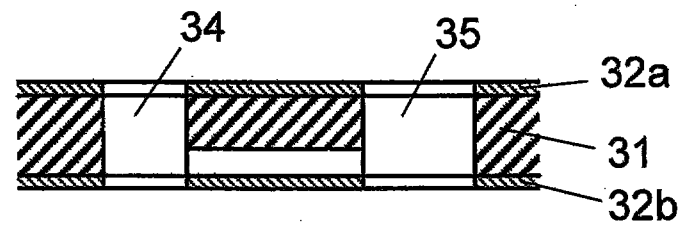


FIG. 3E



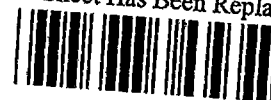


FIG. 4A

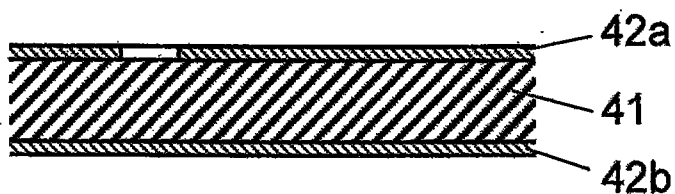


FIG. 4B

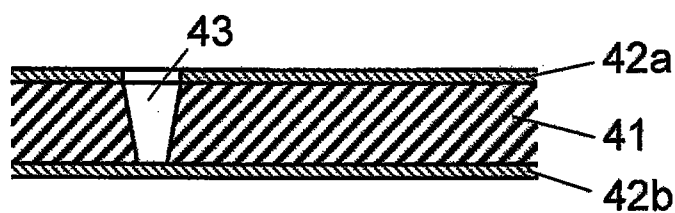


FIG. 4C

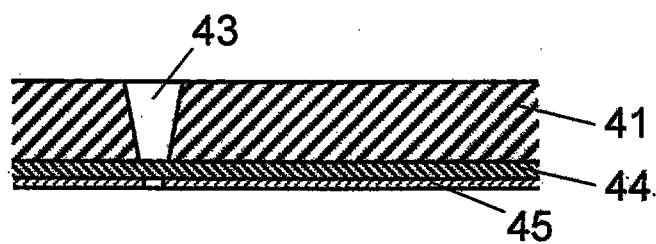


FIG. 4D

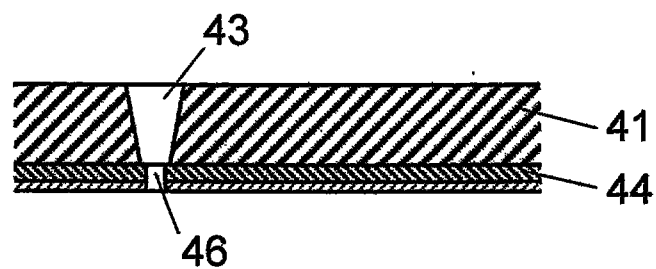


FIG. 4E

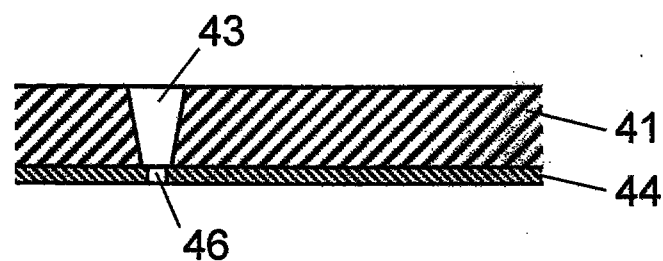




FIG. 5A

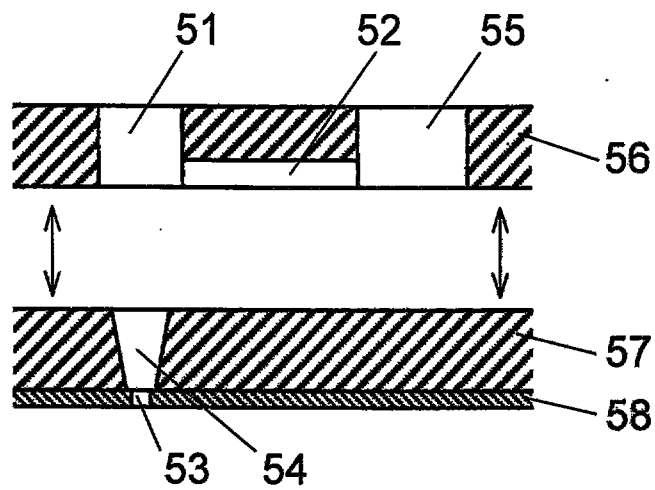


FIG. 5B

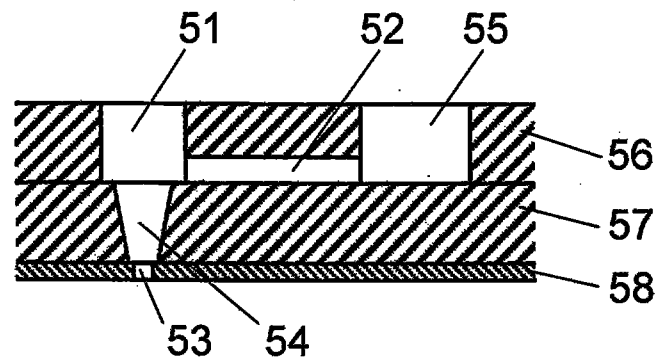


FIG. 5C

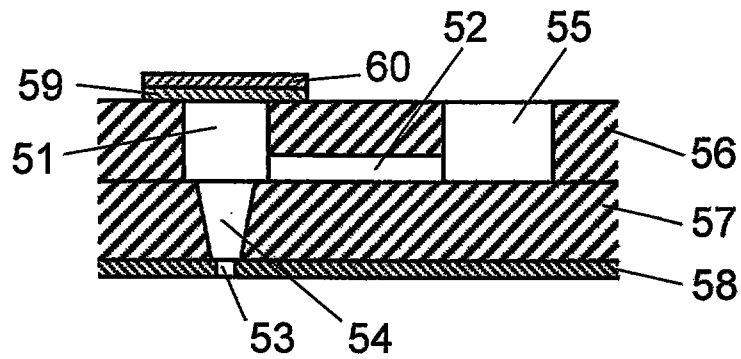
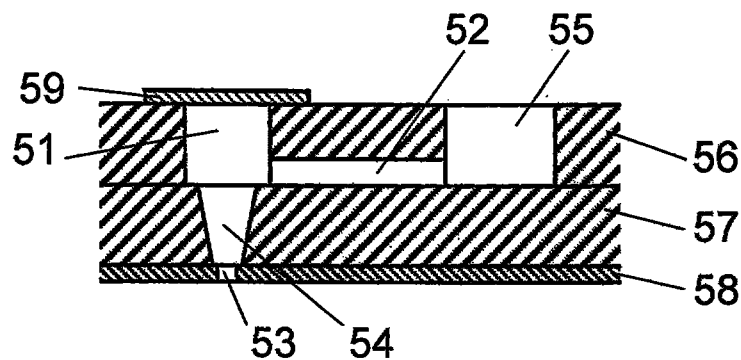


FIG. 5D



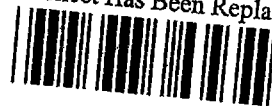


FIG. 6A



FIG. 6B



FIG. 6C

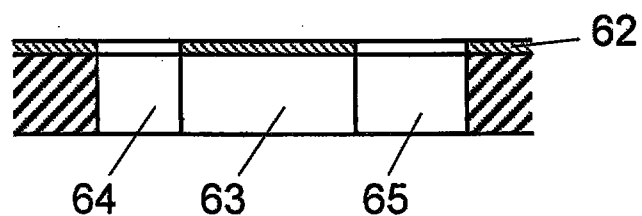


FIG. 6D

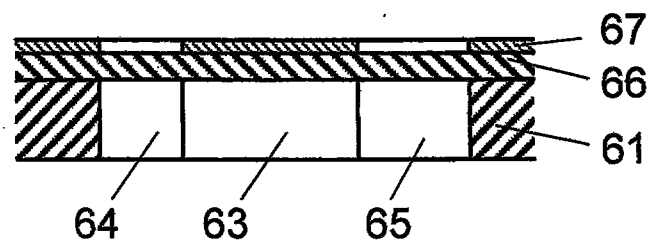


FIG. 6E

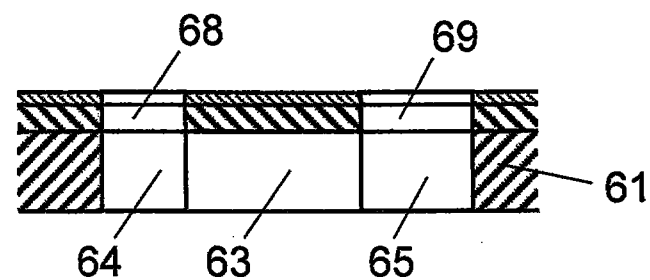


FIG. 6F

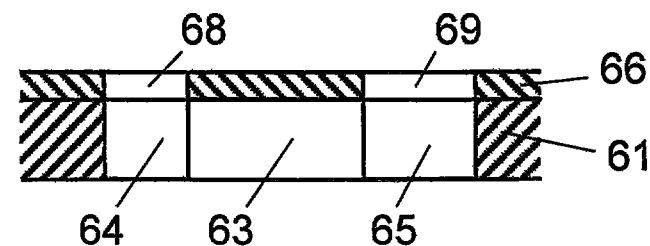




FIG. 7A

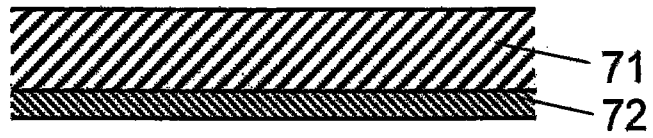


FIG. 7B

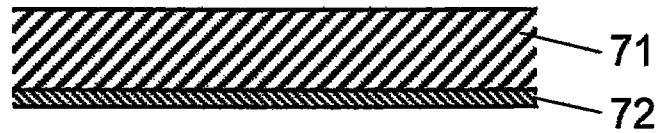


FIG. 7C

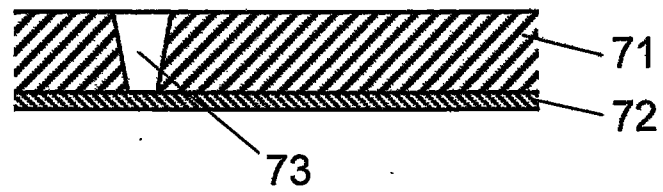


FIG. 7D

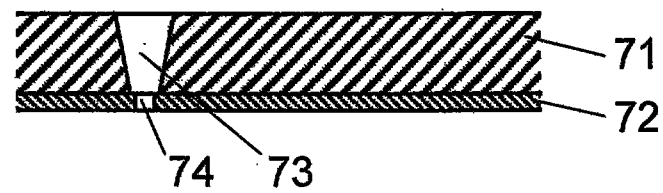
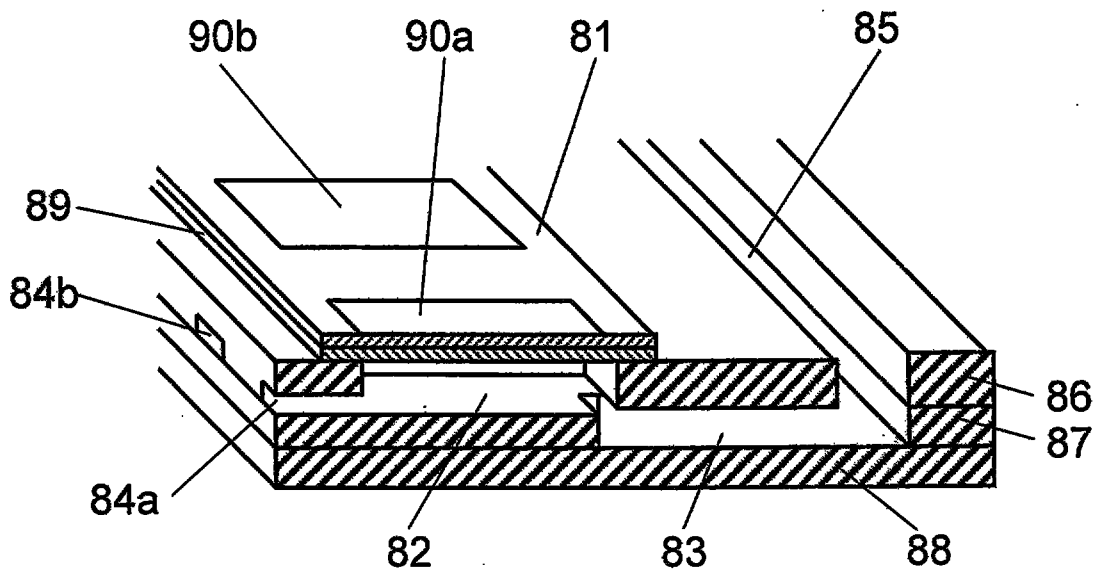




FIG. 8



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FIG. 9A



FIG. 9B

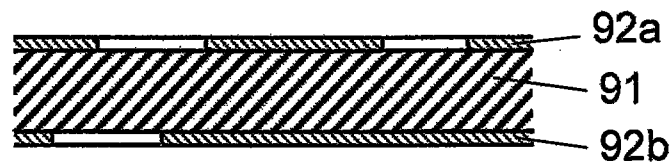


FIG. 9C

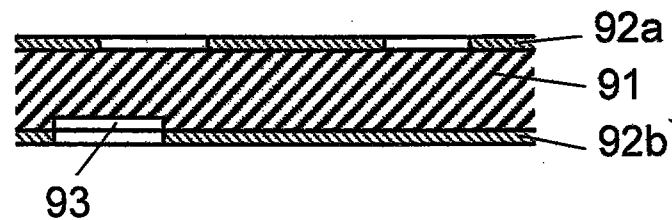


FIG. 9D

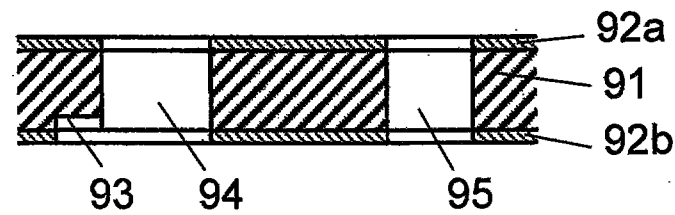
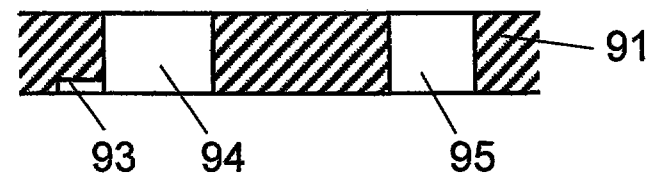


FIG. 9E



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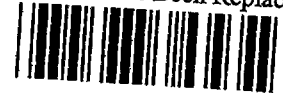


FIG. 10A

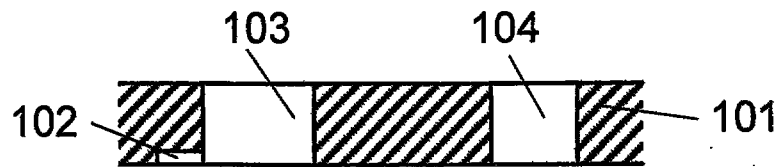


FIG. 10B

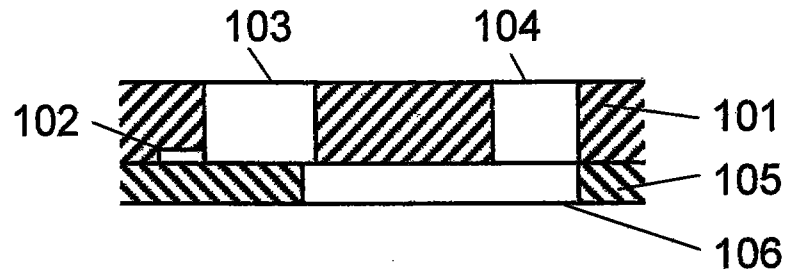


FIG. 10C

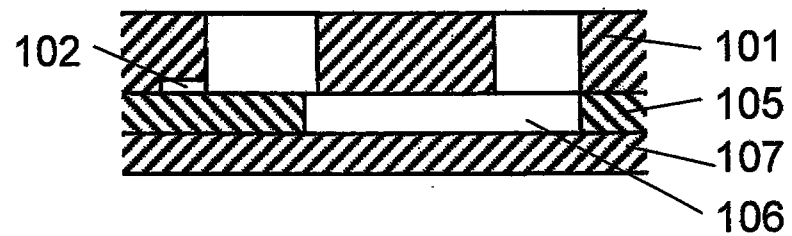


FIG. 10D

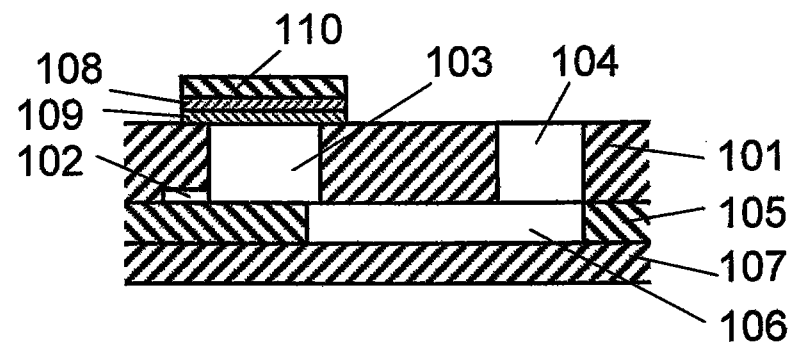


FIG. 10E

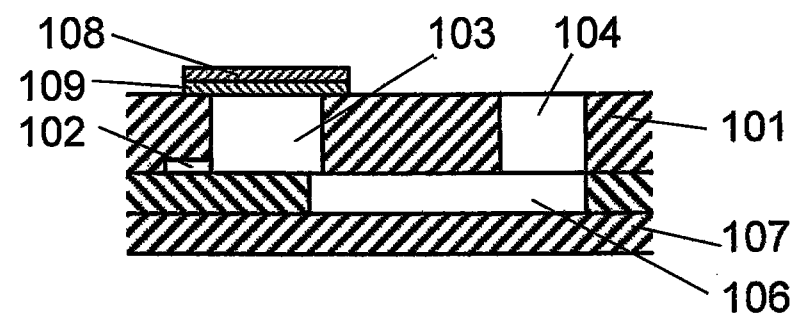
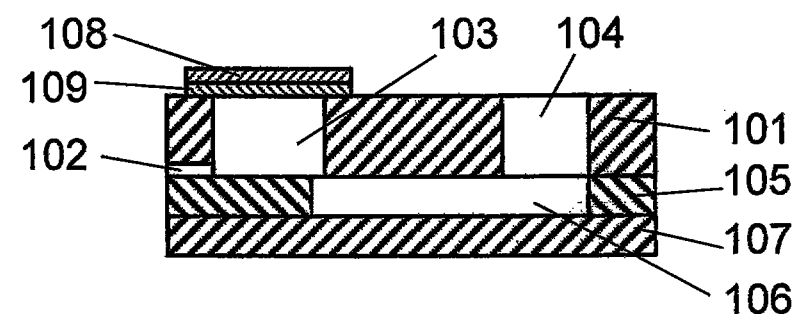


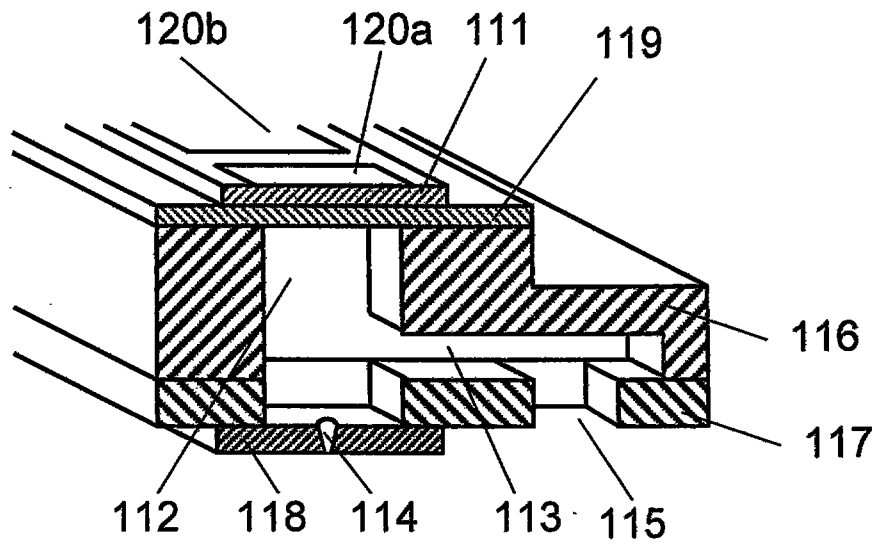
FIG. 10F



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FIG. 11 PRIOR ART

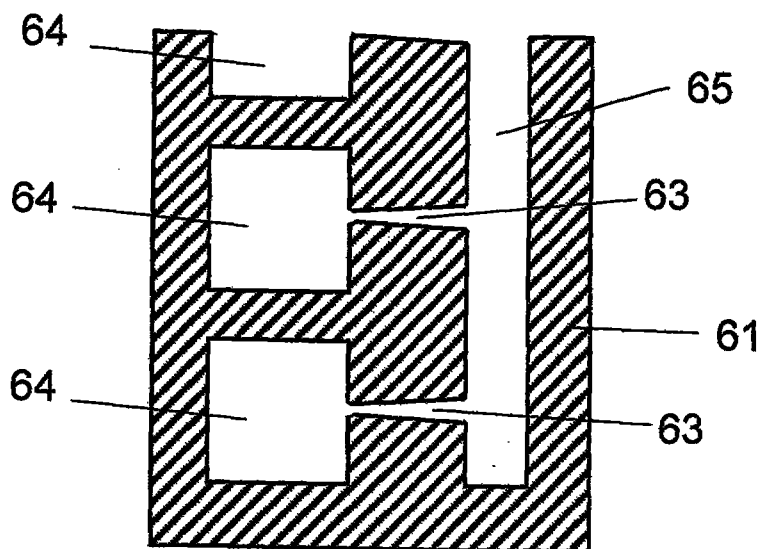


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FIG. 12



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FIG.13A



FIG.13B

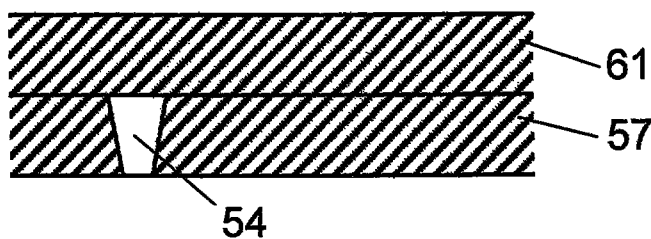


FIG.13C

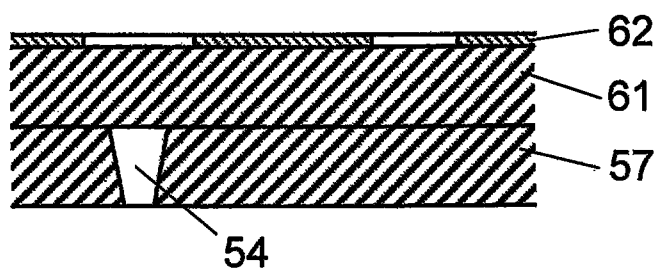


FIG.13D

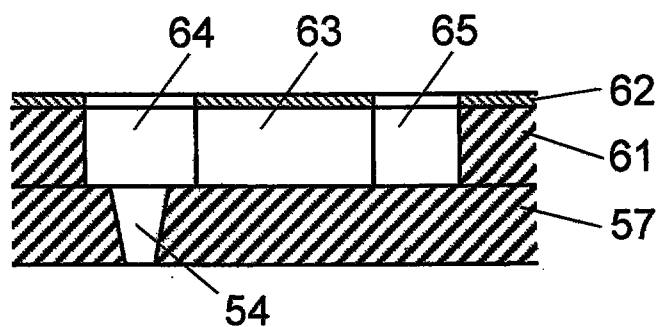
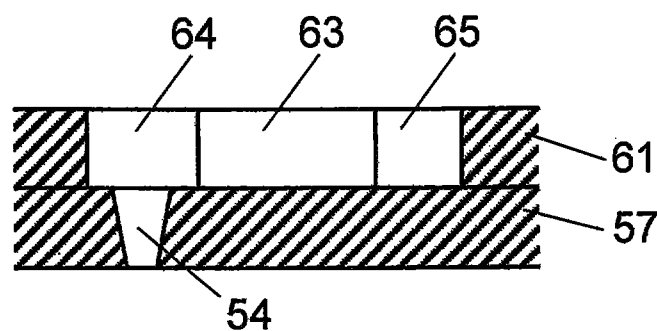


FIG.13E



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FIG. 14A

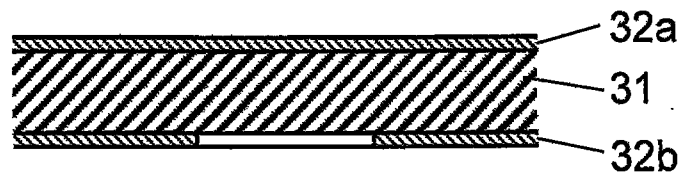


FIG. 14B

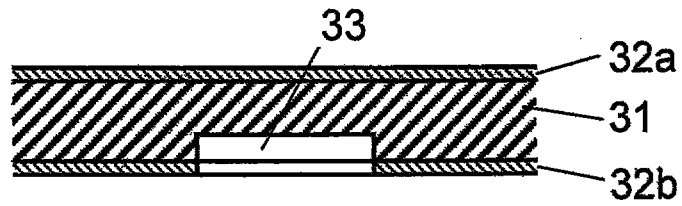


FIG. 14C

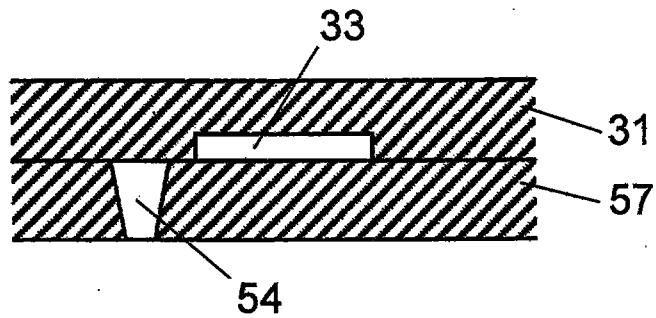


FIG. 14D

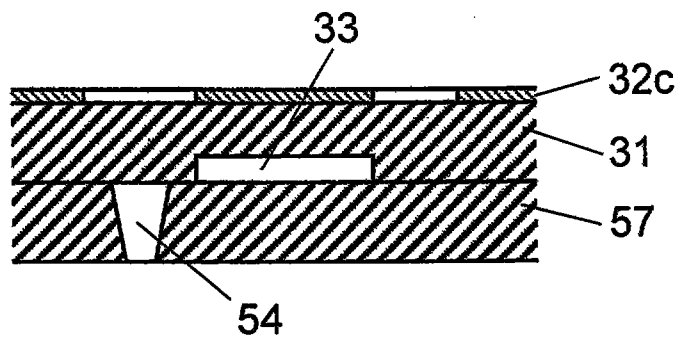
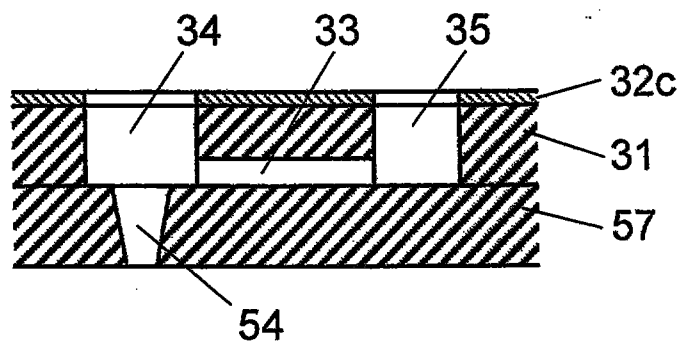


FIG. 14E



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FIG. 15A

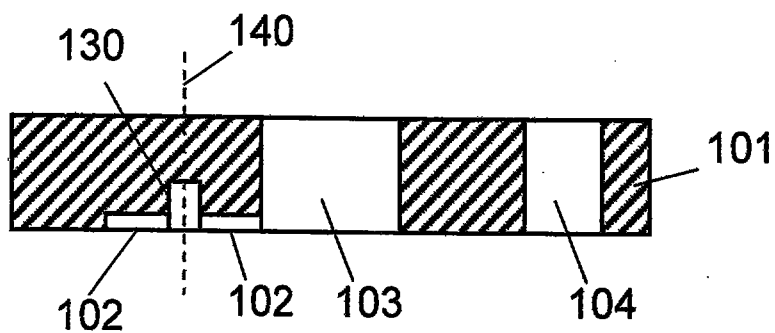
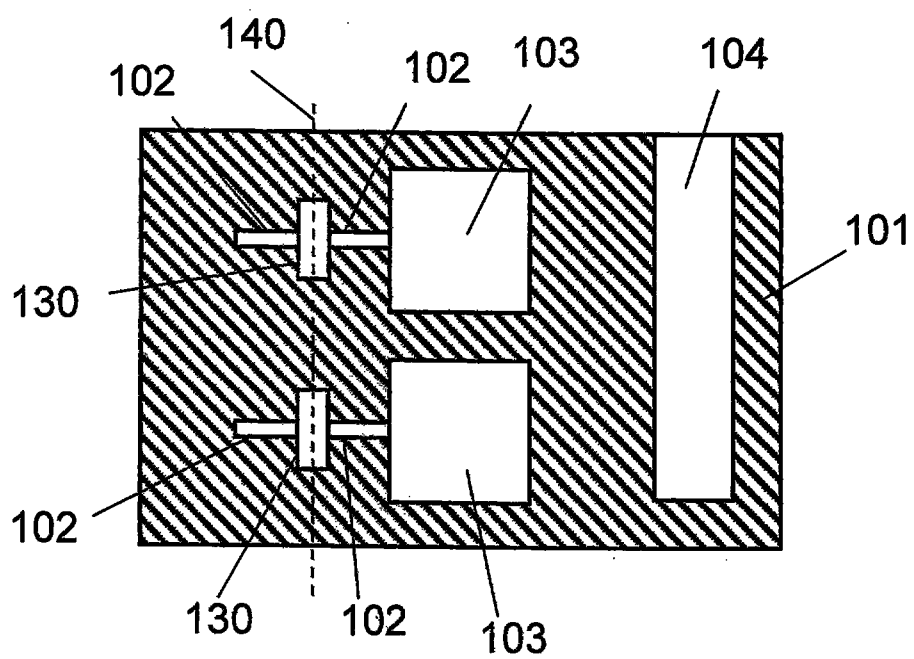


FIG. 15B



THIS SHEET HAS BEEN
REPLACED

**FLUID EJECTION DEVICE AND
PROCESS FOR THE PRODUCTION THEREOF**

FIELD OF THE INVENTION

5 The present invention relates to a fluid ejection device to be used in a printhead of an ink jet printer for ejecting fluid, such as ink, in a well-controlled manner, and a process for the production thereof.

BACKGROUND OF THE INVENTION

10 With the development of a computerized society in recent years, demand for office automation or OA devices has been growing rapidly. Under such circumstances, demand for various kinds of printers has become increasingly stronger, not only with respect to their performance as a recording means but for higher-speed printing and improved picture quality.

15 In widely used ink jet printers, the ink jet printhead of the on-demand system which enables a high-speed ejection of the ink at the user's will, is critical for the performance of the printer. The ink jet printhead, in general, comprises an ink channel, a pressure chamber where ink is pressurized, a pressurizing means for the ink such as an actuator, and an ink outlet through which the ink is ejected. To realize an on-demand ink
20 jet printer system, a pressurizing means with high controllability is required. Most conventional systems employ a bubble ejecting method, also known as a heating method, whereby the ink is heated to produce bubbles that eventually eject the ink, or a piezoelectric method, in which ink is directly pressurized by a deformation of a piezoelectric ceramic or the like.

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Fig 11 is a sectional perspective view showing an example of the construction of a conventional ink jet printhead. The conventional ink jet printhead consists of a piezoelectric member 111, a pressure chamber 112, an ink channel 113, an ink outlet 114, a fluid (ink) inlet 115, a first structure member 116, a second structure member 117, a third structure member 118, a diaphragm 119 and individual electrodes 120.

On a first side of the piezoelectric member 111, individual electrodes 120a, 120b, and so on are formed thereon. On a second side thereof electrodes are also formed in the same manner, 120au, 120bu, and so on. The piezoelectric member 111 is bonded to the diaphragm 119 via the electrode on the second side.

The diaphragm 119 and the first structure member 116, the second structure member 117 and the third structure member 118 are bonded by an adhesive or similar material, thereby forming a laminated structure. The pressure chamber 112 and the ink channel 113 comprise a cavity in first structure member 116. In general, a plurality of sets, each set comprising a the pressure chamber 112, an ink channel 113 and individual electrodes 120 are formed and disposed such that each set is separated from the other sets. The second structure member 117 is similarly formed with a plurality of separate ink inlets 115. Third structure member 118, comprising a plurality of separate ink outlets 114, is aligned with the second structure member so that the outlets align with the pressure chambers 112. The ink is supplied through the ink inlet 115, filling the ink channel 113 and the pressure chamber 112 with ink.

The diaphragm 119 is made of a conductive material and is in conductive communication with the electrodes 120au, 120bu, and so on mounted on the bonded surface of the piezoelectric member 111. Thus, if an electric voltage is applied between the diaphragm 119 and the individual electrodes 120a, 120b, and so on, diaphragm 119

conducts current and deforms, also deforming the section of the piezoelectric member 111 laminated to the diaphragm 119. Thus a selected section of piezoelectric member 111 and diaphragm 119 corresponding to each set of electrodes 120a, 120b, and so on can be deformed by selecting the set of electrodes to be energized with an electric voltage. The deformation pressurizes ink in the pressure chamber 112 underlying energized electrode 120a, for example, and the amount of ink responsive to the pressure is ejected from the ink outlet 114. The amount of deformation depends on the electric voltage applied to the piezoelectric member 111. Therefore, by controlling the magnitude of the electric voltage and the location at which the electric voltage is applied, the amount and location of the ink ejection can be arbitrarily changed.

The conventional thermal ink jet printhead, in general, is inferior to the piezoelectric method in terms of the response speed. On the other hand, a drawback of piezoelectric ink jet printheads is that the displacement of the piezoelectric member and the diaphragm is restricted by the thickness of the piezoelectric member. If the piezoelectric member is too thick, insufficient displacement may be provided due to the rigidity of the piezoelectric member itself. If the area of the piezoelectric member is increased to enlarge the displacement, the size of the ink jet printhead increases, making it difficult to achieve higher nozzle densities (the number of nozzles within a particular area). As a result, material cost increases. When the area of the piezoelectric member can not be increased, a higher driving voltage is required for a sufficient deformation.

Piezoelectric members with thickness of about 20 μ m have become available now through thick film forming and the integrated firing techniques, however, a higher nozzle density is still required for improved print quality. In order to reduce the area of the piezoelectric member to achieve a higher nozzle density, reduction of the piezoelectric

member thickness is essential. However, conventional methods have limitations in this regard.

A cavity is typically provided within structures made of stainless steel or the like in order to form the ink channel, so for precise and complex ink channels, an increased number of layers may be required. Adhesive used on the bonded section is exposed to fluid for a long time, and therefore, reliability of the adhesive bond has always required close attention.

SUMMARY OF THE INVENTION

A fluid ejection device of the present invention includes at least one pressure chamber divided independently from other pressure chambers, an ink channel communicating with the pressure chamber, an ink outlet communicating with the pressure chamber, and a pressure generating section having a laminated body made of a piezoelectric material and an elastic body, the pressure generating section covering one face of the chamber. The pressure chamber, the ink channel and the ink outlet are defined by a structure comprising at least one planar silicon substrate bonded to at least one planar glass substrate.

A process for manufacturing the fluid ejection device of the present invention comprises the steps of: forming a through-hole for the pressure chamber and a through-hole for the ink inlet on a first substrate; bonding the first substrate to a second substrate; bonding the second substrate to a third substrate; and forming a pressure generating section comprising a laminated body including piezoelectric material and an elastic material such that the pressure generating section covering the through-hole for the

pressure chamber with the pressure-generating section.

The piezoelectric material may be a thin film material of PZT deposited by sputtering. The silicon substrates may be processed by reactive ion etching (RIE) and the glass substrates may be processed by sand-blasting. The substrates may be directly bonded to one another by processing the surfaces and heating without the use of resin or other adhesives.

The configuration discussed above provides a thinner piezoelectric member, allowing a higher nozzle density. A plurality of silicon and glass substrates may be simultaneously finely processed by etching and sand-blasting, thereby improving processing precision and reducing the number of production steps. The silicon and glass substrates can be directly bonded, increasing the long-term reliability against inflow of fluid. Furthermore, multiple substrates can be bonded at one time, contributing to streamlining of the production processes.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a sectional perspective view of a fluid ejection device in accordance with the first exemplary embodiment of the present invention.

Figs. 2A-2E show a manufacturing process of a piezoelectric thin film of the first exemplary embodiment as set forth in Fig. 1.

Figs. 3A-3E show a manufacturing process of a silicon substrate of the first exemplary embodiment as set forth in Fig. 1.

Figs. 4A-4E show a manufacturing process of an ink outlet of the first exemplary embodiment as set forth in Fig. 1.

Figs. 5A-5D show a manufacturing process of the fluid ejection device of the first exemplary embodiment as set forth in Fig. 1.

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Figs. 6A-6F show an alternative manufacturing process of a silicon substrate.

Figs. 7A-7D show an alternative manufacturing process of an ink outlet.

Fig. 8 shows a sectional perspective view of a fluid ejection device in accordance with the second exemplary embodiment of the present invention.

Figs. 9A-9E show a manufacturing process of a silicon substrate of the second exemplary embodiment as set forth in Fig. 8.

Figs. 10A-10F show a manufacturing process of the fluid ejection device of the second exemplary embodiment as set forth in Fig. 8.

Fig. 11 shows a sectional perspective view of a fluid ejection device of the prior art.

Fig. 12 shows a plan view of the processed silicon substrate in accordance with the first exemplary embodiment of the present invention.

Fig. 13A-13E show a manufacturing process chart illustrating processing steps of the silicon and glass substrates.

Fig. 14A-14E show a manufacturing process chart illustrating another processing steps of the silicon and glass substrates.

Fig. 15A and 15B show a cross-sectional view and a plan view, respectively, of a silicon substrate processed in accordance with the second exemplary example of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First exemplary embodiment

Fig. 1 is a perspective cross sectional view illustrating an example of a fluid

ejection device comprising silicon, glass and piezoelectric thin films.

As shown in Fig. 1, a fluid ejection device in accordance with the first exemplary embodiment comprises: a piezoelectric thin film 11, a pressure chamber 12, an ink channel 13, an ink outlet 14, a through-hole 15, an ink inlet 16, a first silicon substrate 17, a glass substrate 18, a second silicon substrate 19, an elastic body 20 and individual electrodes 21 (21a and 21b shown in Fig. 1). More specifically, the fluid ejection device of this embodiment comprises a laminated body comprising first silicon substrate 17, the glass substrate 18 and the second silicon substrate 19, the piezoelectric thin film 11, the elastic body 20, and the individual electrodes 21 mounted on the piezoelectric thin film 11.

First silicon substrate 17 is provided with such elements as a plurality of pressure chambers 12, each formed as an individual through-section at the position corresponding to the individual electrodes 21, a plurality of ink channels 13, each having a depth that is about half the thickness of silicon substrate 17 and in communication with pressure chamber 12, and a plurality of ink inlets 16, each comprising a through-section communicating with one of the ink channels 13. The cross-sectional area of the ink channel 13 expands outwardly as it goes away from the pressure chamber 12 (illustrated as dotted lines in Fig. 1). Fig. 1 shows a single set comprising one of the individual electrodes 21a, the pressure chamber 12, the ink outlet 16 and so on. A fluid ejection device generally has a plurality of sets constructed in a similar manner including the individual electrodes, the pressure chamber and the ink outlet. Fig. 1 also shows one of the individual electrodes 21b from a second set.

Silicon substrate 17 and the glass substrate 18 are bonded together such that pressure chamber 12 and the ink channel 13 are sealed except for through-hole 15 aligned with pressure chamber 12. Centered with the through-hole 15 is ink outlet 14, having an

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area smaller than the opening portion of the through-hole 15 on the second silicon substrate

19. The glass substrate 18 and the second silicon substrate 19 are bonded together. The piezoelectric thin film 11 is bonded to elastic body 20, which is bonded over pressure chamber 12 opposite the through-hole 15. The piezoelectric thin film 11 has the individual electrode 21a formed on front surface thereof, and another individual electrode on the back surface (not shown in the drawing).

The fluid flows in from the ink inlet 16, fills the ink channel 13, pressure chamber 12 and the through-hole 15, and is held at ink outlet 14. When an electric voltage is applied between the elastic body 20 and the individual electrodes 21a, 21b, and so on of the piezoelectric thin film 11, the laminated body of the piezoelectric thin film 11 and the elastic body 20 are deformed. Because elastic body 20 is made of a conductive material, it conducts current from electrode 21a mounted on the front side of piezoelectric thin film 11 to the electrode mounted on the back face of the piezoelectric thin film, and deformation occurs when the voltage is applied between the elastic body 20 and individual electrodes 21. The exact position of the laminated body to be deformed can be changed freely by selecting the individual electrode 21 to be energized with voltage. The deformation of the laminated body comprising the piezoelectric thin film 11 and the elastic body 20 pressurizes the fluid in the pressure chamber 12, and the fluid is ejected from the ink outlet 14 in a volume responsive to the strength of the pressure.

In general, a piezoelectric thin film 11 is made of a material with a high piezoelectric constant, such as a lead zirconium titanium oxide (also known as PZT), for example $\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$ or another PZT related material. A thin film made of such material is manufactured, under certain conditions known in the art, by depositing a film on a magnesium oxide (MgO) substrate for the piezoelectric thin film by sputtering. The MgO

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substrate is then etched away in phosphate or in a similar chemical such that the piezoelectric thin film 11 remains.

The shape of the ink outlet 14 affects ejection speed and the area of the ejected fluid, and thus is a key element determining the printing performance of an ink jet printer. A smaller opening area of the ink outlet 14 enables finer printing, however, an excessive difference in the area of the pressure chamber as compared to the ink outlet may result in a large pressure loss across the ink outlet, thus negatively impacting the desirable ejection. This loss can be reduced when the glass substrate 18 is provided with a through-hole 15 having a cross-sectional area that tapers from the pressure chamber toward the ink outlet. This construction comprising ink outlet 14 on second silicon substrate 19 plus tapered through-hole 15 on glass substrate 18 makes the shape of the ink outlet more controllable than a construction having a tapered hole alone, resulting in the ink outlet 14 with finer and more uniform shape.

When pressure is applied to pressure chamber 12, the pressure is not kept within the ink outlet 14 but is also transmitted to the ink channel 13, which may trigger a back flow of the fluid. To solve this problem, the ink channel 13 is shaped in a manner that its opening space (illustrated as dotted lines in Fig. 1) tapers narrower toward the pressure chamber 12, thereby increasing resistance against back flow, and improving ink ejection. The same effect can be obtained by providing a narrower section in the ink channel 13. When the area of the narrower section in the ink channel 13 is about 0.5 to 1.5 times as large as the area of the ink outlet 14, good ejection is secured by preventing the back flow.

A piezoelectric thin film 11 of several μm in thickness can easily be obtained using the sputtering method, such film being thinner than conventional films. When the piezoelectric thin film 11 is thinner, its own rigidity is reduced, thus a larger

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deformation is more easily obtained. When the magnitude of deformation is the same, the strain is smaller on the thinner film, and therefore reliability for repeated loading can be improved. As it has been described, the thinner piezoelectric material contributes to a reduced size actuator and its surrounding area, including the area of the ink outlet 14, contributing to a higher nozzle density and in turn, improved print quality.

If the piezoelectric thin film 11 is too thin, a poor driving force may result. Manufacturing thicker material using the thin film technique is generally inefficient because it requires a longer sputtering time. Therefore, it is preferable for the thickness of a piezoelectric thin film to be less than about $7\mu\text{m}$ to provide a secure driving force and a reasonable film manufacturing cost. Because the piezoelectric thin film 11 generally cannot deform by itself, it is preferably laminated to elastic body 20. In order for the elastic body 20 to be elastic while maintaining conductivity, stainless steel or another metallic material is preferably used. The thickness and the rigidity of each layer affect the position of the neutral plane during deformation. The further the neutral plane moves away from the boundary surface, the more the stress generated at the boundary surface increases, increasing the risk of delamination. Conversely, when the neutral plane is formed inside the piezoelectric member, driving efficiency declines. Therefore, in order to secure the neutral point in the vicinity of the boundary surface, the thickness of the elastic body made of metallic material is preferably the same or smaller than the thickness of the piezoelectric member.

The piezoelectric material needs to deform only over each pressure chamber, therefore, the piezoelectric material is not needed in the partitions of adjacent pressure chambers. Rather, when the piezoelectric material is separated between each pressure chamber, interference between adjacent piezoelectric members and stress imposed

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on the piezoelectric material during the bonding process and during actual deformation can be avoided, so that cracking in the piezoelectric material is minimized.

Fig. 2 shows sectional views illustrating an example of the production method for dividing the piezoelectric material.

5 First, as shown in Fig. 2A, a material for the individual electrode 23 and a piezoelectric thin film 22 are deposited on a MgO substrate 24 by the sputtering method. Second, the material for the individual electrode 23 and the piezoelectric thin film 22 are selectively etched away and divided into individual electrodes 23a, 23b and 23c, and piezoelectric thin films 22a, 22b and 22c respectively (Fig. 2B).

10 Third, an elastic body 28 made of chromium or another metallic material is formed by the sputtering method or the like. The elastic body 28 not only supports the piezoelectric thin film but also serves as the electrodes on the other side of the piezoelectric film. Then a resin material 25 such as polyimide is coated thereon (Fig. 2C). Then, a silicon substrate 27 is bonded to the dividing portion or the portion where the
15 material for the individual electrode 23 and the piezoelectric thin film 22 are etched away selectively, such that only pressure chambers 26a, 26b and 26c contact the piezoelectric thin films 22a, 22b and 22c. Finally, the MgO substrate for the piezoelectric thin film is immersed in a phosphate solution and removed (Fig. 2D).

Finally a well known process is performed, namely, portions of the elastic
20 body 28 around each individual electrode 23 are etched away in order to electrically separate each individual electrode 23 from the elastic body 28. This is performed by coating the whole surface except for the portions around each individual electrode 23 with photoresist and immersing the entire body in an etching solution (Fig. 2E). It is noted that, although the portions of the elastic body around each individual electrode 23 are removed,

entire remaining part of the elastic body 28 is still kept continuous.

By the process described above, the dividing portions are strengthened by the resin material 25. Moreover, since the rigidity of the resin material 25 is low, it does not significantly affect the driving process.

5 The construction discussed above provides a fluid ejection device that ejects fluid from an arbitrarily selected ink outlet in a plane of a substrate.

Following is an example of a manufacturing process. Figs. 3A-3E, Figs. 4A-4E and Figs. 5A-5D show sectional views illustrating steps in the manufacturing process of the fluid ejection device of the present invention.

10 Figs. 3A-3E show an example of the processing of the first silicon substrate 31. Both sides of a first silicon substrate 31 as shown in Fig. 3A are coated with resists 32a and 32b, and the patterning is carried out by the photolithography technique (Fig. 3B). In this process, patterns are formed corresponding to the position and shape of each pressure chamber 34 and ink channel 33.

15 Next, silicon is etched from the side coated with the resist 32b, such as by reactive ion etching (RIE). The etching stops at a predetermined depth in the thickness of the substrate so that an opening is formed on only one side, forming ink channel 33 (Fig. 3C). Then, etching is performed from the resist 32a side forming a through-section communicating with the ink channel 33. By this process, a pressure chamber 34 and an ink
20 inlet 35 are formed (Fig. 3D). Finally, the resists 32a and 32b are removed to conclude the manufacturing process of the first silicon substrate 31 (Fig. 3E).

Figs. 4A-4E show an example of a manufacturing process of a glass substrate 41 and a second silicon substrate 44.

First, both sides of the glass substrate 41 are coated with resists 42a and 42b

Then, a pattern is formed only on the resist 42a side at a place corresponding to the pressure chamber (Fig. 4A). Next, abrasive grains are sprayed by the sand-blasting method from the resist 42a side, forming a through-hole 43 in glass substrate 41. (Fig. 4B). This process forms a through-hole 43 that tapers from the side being sprayed with the abrasive grains toward the other side. The resist 42b protects the other face from damage caused by the abrasive grains.

Then, after the resists 42a and 42b are removed, the second silicon substrate 44 and the glass substrate 41 are directly bonded by a direct bonding technique. Patterning of a resist 45 coated on the second silicon substrate 44 is processed so as to form ink outlets 46 in positions corresponding to each pressure chamber (Fig. 4C).

The direct bonding technique is a method to bond substrates by washing the substrates and heating them without using any inclusions such as resin or applying a high electric voltage, as is the case with the anodic bonding method. In the direct bonding technique, for example, glass and silicon with a smooth surface are washed in peroxomonosulfuric acid, peroxodisulfuric or the like, and stacked after drying.

When the substrates are pressed, some bonding is gained, and the stacked body is heated at several hundred degrees Celsius to increase bonding strength. This method can lead to an extremely strong bond when optimum substrate materials are used and optimum washing and heating conditions are provided. For example, one delamination test revealed that in the bonding of glass substrates, bonding strength was so high that, in some failure modes, damage was caused not on the bonded surfaces but inside the substrate itself. The direct bonding technique provides high reliability free from degradation in the bonded layers occurring over time or as a result of contact with fluid as is the case with the bonding methods using resin or similar material. Furthermore, the

manufacturing process is very simple, requiring only washing and heating processes.

Following the bonding process, the second silicon substrate 44 is etched, such as by RIE (Fig. 4D), and the resist 45 is removed to complete the process (Fig. 4E).

The method illustrated in Figs. 4A-4E and described above allows for easy alignment of both through-holes. Moreover, the substrates can be handled more easily because the bonding process increases the total thickness of the stacked substrates. As a result, a thinner second substrate can be used, and a through-hole for the ink outlet on the second silicon substrate, which has a strong influence on the ejection performance, can be formed precisely and uniformly.

Figs. 5A-5D show sectional views illustrating the bonding process of a laminated body comprising a processed first silicon substrate 56, a glass substrate 57 and a second silicon substrate 58, and a piezoelectric thin film 59 (including an elastic body).

First silicon substrate 56 processed in a manner illustrated in Figs. 3A-3E and the laminated body of the second silicon substrate 58 and the glass substrate 57 processed in a manner illustrated in Figs. 4A-4E (Fig. 5A) are bonded by the direct bonding method described above (Fig. 5B). Before this process, pressure chamber 51 and through-hole 54 are aligned. Next, the piezoelectric thin film 59 (including an elastic body) formed on a substrate 60 made of MgO or the like is bonded onto the top of the pressure chamber 51 (Fig. 5C). Finally, the MgO substrate 60 is removed to complete the process (Fig. 5D). For a substrate 60 made of MgO, the substrate can be removed by immersing it in a phosphate solution or the like.

By the aforementioned method, a micro-fabrication technique can be adopted to realize high-precision and high-efficiency processing. Moreover, the bonding process is simple and the end product is highly reliable. When sand-blasting is used, fragile

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material such as glass can be processed rapidly with the through-hole automatically given an even tapering shape suitable for ejecting the ink. The technique described above has a potential for processing a variety of shapes by pattern designing and is applicable to a wide range of designs.

5 The ink channel formation method described above for the first silicon substrate 56 forms a groove with a predetermined depth in the direction of the thickness of the substrate, however, an alternative method for forming a through-section as the ink channel is also available. The method is described below.

 Figs. 6A-6F are sectional views illustrating processing and assembly
10 methods of a first silicon substrate 61.

 The first silicon substrate 61 is coated with a first resist 62, and the patterning is carried out in predetermined positions (Fig. 6B) so as to allow an ink channel 63, a pressure chamber 64 and an ink inlet 65 to be processed. Next, the ink channel 63, the pressure chamber 64 and the ink inlet 65 are formed by RIE or a similar technique such
15 that each of the three elements mentioned above forms a through-section extending through the thickness of the silicon substrate 61 (Fig. 6C). After the first resist 62 is removed, the first silicon substrate 61 is directly bonded to a sealing glass substrate 66, coated with a second resist 67, and patterned (Fig. 6D). Following this process, portions corresponding to the pressure chamber 64 and the ink inlet 65 are processed by sand-
20 blasting, forming a first glass through-hole 68 and a second glass through-hole 69 respectively communicating with the pressure chamber 64 and the ink inlet 65 (Fig. 6E). If the first silicon substrate 61 has to be protected from the sand-blasting, it can be coated with resists on both sides. Alternatively, processing by sand-blasting can be stopped immediately before penetration, and the glass through-hole formed by etching the

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remaining glass by ammonium fluoride or the like. Finally, the second resist 67 is removed to complete the process (Fig. 6F).

Fig. 12 shows a schematic view illustrating the shape of the first silicon substrate already processed by the aforementioned method, as viewed from the surface of the substrate. The ink channel 63, which communicates with the pressure chamber 64 and ink inlet 65, is shaped such that it tapers toward the pressure chamber, as is illustrated. This taper increases resistance to back flow of fluid as described previously.

With the aforementioned method, the processing of the first silicon substrate 61 is efficient since it does not require additional processing, as set forth in Figs. 3A-3E. In addition, because ink channel 63 is determined by the thickness of the first silicon substrate 61, it can be shaped evenly. Moreover, the cavity in the pressure chamber can be expanded by the thickness of the sealing glass substrate 66 so that more fluid can be injected into the pressure chamber, further optimizing ejection conditions. If a silicon substrate is too thick, the formation of a through-hole may be difficult. Thus, this method allows formation of a larger pressure chamber without the difficulties inherent in forming through-holes in thick silicon. One end of the ink channel 63 is sealed in the process described in Fig. 6, and therefore, bonding to other elements is also possible in the same manner as the other examples shown in Fig. 5. In Fig. 6, the glass substrate was processed after being bonded directly to the silicon substrate. This method is also applicable to the other processes described herein.

Another alternative method for forming an ink channel is given below as an example, referring to Fig. 13. The glass substrate 57 already having a through-hole 54, such as formed by sand-blasting (Fig. 13A), is directly bonded to the first silicon substrate 61 (Fig. 13B). Next, the first silicon substrate 61 is coated with the resist 62 and is

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patterned (Fig. 13C). The resist is patterned as shown in Fig. 12. Then, through-holes 64, 65 and a through-hole for ink channel 63 corresponding to the pressure chamber and the ink inlet are processed at the same time (Fig. 13D) and the resist 62 is removed to complete the process (Fig. 13E).

5 With this method, the total thickness of the substrate becomes larger, thereby intensifying its strength. As a result, damages occurring during the processing can be minimized. In addition, the direct bonding process, which is easily influenced by dust and dirt, is conducted first. Therefore, concerns over the influence of dust and dirt can be eliminated in subsequent processes. Since the substrates are bonded directly, erosion into
10 the boundary surfaces during etching is not a significant concern, unlike bonding using resin or other similar material. Furthermore, because the processing on the first silicon substrate is conducted after the bonding of the glass substrate and the first silicon substrate, the through-holes may be easily aligned. Increasing the effective thickness of the substrate by lamination reduces cracking. In addition, because etching on the first silicon substrate is
15 stopped at the bonding plane with the glass substrate, the shape of the grooves can be uniformly controlled, enabling formation of highly uniform channels.

Referring now to Figs. 14A-14E, the following processing methods are applicable to the other methods of this embodiment described earlier (Fig. 3A-Fig. 5D). The first silicon substrate 31 is coated with the resist 32a and 32b, and patterned (Fig.
20 14A). The silicon substrate 31 is processed, such as by RIE, up to the certain depth in the direction of the thickness to form the ink channel 33 (Fig. 14B). Next, the first silicon substrate 31 is bonded directly to the glass substrate 57 on which the through-hole 54 has already been formed, such as by sand-blasting (Fig. 14C). The first silicon substrate 31 is coated with a resist 32c and is patterned (Fig. 14D). Then, through-holes 34 and 35

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corresponding to the pressure chamber and the ink inlet are processed on the first silicon substrate 31, such as by RIE (Fig. 14E). This method can facilitate precise positioning and control of the size of the through-hole 34 on the first silicon substrate 31 because it can be conducted by referring to the through-hole 54 of the glass substrate 57. Etching speeds are different between the bonded surfaces of the first silicon substrate 31 and the glass substrate 57 because the characteristics of these materials are different. As a result, the processing of the through-holes 34 and 35 precisely stopped, thereby forming the through-holes uniformly.

The same method can be applied to the bonding process of the glass substrate 71 and the second silicon substrate 72 as shown in Fig. 7A-7D. In this case as well, a through-hole can be formed after bonding them directly.

In addition, by making a second silicon substrate 72 thinner by lapping, a finer and more precise processing can be expected..

Figs. 7A-7D show sectional views illustrating an example of the process for thinning the second silicon substrate 72 by lapping.

A glass substrate 71 and a second silicon substrate 72 are directly bonded as set forth in the foregoing example (Fig. 7A). After this process, the second silicon substrate 72 is lapped to reduce its thickness (Fig. 7B) and subsequently, a through-hole 73 and an ink outlet 74 are formed, such as by sand-blasting and RIE respectively (Figs. 7C and 7D). If the second silicon substrate 72 is thick, processing takes time and tends to be uneven, which makes difficult to form uniform holes. Moreover, a very small and deep through-hole is difficult to form.

Therefore, the second silicon substrate 72 is preferably thin. However, in the case of a single silicon plate, there is a limitation in terms of the handling during the

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manufacturing process and the yield of the processing. The direct bonding with the glass substrate increases rigidity, and thus the substrate can be lapped with ease. After lapping, the silicon substrate can be sent as is to the next process. In order to provide a fluid ejection device with a higher ejection density, it is desirable to provide the diameter of the ink outlet as narrow as less than tens of μm . If the silicon plate is also thinned to around 50 μm or less, more compact ink outlets, with a high ink outlet density and uniform shape can be formed. Since the through-holes on the glass substrate and the second silicon substrate are processed after the substrates are bonded, there is no need for alignment prior to the bonding step. Moreover, as the substrates are bonded prior to the processing, there is little risk of damage on the bonded surfaces during processing, or of dirt negatively effecting a good bond.

If there is no problem with the lapping step, the direct bonding and lapping are carried out after a through-hole is formed in the glass substrate. This method can also produce a similar effect when the first silicon substrate is excessively thick.

The through-hole processed by sand-blasting has a shape tapering from the opening exposed to the spraying of the abrasive grains toward the opposite end. Therefore, although it is slightly affected by the size of the abrasive grains and the intensity of the spray, if the thickness of the glass plate and the diameter of the opening exposed to the spray of the abrasive grains (opening area of the resist) are uniformly set, the diameter of the opening on the opposite side is naturally set as well. Thus, by setting the thickness of the glass plate and the diameter of the opening on the spray side so that the diameter of the opening on the opposite side is slightly larger than the diameter of the ink outlet, an optimum shape is uniquely processed. To provide an ink outlet having a diameter of tens of μm or less, the glass substrate is preferably provided with a thickness of less than or equal

to about 0.8mm, in a range of thickness of about 1.2 to about 1.9 times the quantity ($rg-rs$), where rg is the diameter of the tapered through-hole on the spray side, and rs is the diameter of the tapered through-hole on the opposite side.

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Second exemplary embodiment

Fig. 8 shows a sectional perspective view illustrating a fluid ejection device according to the second exemplary embodiment of the present invention.

In Fig. 8, a silicon substrate 86, a first glass substrate 87 and a second glass substrate 88 are directly bonded as described in the first exemplary embodiment, forming a laminated body. The silicon substrate 86 has ink outlets 84 (84a, 84b) having openings formed on the edge of the substrate, a pressure chamber 82 penetrating and communicating with the ink outlets 84, and a through-hole which partially forms an ink inlet 85, each of them formed by RIE or similar method. The first glass substrate 87 also has a through-section. A part of the through-section communicates with the pressure chamber 82 and forms an ink channel 83 while another part partially forms the ink inlet 85.

A laminated body comprising a piezoelectric thin film 81, having individual electrodes 90(90a, 90b) mounted thereon and an elastic body 89, is bonded right on the pressure chamber 82. Each pressure chamber 82 and the ink channel 83 are separated from each other and are independent. The individual electrodes 90a, 90b are disposed to correspond to each pressure chamber 82. The second glass substrate 88 seals one end of the through-section of the first glass substrate 87, forming a part of the ink channel 83. The fluid, supplied from the ink inlet 85, fills the pressure chamber 82 via the ink channel 83, is pressurized by the displacement of the piezoelectric thin film 81 when energized by an electric voltage, and is ejected from the ink outlets 84a and 84b.

Following is the description of a manufacturing method.

Figs. 9A-9E show sectional views illustrating the processing method of a silicon substrate.

First, both faces of a silicon substrate 91 as shown in Fig. 9A are coated
5 with resists 92a and 92b, and patterning is carried out (Fig. 9B). Next, one side of the silicon substrate 91 is shallowly etched, such as by RIE, and an ink outlet 93 is formed (Fig. 9C). Then, a through-section is formed from the other face to form a pressure chamber 94 and an ink inlet 95 such that the pressure chamber 94 partially communicates with the ink outlet 93 (Fig. 9D). Finally, the resists are removed from both sides to
10 complete the process (Fig. 9E).

Figs. 10A-10F show sectional views illustrating assembly method of the whole device.

A first glass substrate 105 of which a through-section is already processed by the sand-blasting with an ink channel 106 being formed therein, is directly bonded to a
15 silicon substrate 101 (Fig. 10B) which is already processed by the method shown in Fig. 9A-9E (Fig. 10A). In this bonding step, the ink channel 106 is set to communicate with a pressure chamber 103 and an ink inlet 104, and the direct bonding is carried out on the face having the ink outlet 102. Next, a second glass substrate 107 and the first glass substrate 105 are directly bonded to seal one side of the ink channel 106 (Fig. 10C).

20 As shown in the description of the first exemplary embodiment, a piezoelectric thin film 108 and an elastic body 109 disposed on a MgO substrate 110 are bonded (Fig. 10D), and the MgO substrate 110 is removed by soaking in a phosphate solution (Fig. 10E). Finally, when a laminate body made of the three substrates is divided, it is diced at right angles to the longitudinal direction of the ink outlet 102 so that the

opening of the ink outlet 102 can face outside (Fig. 10F).

The shape of the ink outlet 102 is an important factor as it determines the fluid ejection capability. When the ink outlet 102 is very fine in shape, however, it might be chipped and the shape damaged during the dicing process discussed above. One method to avoid such damage is to cut the silicon substrate prior to forming the ink outlet by etching the silicon substrate at the point where an ink outlet is to be formed. This eliminates processing after the ink outlet is formed. When cutting causes problems in the processing of the wafer, another method can be adopted in which the portion where the ink outlet is to be formed is cut to a certain depth rather than cut completely. For example, as shown in Fig. 15A and Fig. 15B, respectively illustrating a sectional view of the silicon substrate 101 and a plan view of the same as viewed from below, a recessed portion 130 is formed on the silicon substrate 101. An ink outlet groove 102 is formed transversely of the recessed portion 130. When dividing the whole substrate, it is cut along a cutting-plane line 140 by a blade narrower than the recessed portion 130, so that the ink outlet is not processed on cutting. In Figs. 15A and 15B, numeral 103 represents the pressure chamber, and numeral 104 an ink inlet. In the above-mentioned method, the ink outlets are formed completely at the same time as the grooves are engraved on the silicon substrate, leaving no need for processing afterwards. Thus, the shape of ink outlets are maintained uniformly and ink ejecting capability is not damaged.

With all the embodiments of the present invention, everything is formed by laminating plane members. Therefore, fine processing is easy and the structure can become finer. Further, the following efficient process can be adopted. At first a number of unit structures as shown in Fig. 9 or Fig. 15 are embedded like a matrix on a large silicon substrate as well as on first and second glass substrates. Then the substrates are bonded by

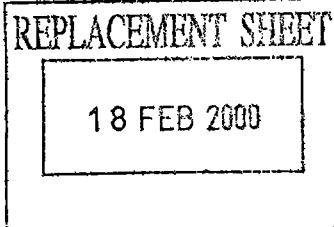
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a method shown in Fig. 10, and cut into individual units. In this manner, a great number of fluid ejection devices are produced at a time, making the process very efficient.

According to the exemplary embodiments discussed above, the effect of the fine processing, direct bonding and piezoelectric thin film as shown in the first exemplary embodiment, is obtained at the same time. In addition, a fluid ejection device with a different ejection mode in which fluid is ejected from an edge of a substrate can be produced. With this method, an ink outlet can be designed freely by patterning resist, which greatly contributes to the optimization of the shape. Easy, uniform and fine control of the ink outlet area is possible just by adjusting the width and depth of the groove. If an ink channel on the first glass substrate is formed by etching up to the midway of the substrate rather than penetrating completely, the second glass substrate is not necessary. Therefore, only one direct bonding step may be required to complete the process, further reducing the number of manufacturing steps.

As described so far, according to the present invention, a fluid ejection device with smaller ink outlets arranged in a higher density configuration can be formed by employing the micro-fabrication technique of silicon and glass substrates and by employing a piezoelectric thin film as described herein. As processing and lamination are conducted from a direction perpendicular to the plane of the substrate, a plurality of units may be produced, providing increased productivity and design freedom. As the substrates are directly bonded to each other, adhesive materials are not needed, simplifying process management and maximizing long-term reliability in fluid sealing capability.

As a result, an on-demand ink jet printhead for an ink jet printer with having higher nozzle density, higher reliability and lower cost can be achieved.

**What is claimed is:**

- 1 1. A fluid ejection device comprising;
2 at least one pressure chamber divided independently from other pressure
3 chambers;
4 an ink channel communicating with said pressure chamber;
5 an ink outlet communicating with said pressure chamber; and
6 a pressure generating section comprising a laminated body made of a
7 piezoelectric material and an elastic body, said section covering one face of said pressure
8 chamber.
9 wherein said pressure chamber, said ink channel and said ink outlet are
10 defined by a structure comprising at least one planar silicon substrate laminated to at least
11 one planar glass substrate.
- 1 2. The fluid ejection device according to claim 1, wherein said piezoelectric
2 material has a thickness of not more than about 7 μ m and said elastic body is has a
3 thickness of the same or less than said piezoelectric material.
- 1 3. The fluid ejection device according to claim 1, wherein said piezoelectric
2 material is divided into a plurality of regions having dividing sections therebetween, each
3 region corresponding to one chamber, and having a layer of resin disposed at least on the
4 dividing sections.
- 1 4. The fluid ejection device according to claim 2, wherein said elastic body
2 comprises a metallic material.



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1 5. The fluid ejection device according to claim 1, wherein said piezoelectric
2 material comprises $\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$.

1 6. The fluid ejection device according to claim 4, wherein said silicon
2 substrate and said glass substrate are directly bonded to one another.

1 7. The fluid ejection device according to claim 1 wherein the ink channel
2 has a cross-sectional area that is about 0.5 to about 1.5 times as large as a cross-sectional
3 area of the ink outlet.

1 8. The fluid ejection device according to claim 1 wherein the ink channel
2 has a cross-sectional area that tapers towards the ink outlet.

1 9. The fluid ejection device according to claim 1 wherein said ink outlet is
2 tapered from a wide end in communication with the pressure chamber to a narrow end.

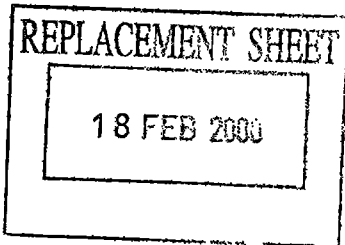
1 10. The fluid ejection device according to claim 1 wherein the laminated
2 structure comprises:

3 a first substrate having a through-hole for the pressure chamber and a
4 through-hole for an ink inlet;

5 a second substrate bonded to said first substrate; and

6 a third substrate bonded to said second substrate.

1 11. The fluid ejection device according to claim 10, wherein the third



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2 substrate has a thickness of not more than about 50 μ m.

1 12. The fluid ejection device according to claim 10 wherein the first
2 substrate comprises a silicon single-crystal substrate, the second substrate comprises a
3 glass substrate; and the third substrate comprises one of a glass substrate or a silicon
4 single-crystal substrate.

1 13. The fluid ejection device according to claim 10 wherein:

2
3 the ink channel comprises a groove in the first substrate in partial
4 communication with the through-hole for the pressure chamber and the through-hole for
5 the ink inlet;

6 the ink outlet comprises a tapered through-hole in the second substrate that
7 tapers from a wide end in contact with the first substrate to a narrow end in contact with
8 the third substrate, and a through-hole in the third substrate.

1 14. The fluid ejection device according to claim 13 wherein the through-
2 hole in the third substrate for said ink outlet is aligned approximately on center with the
3 narrow end of the tapered through-hole in the second substrate, said through-hole in the
4 third substrate having a diameter smaller than a diameter of the narrow end of the tapered
5 through-hole in the second substrate.

1 15. The fluid ejection device according to claim 14 wherein the third
2 substrate has a thickness of not more than about 50 μ m and the second substrate has a
3 thickness of less than about 0.8mm in a range of thickness comprising about 1.2 to about

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4 1.9 times ($rg-rs$), where rg is the diameter of the wide end of the tapering through-hole in
5 the second substrate and rs is the diameter of the narrow end of the tapering through-hole
6 in the second substrate.

1 16. The fluid ejection device according to claim 10 wherein:
2 the ink channel comprises a through-hole in the first substrate;
3 the ink outlet comprises a through-hole in the second substrate tapering
4 from a wide end in contact with the first substrate to a narrow end in contact with the third
5 substrate, and a through-hole in the third substrate;
6 the device further comprises a fourth substrate bonded to the first substrate
7 and having a through-hole therein for the pressure chamber and a groove therein for the ink
8 channel.

1 17. The fluid ejection device according to claim 16 wherein the first
2 substrate comprises a silicon single-crystal substrate, the second substrate comprises a
3 glass substrate; and each of the third substrate and the fourth substrate comprises one of a
4 glass substrate or a silicon single-crystal substrate,

1 18. The fluid ejection device according to claim 16 wherein the through-
2 hole in the third substrate for said ink outlet is aligned approximately on center with the
3 narrow end of the tapered through-hole in the second substrate, said through-hole in the
4 third substrate having a diameter smaller than a diameter of the narrow end of the tapered
5 through-hole on the second substrate.

1 19. The fluid ejection device according to claim 18 wherein the third
2 substrate has a thickness of not more than about $50\mu\text{m}$ and the second substrate has a



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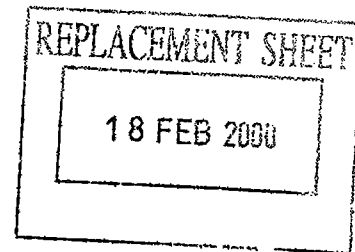
3 thickness of less than about 0.8mm in a range of thickness comprising about 1.2 to about
4 1.9 times ($r_g - r_s$), where r_g is the diameter of the wide end of the tapering through-hole
5 formed on the second substrate and r_s is the diameter of the narrow end of the tapering
6 through-hole in the second substrate.

1 20. The fluid ejection device according to claim 10 wherein the ink outlet
2 comprises a groove in the first substrate in partial communication with the through-hole for
3 the pressure chamber, and the ink channel comprises a through-section in the second
4 substrate.

1 21. The fluid ejection device according to claim 20 wherein the ink channel
2 further comprises the through-section for the ink channel in the second substrate aligned
3 and in partial communication with the through-hole for the pressure chamber and the
4 through-hole for the ink inlet on the first substrate.

1 22. The fluid ejection device according to claim 20 wherein the groove for
2 the ink outlet is located on an edge of the first substrate.

1 23. A process for manufacturing a fluid ejection device comprising at least
2 one pressure chamber divided independently from other pressure chambers, an ink channel
3 communicating with said pressure chamber, an ink outlet communicating with said
4 pressure chamber; and a pressure generating section comprising a laminated body made of
5 a piezoelectric material and an elastic body, said pressure generating section covering one
6 face of said pressure chamber; said pressure chamber, said ink channel and said ink outlet
7 defined by a structure comprising at least one planar silicon substrate bonded to at least one



8 planar glass substrate, the process comprising the steps of:

9 (a1) forming a through-hole for the pressure chamber and a through-hole for
10 an ink inlet on a first substrate;

11 (b) bonding the first substrate to a second substrate;

12 (c) bonding the second substrate to a third substrate; and

13 (d) covering the through-hole for the pressure chamber with the pressure
14 generating section.

1 24. The process according to claim 23 further comprising the steps of:

2 (a2) forming the ink channel in the first substrate, the ink channel
3 comprising a groove in partial communication with the through-hole for the pressure
4 chamber and the through-hole for the ink inlet;

5 (e) forming a through-hole in the second substrate, said through-hole
6 tapering from a wide end in contact with the first substrate to a narrow end in contact with
7 the third substrate; and

8 (f) forming a through-hole in the third substrate for the ink outlet.

1 25. The process according to claim 24, wherein step (a1) is conducted after
2 step (a2) and step (b).

1 26. The process according to claim 23 further comprising the steps of;

2 (a3) forming a through-hole for the ink channel in the first substrate;

3 (e) forming a through-hole in the second substrate, the through-hole

4 tapering from a wide end in contact with the first substrate to a narrow end in contact with

5 the third substrate;



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- 6 (f) forming a through-hole in the third substrate for the ink outlet;
7 (g) forming a through-hole in a fourth substrate for the pressure chamber;
8 and
9 (h) forming a groove for the ink channel by bonding the first and fourth
10 substrates.

1 27. The process according to claim 26, wherein step (a1) and step (a3) are
2 conducted after step (e) and step (b).

1 28. The process according to claim 24, wherein step (f) is conducted after
2 step (e) and step (c).

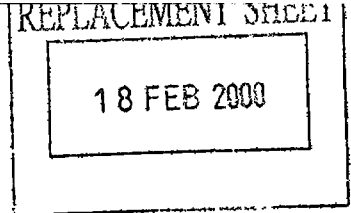
1 29. The process according to claim 26, wherein step (f) is conducted after
2 step (e) and step (c).

1 30. The process according to claim 24 , wherein step (e) and step (f) are
2 conducted after step (c).

1 31. The process according to claim 26, wherein step (e) and step (f) are
2 conducted after step (c).

1 32. The process according to claim 24 , wherein step (c) is conducted after
2 step (e) and optionally after step (f), said method further comprising thinning at least a
3 section of the third substrate by lapping, the thinned section aligned with the through-hole
4 on the second substrate.

1 33. The process according to claim 26, wherein step (c) is conducted after



2 step (e) and optionally after step (f), said method further comprising thinning at least a
3 section of the third substrate by lapping, the thinned section aligned with the through-hole
4 on the second substrate.

1 34. The process according to claim 24, comprising:

2 in step (f) forming the through-hole for the ink outlet on the third substrate
3 with a diameter smaller than a diameter of the narrow end of the tapered through-hole on
4 the second substrate; and

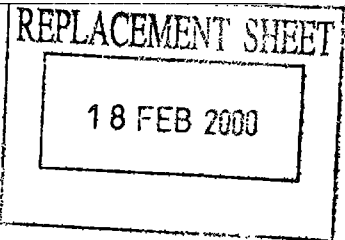
5 in step (c) aligning the through-hole for the ink outlet on the third substrate
6 with approximately a center of the diameter of the narrow end of the through-hole on the
7 second substrate.

1 35. The process according to claim 26, comprising:

2 in step (f) forming the through-hole for the ink outlet in the third substrate,
3 the through-hole having a diameter smaller than a diameter of the narrow end of the
4 tapered through-hole in the second substrate; and

5 in step (c) aligning the through-hole for the ink outlet in the third substrate
6 with approximately a center of the diameter of the narrow end of the tapered through-hole
7 in the second substrate.

1 36. The process of claim 24 wherein the third substrate has a thickness of not more than
2 about 50 μ m and the second substrate has a thickness of less than about 0.8mm and is in a
3 range of thickness comprising about 1.2 to about 1.9 times the quantity ($rg-rs$), where rg is
4 the diameter of the wide end of the tapering through-hole formed on the second substrate



5 and r_s is the diameter of the narrow end of the tapering through-hole in the second
6 substrate.

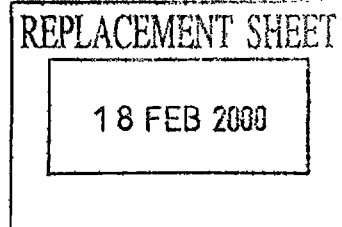
1 37. The process of claim 26 wherein the third substrate has a thickness of
2 not more than about $50\mu\text{m}$ and the second substrate has a thickness of less than about
3 0.8mm and has a range of thickness comprising about 1.2 to about 1.9 times the quantity
4 $(r_g - r_s)$, where r_g is the diameter of the wide end of the tapering through-hole formed on the
5 second substrate and r_s is the diameter of the narrow end of the tapering through-hole in
6 the second substrate.

1 38. The process according to claim 23, further comprising the steps of:
2 (a4) forming a groove for the ink outlet in partial communication with the
3 through-hole for the pressure chamber in the first substrate; and
4 (i) forming a through-section in the second substrate for the ink channel.

1 39. The process according to claim 38 comprising forming the ink channel
2 by bonding the first substrate to the second substrate so that the through-hole for the
3 pressure chamber and the through-hole for the ink inlet on the first substrate align with and
4 partially communicate with the through-section for the ink channel on the second substrate.

1 40. The process according to claim 38 comprising forming the groove for
2 the ink outlet on an edge of the first substrate in step (a4).

1 41. The process according to claim 38 comprising:
2 forming a recessed section on the first substrate;



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3 forming the groove for the ink outlet transversely of the recessed portion;
4 forming an opening section at a right angle to a longitudinal direction of the
5 groove for the ink outlet; and
6 cutting the first substrate along the recessed portion without contacting the
7 opening section.

1 42. The process according to claim 41 further comprising cutting the first
2 substrate at a right angle to the longitudinal direction of the groove for the ink outlet.

1 43. The process according to claim 24 comprising forming the ink channel
2 with a cross-sectional area that is about 0.5 to about 1.5 times as large as a cross-sectional
3 area of the ink outlet.

1 44. The process according to claim 26 comprising forming the ink channel
2 with a cross-sectional area that is about 0.5 to about 1.5 times as large as a cross-sectional
3 area of the ink outlet.

1 45. The process according to claim 38 comprising forming the ink channel
2 with a cross-sectional area that is about 0.5 to about 1.5 times as large as a cross-sectional
3 area of the ink outlet.

1 46. The process according to claim 24 comprising forming the ink channel
2 in step (a2) having a cross-sectional area that tapers towards the ink outlet.

1 47. The process according to claim 26 comprising forming the ink channel



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2 in step (a3) having a cross-sectional area that tapers towards the ink outlet.

1 48. The process according to claim 38 comprising forming the ink channel
2 step (i) having a cross-sectional area that tapers towards the ink outlet.

1 49. The process according to claim 24 wherein bonding steps (b) and (c)
2 comprise direct bonding.

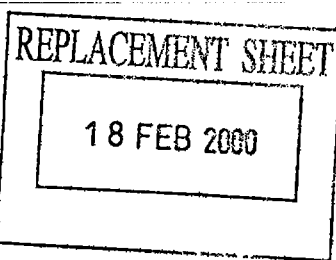
1 50. The process according to claim 26 wherein bonding steps (b) and (c)
2 and (h) comprise direct bonding.

1 51. The process according to claim 38 wherein bonding steps (b) and (c)
2 comprise direct bonding.

1 52. The process according to claim 24 wherein the steps of forming features
2 on said substrates comprise performing at least one reactive ion etching step on at least one
3 of said silicon substrates, and performing at least one sand-blasting step on at least one of
4 said glass substrates.

1 53. The process according to claim 26 wherein the steps of forming features
2 on said substrates comprise performing at least one reactive ion etching step on at least one
3 of said silicon substrates and performing at least one sand-blasting step on at least one of
4 said glass substrates.

1 54. The process according to claim 38 wherein the steps of forming features
2 on said substrates comprise performing at least one reactive ion etching step on at least one



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- 3 of said silicon substrates and performing at least one sand-blasting step on at least one of
- 4 said glass substrates.

ABSTRACT OF THE DISCLOSURE

A fluid ejection device, such as for an ink jet printer or the like, and a process for manufacture thereof for increasing nozzle density and improving efficiency of the production process. A through-hole (15) is provided in a glass substrate (18) to which a
5 second silicon substrate (19) is directly bonded to form an ink outlet (14). The first silicon substrate (17) is etched to form a pressure chamber (12), an ink channel (13) and an ink inlet (16), and bonded directly to the glass substrate (18). The piezoelectric thin film (11) having a conductive, elastic body (20) is bonded to the first substrate covering the pressure chamber (12).

FIG. 1

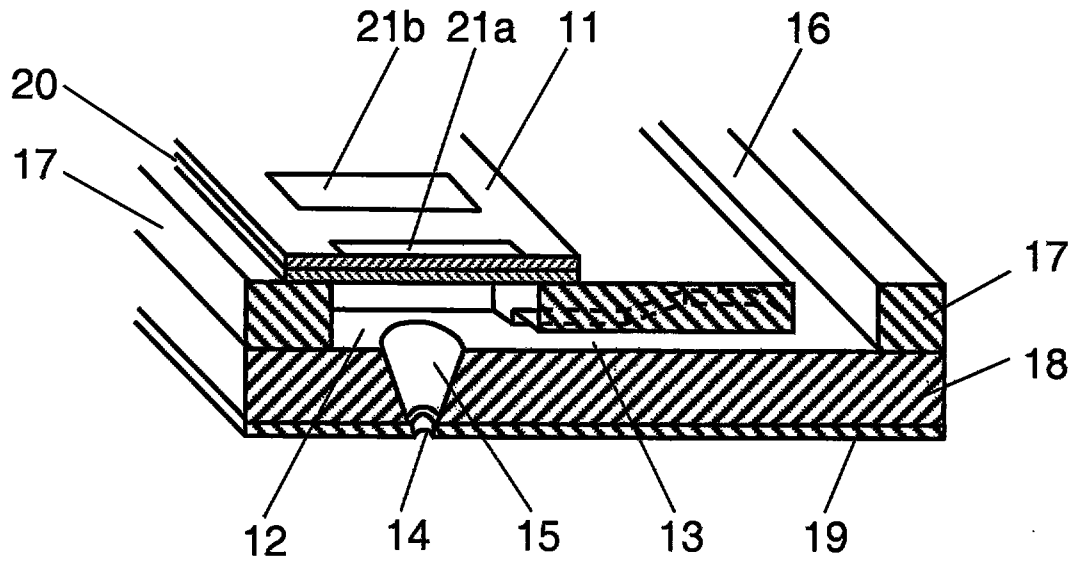


FIG. 2A

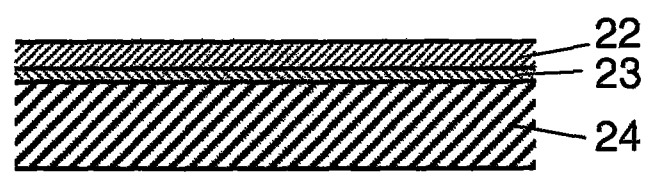


FIG. 2B

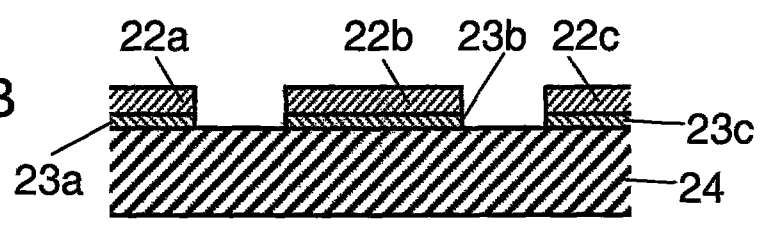


FIG. 2C

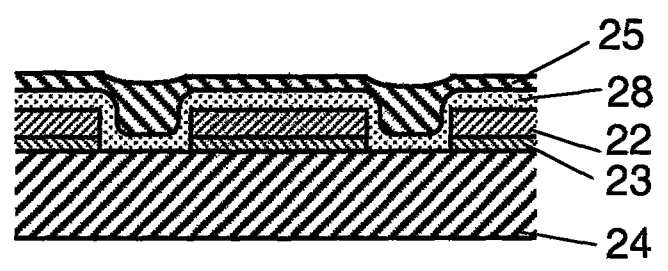


FIG. 2D

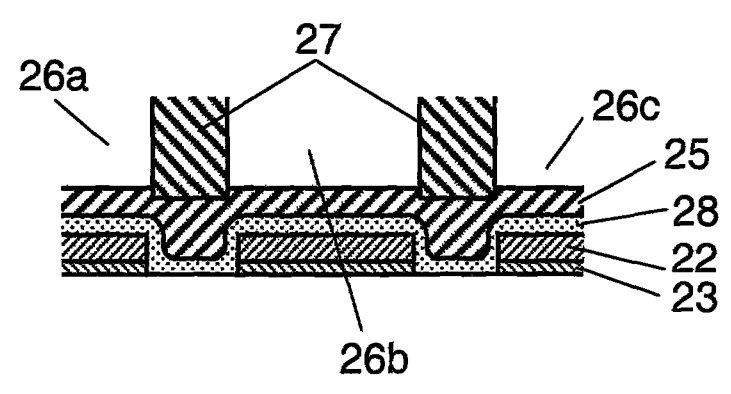


FIG. 2E

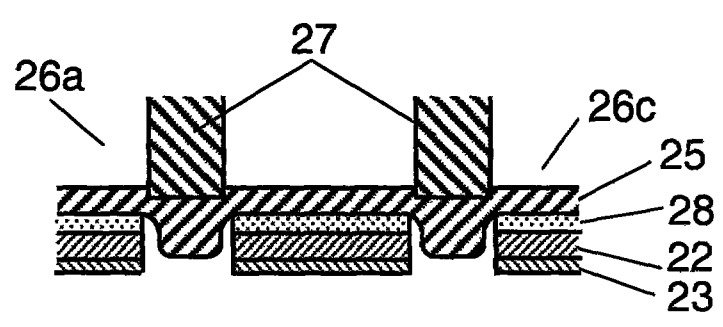


FIG. 3A



FIG. 3B

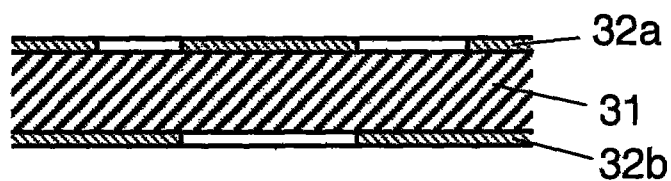


FIG. 3C

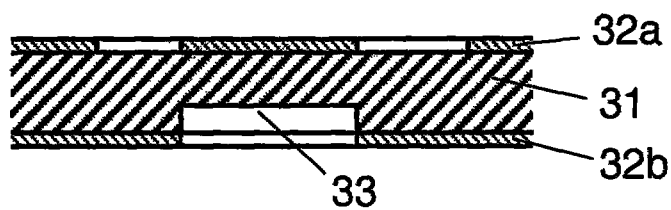


FIG. 3D

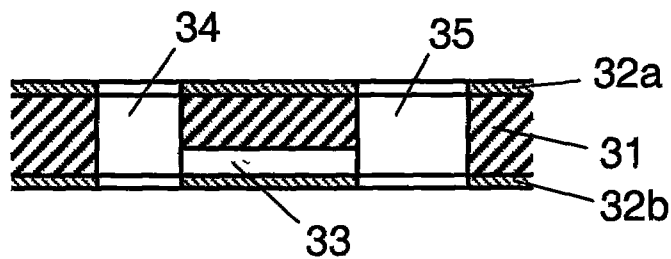


FIG. 3E

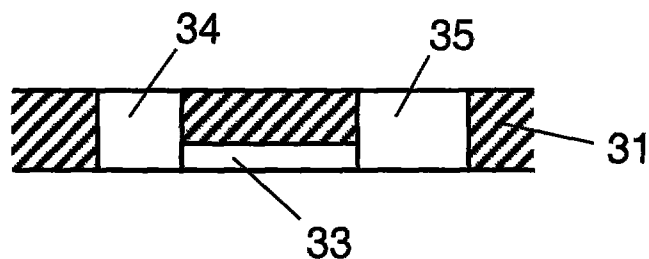


FIG. 4A

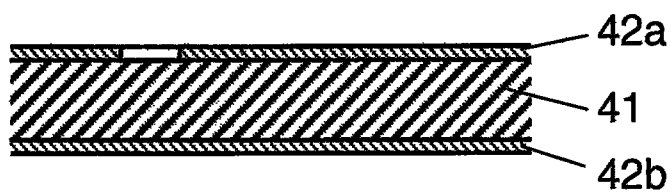


FIG. 4B

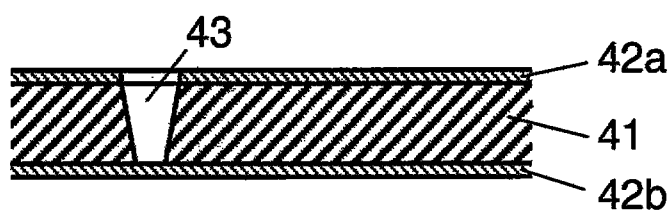


FIG. 4C

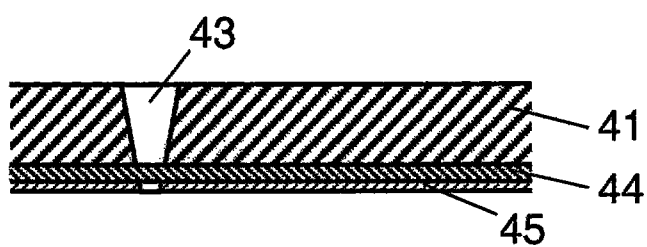


FIG. 4D

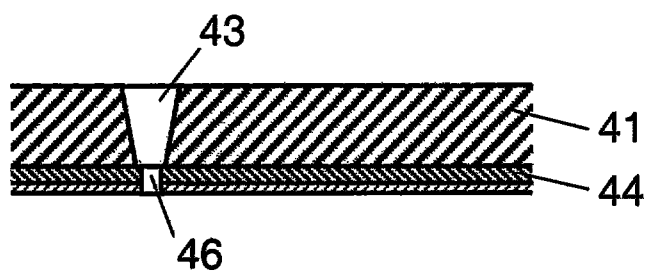


FIG. 4E

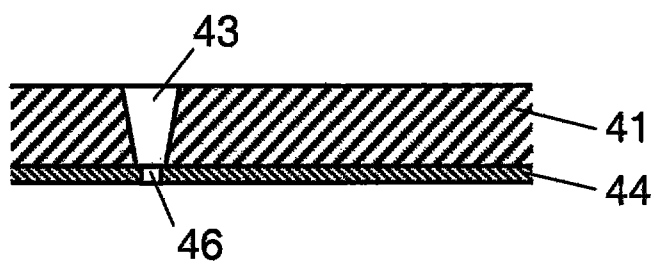


FIG. 5A

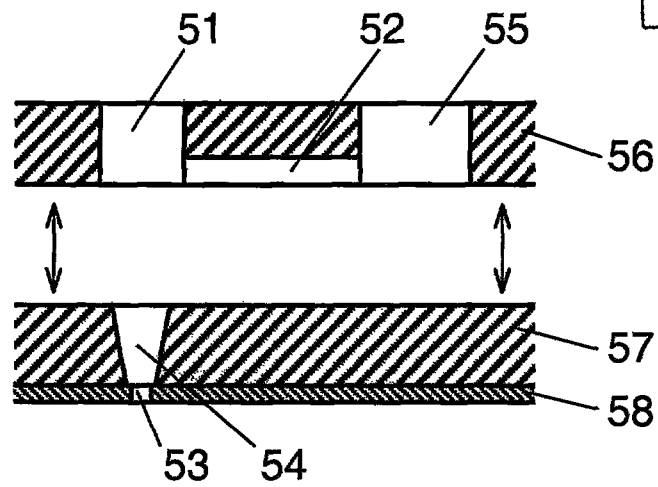


FIG. 5B

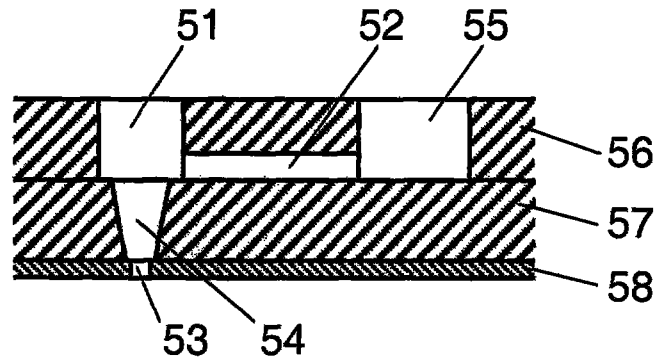


FIG. 5C

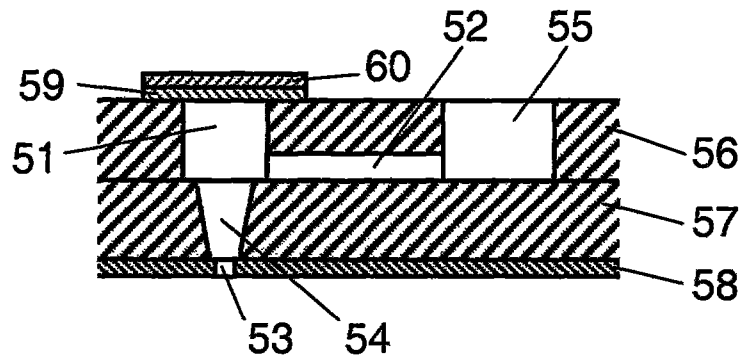


FIG. 5D

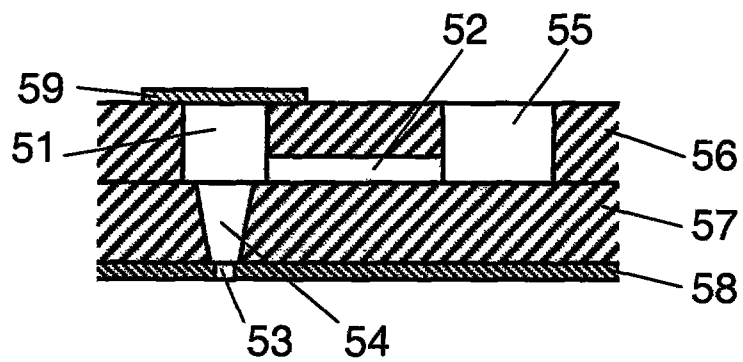


FIG. 6A



FIG. 6B



FIG. 6C

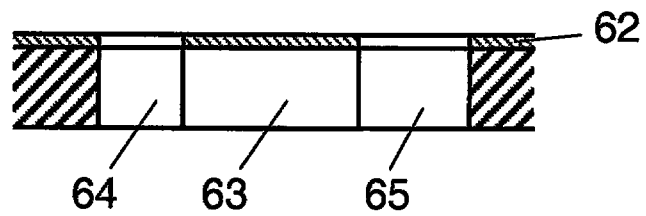


FIG. 6D

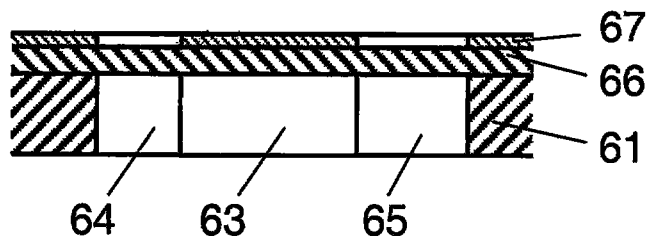


FIG. 6E

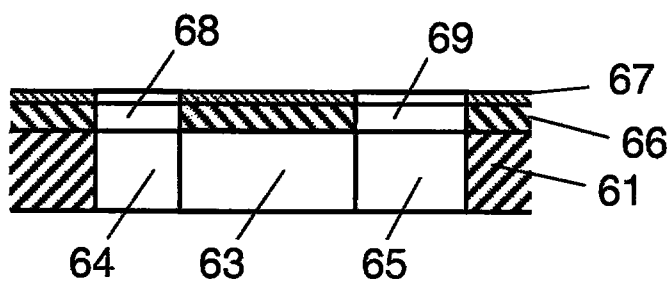


FIG. 6F

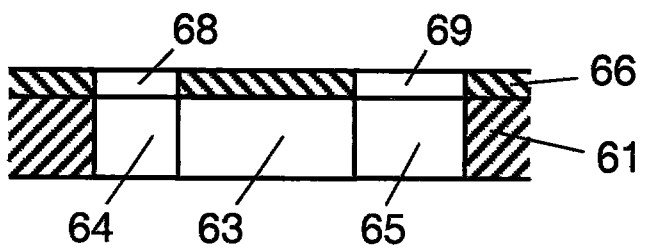


FIG. 7A

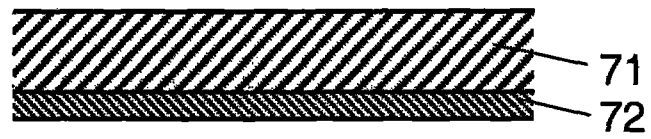


FIG. 7B



FIG. 7C

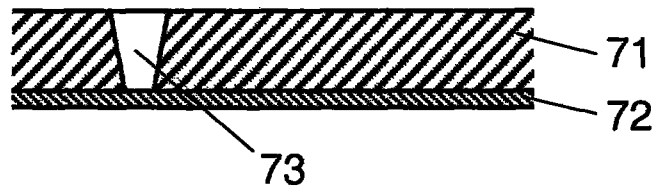


FIG. 7D

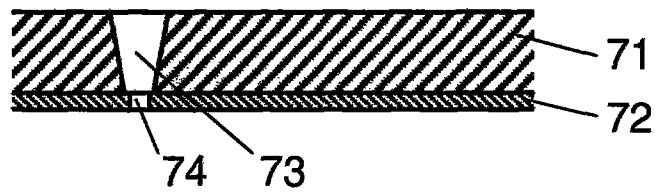


FIG. 8

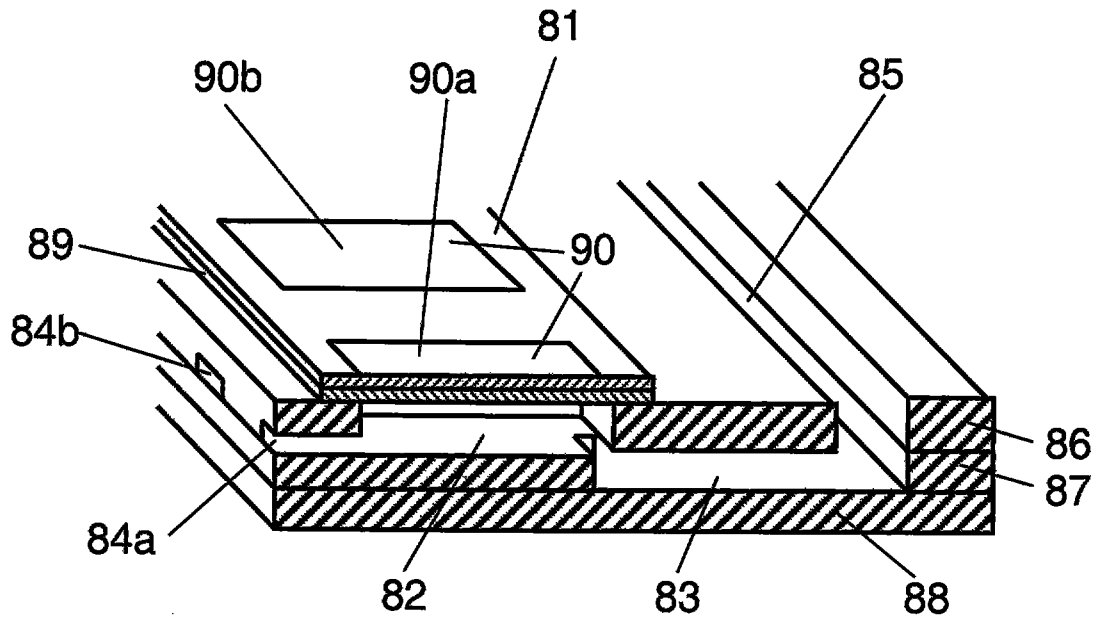


FIG. 9A



FIG. 9B

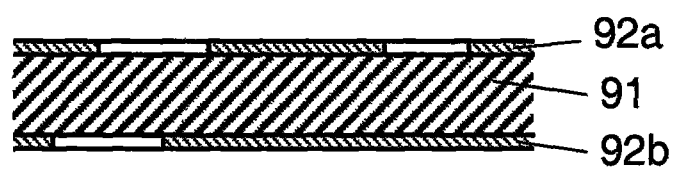


FIG. 9C

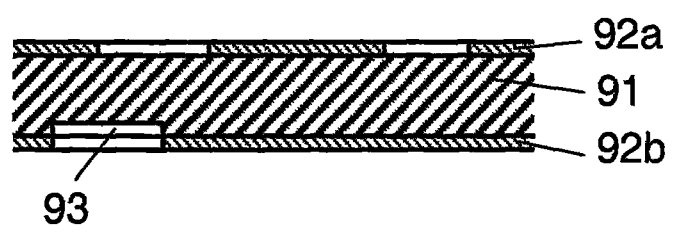


FIG. 9D

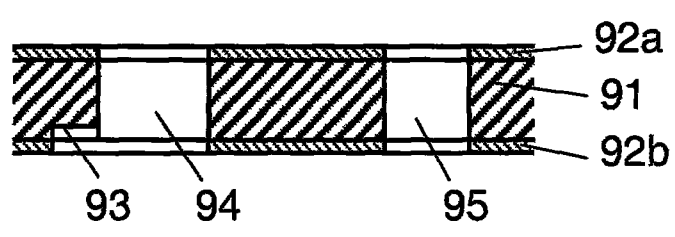
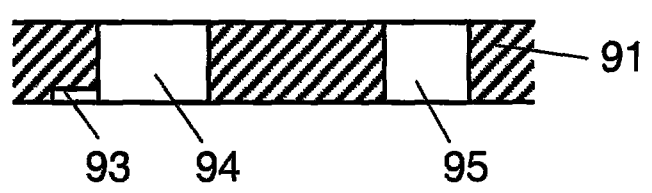


FIG. 9E



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FIG. 10A

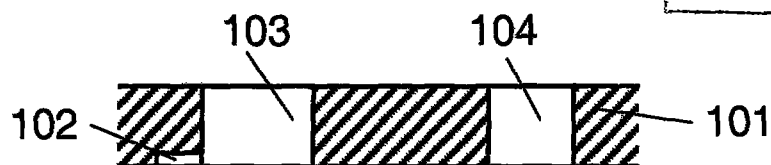


FIG. 10B

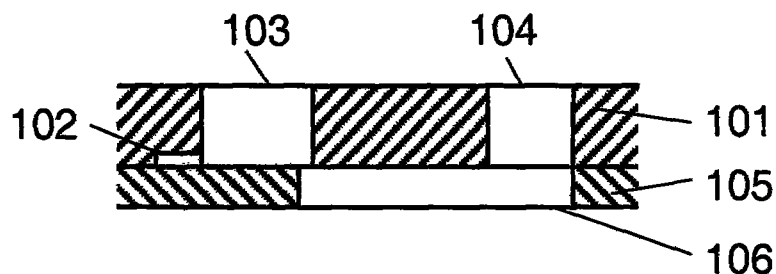


FIG. 10C

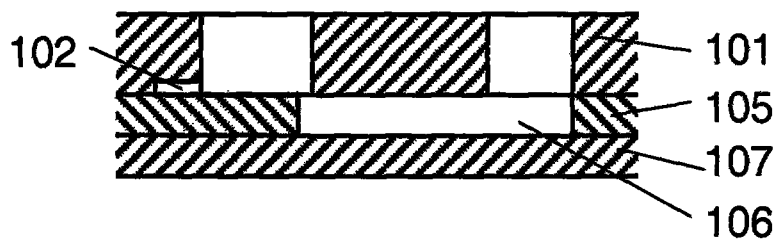


FIG. 10D

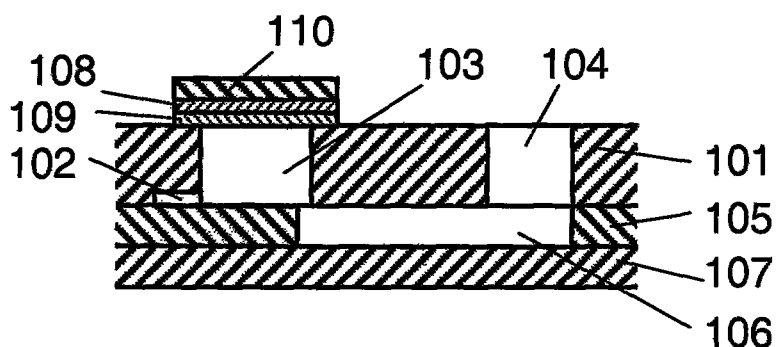


FIG. 10E

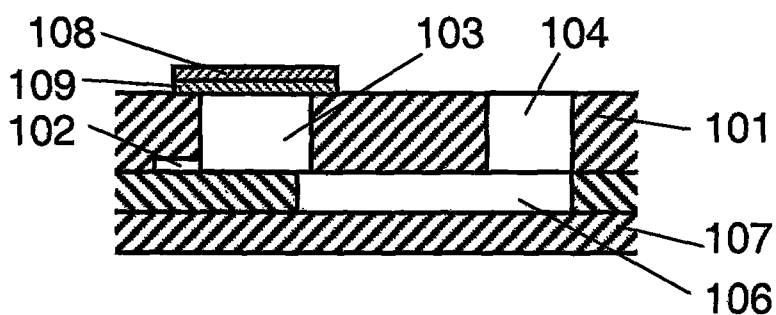


FIG. 10F

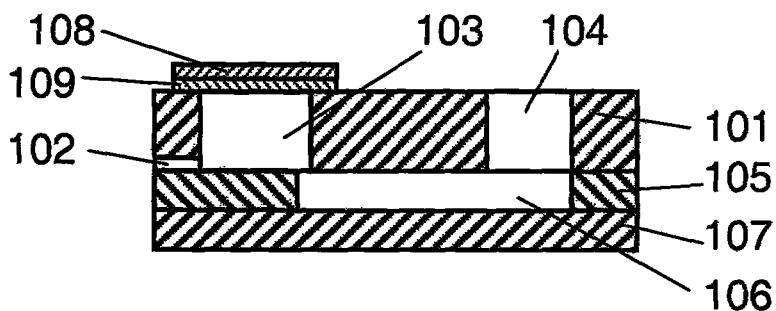


FIG. 11 (PRIOR ART)

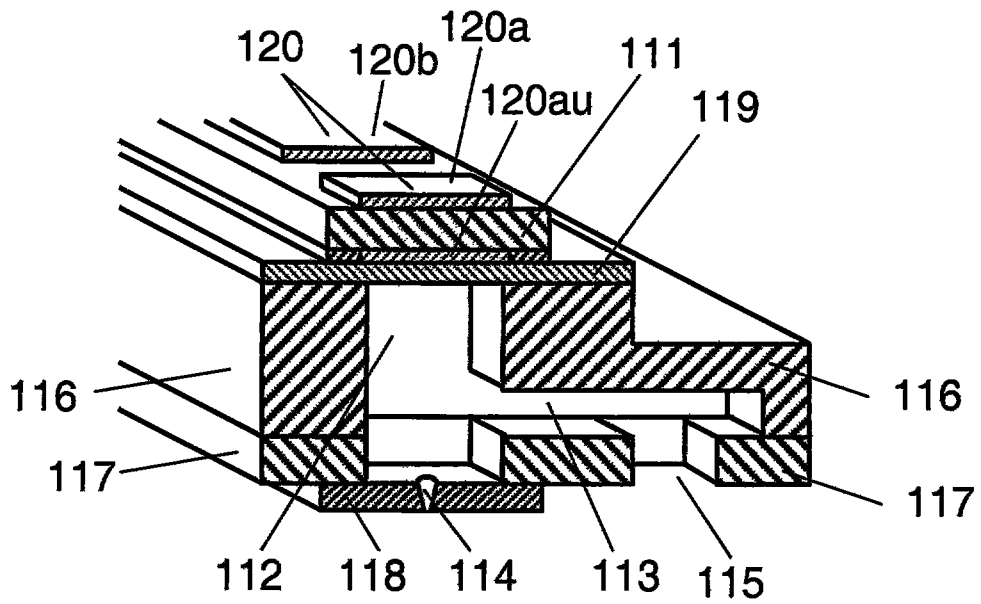


FIG. 12

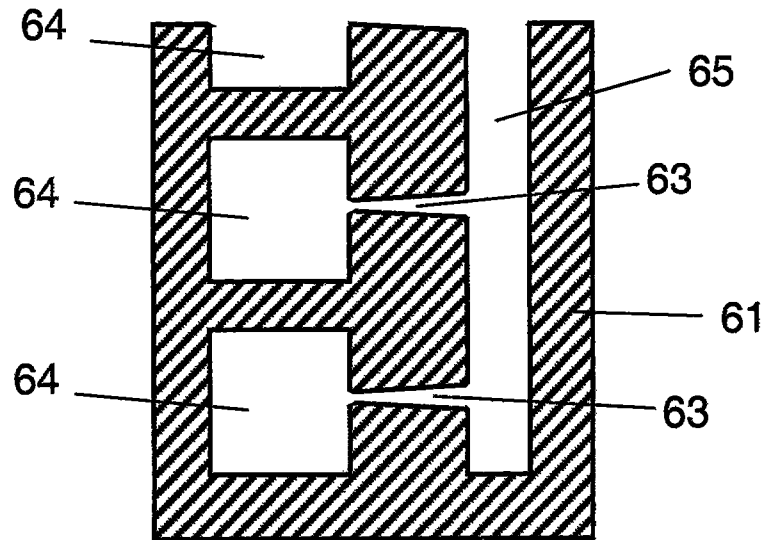


FIG.13A



FIG.13B

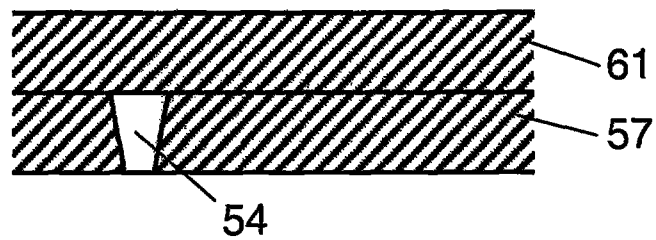


FIG.13C

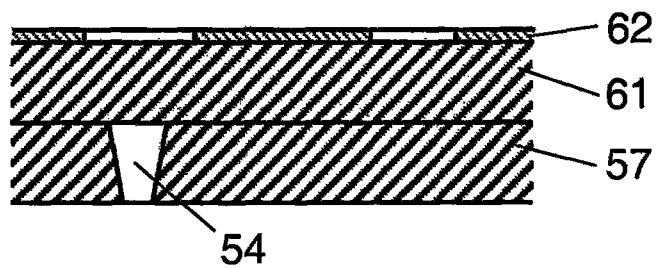


FIG.13D

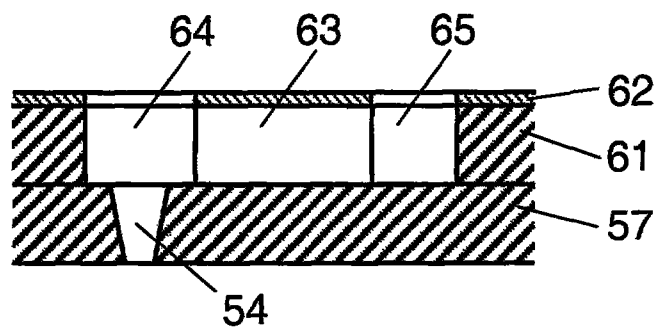


FIG.13E

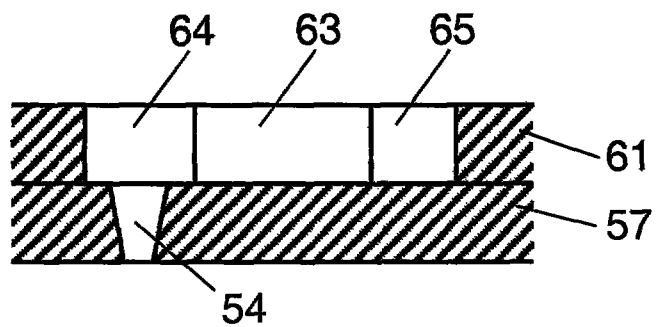


FIG. 14A

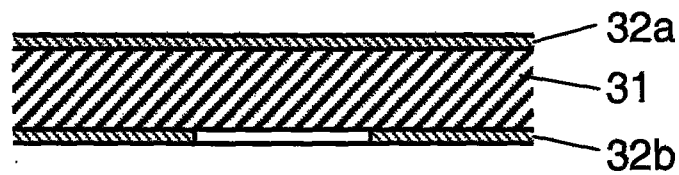


FIG. 14B

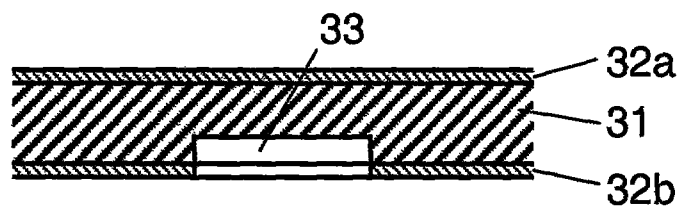


FIG. 14C

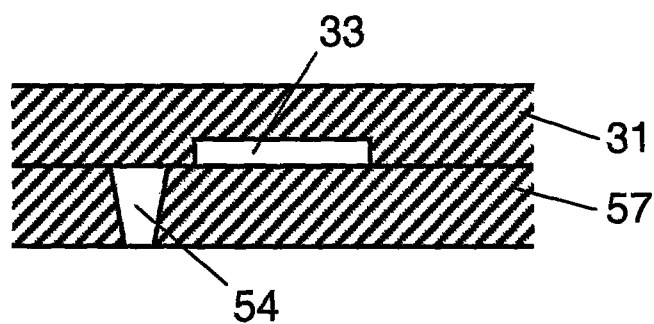


FIG. 14D

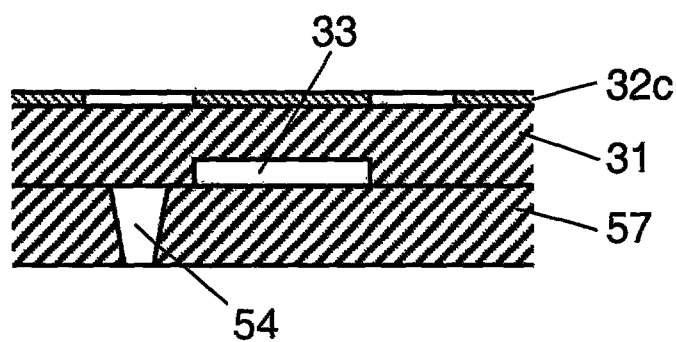


FIG. 14E

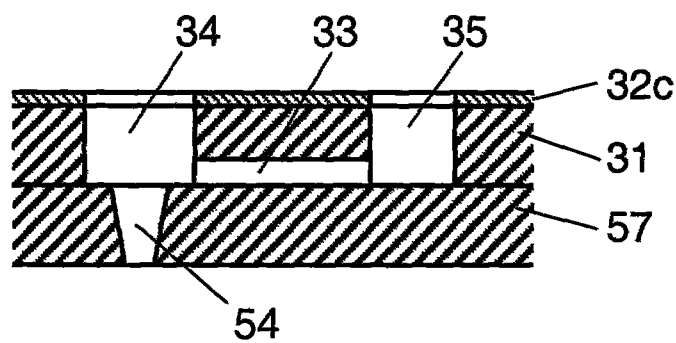


FIG. 15A

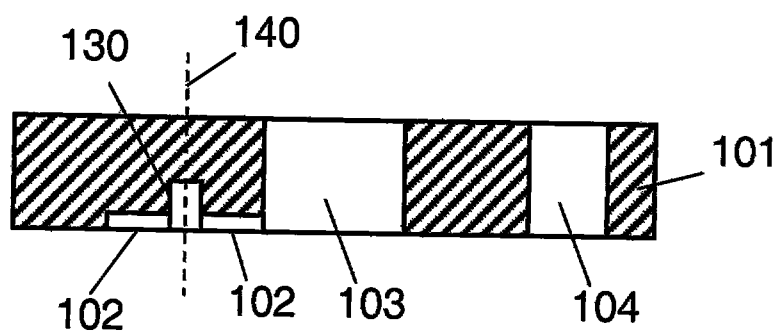


FIG. 15B

