

Description

[0001] The present invention relates to a micro-pump, and more particularly, to a micro-pump driven by the phase change of a fluid.

[0002] Due to recent, incredible developments in micro-machining technology, micro electro mechanical systems (MEMS) with a variety of functions have been developed. MEMS devices have many advantages in terms of their size, manufacturing costs, and reliability, and thus research has been vigorously carried out on ways to apply such MEMS devices to a variety of fields.

[0003] Currently, research on a method of implementing a compact-sized fluid system onto a single chip is under way, which invigorates various attempts to develop techniques regarding a micro structure, such as a micro-pump or a valve, which can control the flow of a very small amount of fluid.

[0004] FIGS. 1A and 1B are cross-sectional views illustrating a conventional micro-pump having check valves. Referring to FIGS. 1A and 1B, the conventional micro-pump is driven by a piezoelectric body 12 attached to an upper film of a pumping chamber 10. A fluid entrance 14 and a fluid exit 16 are connected to the pumping chamber 10, and first and second check valves 15 and 17 are provided at the interface between the fluid entrance 14 and the pumping chamber 10 and at the interface between the fluid exit 16 and the pumping chamber 10, respectively. As shown in FIG. 1A, when the piezoelectric body 12 is transformed due to voltage applied thereto, the volume of the pumping chamber 10 increases. Then, the second check valve 17 is shut, and the first check valve 15 is opened so that a fluid can be supplied into the pumping chamber 10 through the fluid entrance 14. As shown in FIG. 1B, when the piezoelectric body 12 is transformed so that the volume of the pumping chamber 10 decreases, the first check valve 15 is shut, and the second check valve 17 is opened. Accordingly, a small amount of fluid is discharged through the fluid exit 16.

[0005] In the conventional micro-pump of FIGS. 1A and 1B, the check valves 15 and 17, which induces the flow of a fluid in one direction, are supposed to operate in a tiny structure. Pumps and valves used in MEMS devices, in particular, are required to have a very small size so that the check valves 15 and 17 can hardly be applied to the MEMS devices. Even if the check valves 15 and 17 are possibly implemented in a MEMS device, it is hard to guarantee the durability of the check valves 15 and 17 for as long as a predetermined amount of time required. In addition, due to the mass inertia of the check valves 15 and 17, the check valves 15 and 17 may not operate well at high frequencies.

[0006] FIG. 2 is a cross-sectional view of another conventional micro-pump disclosed in U.S. Patent No. 5,901,037. Referring to FIG. 2, the conventional micro-pump does not have such movable elements as the check valves 15 and 17 of FIGS. 1A and 1B. Rather, the

conventional micro-pump includes a pair of fluid passages 22 and 23 which are pyramid-shaped. The fluid passages 22 and 23 are connected to a lower part of a pumping chamber 20 so that they can extend along different directions: A piezoelectric body 21 is installed at an upper film of the pumping chamber 20 as a driving means. The fluid passage 22 has such a structure that its cross-sectional area decreases along a direction toward the pumping chamber 20. On the other hand, the fluid passage 23 has such a structure that its cross-sectional area increases along the direction toward the pumping chamber 20.

[0007] If the fluid passage 22 or 23 is formed with a relatively large inclination angle of about $50 \sim 70^\circ$, flux resistance in a direction along which the cross-sectional area of the fluid passage 22 or 23 decreases is smaller than flux resistance in a direction along which the cross-sectional area of the fluid passage 22 or 23 increases. Accordingly, fluids respectively passing through the fluid passages 22 and 23 are affected by different levels of flux resistance due to volume variations in the pumping chamber 20 caused by vibration of the piezoelectric body 21. The conventional micro-pump can enable a net flow rate in a direction where it pumps out a fluid without the need of check valves.

[0008] FIGS. 3A and 3B are cross-sectional views of still another conventional micro-pump disclosed by Erik Stemme and Goran Stemme in "A Valveless Diffuser/Nozzle-Based Fluid Pump", Sensors and Actuators A. 39, pp. 159-167, 1993.

[0009] Referring to FIGS. 3A and 3B, the conventional micro-pump does not have valves. Rather, the conventional micro-pump includes a pair of fluid passages, i.e., a fluid exit 33 and a fluid entrance 34, whose cross-sectional area varies along a direction where a fluid is pumped. The fluid exit 33 and the fluid entrance 34 are connected to a pumping chamber 30 at either side of the pumping chamber 30, and a piezoelectric membrane 32 is provided onto the pumping chamber 30 as a driving means. The fluid entrance 34 has an increasing cross-sectional area in a direction toward the pumping chamber 30, while the fluid exit 33 has a decreasing cross-sectional area in the direction toward the pumping chamber 30. If the fluid passages 33 and 34 are formed with a relatively small inclination angle of about $15 \sim 30^\circ$, flux resistance in a direction where their cross-sectional area increases is smaller than flux resistance in a direction where their cross-sectional area decreases. Therefore, as shown in FIG. 3A, when a fluid is pumped into the pumping chamber 30 due to a transformation of the piezoelectric membrane 32, the amount of fluid passing through the fluid entrance 34 is larger than the amount of fluid passing through the fluid exit 33. On the other hand, as shown in FIG. 3B, when the fluid is discharged from the pumping chamber 30, the amount of fluid passing through the fluid exit 33 is much larger than the amount of fluid passing through the fluid entrance 34. Therefore, the conventional micro-pump of FIGS. 3A

and 3B can generate a net flow rate in a direction where the fluid is pumped due to a difference between the flux resistance in the direction where the cross-sectional area of the fluid passages 33 and 34 increases and the flux resistance in the direction where the cross-sectional area of the fluid passages 33 and 34 decreases.

[0010] The above-mentioned conventional micro-pumps generate a net flow rate by taking advantage of the variation of the volume of a pumping chamber caused by vibration of a piezoelectric body. However, because of its complex structure, the piezoelectric body is relatively difficult to manufacture. In addition, in order to increase a pumping flow rate, the area of the piezoelectric body should be increased. However, given the current level of technology, it is very difficult and very expensive to increase the area of the piezoelectric body. A pumping flow rate can be increased by increasing the volume of a pumping chamber. In this case, however, the degree to which an upper film of the pumping chamber is transformed due to vibration of the piezoelectric body should be enlarged, which may result in a high possibility of serious damage to the upper film.

[0011] According to an aspect of the present invention, there is provided a micro-pump. The micro-pump includes a pumping chamber which has a predetermined inner space so that it can be filled with a fluid; at least one fluid entrance and at least one fluid exit which are connected to the pumping chamber; a heating element which is provided at one side of the pumping chamber to generate bubbles in the pumping chamber by heating the fluid; and electrodes which apply current to the heating element. Here, the fluid is made to flow into or flow out of the pumping chamber due to expansion and contraction of the bubbles, and the cross-sectional area of at least one of the fluid entrance and the fluid exit varies along a direction where the fluid flows.

[0012] The present invention provides a micro-pump, which has a relatively simple structure but shows enhanced durability and high pumping efficiency without the need of movable elements by pumping out a fluid supplied into a pumping chamber simply taking advantage of the phase change of the fluid.

[0013] Preferably, the fluid entrance has a decreasing cross-sectional area in a direction toward the pumping chamber, and the fluid exit has an increasing cross-sectional area in a direction toward the pumping chamber.

[0014] Preferably, the fluid entrance and the fluid exit are respectively formed to have an inclination angle of 50° or larger.

[0015] Preferably, the fluid entrance has an increasing cross-sectional area in the direction toward the pumping chamber, and the fluid exit has a decreasing cross-sectional area in the direction toward the pumping chamber.

[0016] Preferably, the fluid entrance and the fluid exit are respectively formed to have an inclination angle of 30° or smaller.

[0017] Preferably, the fluid entrance is provided at one

side of the pumping chamber, and the fluid exit is provided at the other side of the pumping chamber to face the fluid entrance.

[0018] Preferably, the fluid entrance and the fluid exit are pyramid-shaped.

[0019] Preferably, the fluid entrance and the fluid exit are respectively formed to have a regular height but have a varying width in a direction where the fluid flows.

[0020] Preferably, the pumping chamber and the heating element are rectangular-shaped.

[0021] Preferably, the pumping chamber and the heating element are circular-shaped.

[0022] Preferably, the heating element is formed of a resistive heating material.

[0023] Preferably, the pumping chamber, the fluid entrance, and the fluid exit are formed by etching a substrate.

[0024] Preferably, an insulation layer formed on the substrate constitutes an upper wall of the pumping chamber, and the heating element and the electrodes are formed on the insulation layer.

[0025] Preferably, a passivation layer having insulation characteristics is formed on the heating element and the electrode.

[0026] Preferably, a heat dissipation layer is formed on the passivation layer for dissipating heat around the heating element and other elements, and the heat dissipation layer is connected to the substrate.

[0027] Preferably, the heat dissipation layer is formed of a metal.

[0028] The above and other features and advantages of the present invention will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

FIGS. 1A and 1B are cross-sectional views illustrating fluid supply mode and fluid pumping mode, respectively, of a conventional micro-pump;

FIG. 2 is a cross-sectional view of another conventional micro-pump;

FIGS. 3A and 3B are cross-sectional views illustrating fluid supply mode and fluid pumping mode, respectively, of still another conventional micro-pump;

FIG. 4A is a plan view of a micro-pump according to a first embodiment of the present invention;

FIG. 4B is a cross-sectional view of the micro-pump according to the first embodiment of the present invention taken along line A - A' of FIG. 4A;

FIG. 4C is a cross-sectional view of the micro-pump according to the first embodiment of the present invention taken along line B - B' of FIG. 4A;

FIGS. 5A and 5B are cross-sectional views illustrating fluid pumping mode and fluid supply mode of the micro-pump according to the first embodiment of the present invention;

FIG. 6A is a plan view of a micro-pump according to a second embodiment of the present invention;

FIG. 6B is a cross-sectional view of the micro-pump according to the second embodiment of the present invention taken along line C - C' of FIG. 6A; FIGS. 7A and 7B are cross-sectional views illustrating fluid pumping mode and fluid supply mode, respectively, of the micro-pump according to the second embodiment of the present invention; and FIGS. 8A through 8C are graphs illustrating the characteristics of a micro-pump according to a preferred embodiment of the present invention.

[0029] Hereinafter, micro-pumps according to preferred embodiments of the present invention will be described in greater detail with reference to the accompanying drawings. In the drawings, the same reference numerals represent the same elements.

[0030] FIG. 4A is a plan view of a micro-pump according to a first embodiment of the present invention, FIG. 4B is a cross-sectional view of the micro-pump according to the first embodiment of the present invention taken along line A - A' of FIG. 4A, and FIG. 4C is a cross-sectional view of the micro-pump according to the first embodiment of the present invention taken along line B - B' of FIG. 4A. Referring to FIGS. 4A through 4C, a micro-pump according to a first embodiment of the present invention includes a pumping chamber 112 which has a predetermined inner space so that it can be filled with a fluid, a fluid entrance 113 and a fluid exit 114 which are connected to the pumping chamber 112, a heating element 130 which is provided at one side of the pumping chamber 112, and electrodes 151 and 152 which apply current to the heating element 130.

[0031] As shown in FIG. 4A, the pumping chamber 112 has a rectangular shape, and the predetermined inner space of the pumping chamber 112 has a rectangular hexahedral shape. In the pumping chamber 112, a driving force is applied to a fluid supplied therinto via the fluid entrance 113 so that the fluid can be discharged through the fluid exit 114.

[0032] The fluid entrance 113, which is provided between an inlet manifold 115 and the pumping chamber 112, supplies a fluid in the inlet manifold 115 into the pumping chamber 112. The fluid exit 114, which is provided between an outlet manifold 116 and the pumping chamber 112, discharges a fluid from the pumping chamber 112 to the outlet manifold 116. As shown in FIGS. 4A through 4C, there can be one fluid entrance 113 and one fluid exit 114 provided to the micro-pump. Alternatively, in order to increase a flow rate, a plurality of fluid entrances and a plurality of fluid exits may possibly be provided to the micro-pump. The fluid entrance 113 is provided at one side of the pumping chamber 112, and the fluid exit 114 is provided at the other side of the pumping chamber so that it can face the fluid entrance 113. The fluid entrance 113 and the fluid exit 114 may possibly be differently arranged. For example, the fluid entrance 113 and the fluid exit 114 may be arranged together at one side of the pumping chamber 112 or under

the pumping chamber 112.

[0033] The fluid entrance 113 has a decreasing cross-sectional area in a direction toward the pumping chamber 112, while the fluid exit 114 has an increasing cross-sectional area in a direction toward the pumping chamber 112. In addition, the fluid entrance 113 and the fluid exit 114 preferably have an inclination angle of 50° or larger, for example, an inclination angle of about 50 ~ 70°. Then, flux resistance affecting a fluid passing through the flow entrance 113 and the flow exit 114 varies depending on the flow direction of the fluid. More specifically, flux resistance in a direction where the cross-sectional area of the fluid entrance 113 and the fluid exit 114 decreases is smaller than flux resistance in a direction where the cross-sectional area of the fluid entrance 113 and the flow exit 114 increases. Due to a difference between the flux resistance in the direction where the cross-sectional area of the fluid entrance 113 and the fluid exit 114 decreases and the flux resistance in the direction where the cross-sectional area of the fluid entrance 113 and the flow exit 114 increases, a net flow rate can be generated in a direction where the fluid is pumped without the need of check valves, which will be described more fully later.

[0034] In order to satisfy the above-mentioned requirements, the fluid entrance 113 and the fluid exit 114 may have a pyramid shape, as shown in FIGS. 4A and 4B, so that their cross-sectional area decreases along the direction where the fluid is pumped. Alternatively, each of the fluid entrance 113 and the fluid exit 114 may have a uniform height but a decreasing width along the direction where the fluid is pumped. Alternatively, the fluid entrance 113 and the fluid exit 114 may have a different shape, for example, with a polygonal or circular cross-section, as long as they meet the above-mentioned requirements.

[0035] Both the fluid entrance 113 and the fluid exit 114 have been described so far as having a varying cross-sectional area along a certain direction. However, a net flow rate still can be achieved by forming one of the fluid entrance 113 and the fluid exit 114 to have a varying cross-sectional area along a certain direction.

[0036] The pumping chamber 112, the fluid entrance 113, the fluid exit 114, and the inlet and outlet manifolds 115 and 116 may be formed by micro-machining a substrate 110 in a variety of ways. Preferably, the pumping chamber 112, the fluid entrance 113, the fluid exit 114, and the inlet and outlet manifolds 115 and 116 may be formed by etching the surface of the substrate 110 to a predetermined depth, in which case the fluid entrance 113 and the fluid exit 114 may be formed on the substrate 110 to a predetermined depth so that they can be connected to an upper portion of the pumping chamber 112.

[0037] An insulation layer 120 is formed on the substrate 110 so that it can form an upper wall of the pumping chamber 112, and the heating element 130 is formed on the insulation layer 120. The heating element 130

generates bubbles in the pumping chamber 112 by heating the fluid in the pumping chamber 112.

Expansions and contractions of the bubbles cause the fluid to flow. The heating element 130 may be formed of a resistive heating element, such as an alloy of tantalum and aluminium or tantalum nitride. As shown in FIG. 4A, the heating element 130, like the pumping chamber 112, preferably has a rectangular shape. The heating element 130, however, may have a different shape.

[0038] A first passivation layer 140, which has insulation characteristics, is formed on the heating element 130 and the insulation layer 120, and the electrodes 151 and 152 are formed on the first passivation layer 140. The electrodes 151 and 152 are connected to the heating element 130 at either side of the heating element 130 through a contact hole C_1 formed in the first passivation layer 140.

[0039] A second passivation layer 160, which has insulation characteristics, is formed on the first passivation layer 140 and the electrodes 151 and 152, and a heat dissipation layer 170 may be formed on the second passivation layer 160. The heat dissipation layer 170 is connected to the substrate 110 through a second contact hole C_2 , which is formed through the first and second passivation layers 140 and 160 and the insulation layer 120. The heat dissipation layer 170 is provided for dissipating heat of the heating element 130 or other elements near the heating element 130 to the substrate 110 or to the outside. The heat dissipation layer 170 may be formed of a metal having superior heat conductivity.

[0040] Hereinafter, a process of pumping a fluid in the micro-pump according to the first embodiment of the present invention will be described in greater detail with reference to FIGS. 5A and 5B. FIGS. 5A and 5B are cross-sectional views illustrating fluid pumping mode and fluid supply mode, respectively, of the micro-pump according to the first embodiment of the present invention.

[0041] Referring to FIG. 5A, the pumping chamber 112 is filled with a fluid 180. When a pulse-type current signal is applied to the heating element 130 via the electrodes 151 and 152, the heating element 130 generates heat to heat the fluid 180 in the pumping chamber 112 via the insulation layer 120. When it is heated to a predetermined temperature or higher, the fluid 180 boils, and accordingly, a bubble 190 is generated. Since the bubble 190 is in a gas phase with high pressure, it expands pushing out nearby fluid 180. Due to the expansion of the bubble 190, the fluid 180 in the pumping chamber 112 is discharged to the outlet manifold 116 through the fluid exit 114, during which the current signal applied to the heating element 130 is removed. The expansion of the bubble 190 also generates a flow rate in the opposite direction by causing the fluid 180 to flow to the inlet manifold 115 through the fluid entrance 113. Since flux resistance in a direction where the cross-sectional area of the fluid entrance 113 and the fluid exit 114 decreases is smaller than flux resistance in a direction

where the cross-sectional area of the fluid entrance 113 and the fluid exit 114 increases, the amount of fluid discharged through the fluid exit 114 is much larger than the amount of fluid discharged through the fluid entrance 113.

[0042] Referring to FIG. 5B, the bubble 190 contracts and disappears after expanding to its maximum size. Then, pressure affects the pumping chamber 112 in a direction from the outside of the pumping chamber 112 to the inside of the pumping chamber 112. Accordingly, the fluid flows into the pumping chamber 112 through both the fluid entrance 113 and the fluid exit 114. In this case, flux resistance at the fluid entrance 113 is smaller than flux resistance at the fluid exit 114. Thus, the amount of fluid flowing into the pumping chamber 112 through the fluid entrance 113 is much larger than the amount of fluid flowing into the pumping chamber 112 through the fluid exit 114. During this process, heat generated by the heating element 130 to generate the bubble 190 is dissipated to the substrate 110 and to the outside via the heat dissipation layer 170. Due to the existence of the heat dissipation layer 170, heat can be more quickly dissipated. Thus, a cycle of expansion and contraction that the bubble 190 undergoes becomes shorter, and the driving frequency of the micro-pump can be increased.

[0043] As described above, when the bubble 190 expands, the amount of fluid 180 discharged from the pumping chamber 112 through the fluid exit 114 is much larger than the amount of fluid 180 discharged from the pumping chamber 112 through the fluid entrance 113. On the other hand, when the bubble 190 contracts, the amount of fluid 180 flowing into the pumping chamber 112 through the fluid entrance 113 is much larger than the amount of fluid 180 flowing into the pumping chamber 112 through the fluid exit 114. Therefore, if the bubble 190 repeatedly undergoes a cycle of expansion and contraction with a predetermined frequency, a net flow rate in a direction from the fluid entrance 113 to the pumping chamber 112 to the fluid exit 114 can be generated, and desired pumping effects can be achieved.

[0044] In the micro-pump according to the first embodiment of the present invention, the heating element 130 provides a driving force for pumping the fluid 180, and the fluid entrance 113 and exit 114 serve as dynamic passive valves. Thus, there is no need to additionally provide movable elements, such as a piezoelectric body or check valves, to the micro-pump. Therefore, it is possible to realize a micro-pump having a relatively simple structure and improved durability. In addition, it is possible to increase a pumping flow rate by increasing the area or caloric value of the heating element 130 provided at one side of the pumping chamber 112.

[0045] FIG. 6A is a plan view of a micro-pump according to a second embodiment of the present invention, and FIG. 6B is a cross-sectional view of the micro-pump according to the second embodiment of the present invention taken along line C - C' of FIG. 6A. In FIG. 6A,

only features of the present invention that are different from their counterparts in the first embodiment of the present invention are illustrated for the convenience of drawing. In addition, the second embodiment of the present invention is the same as the first embodiment of the present invention except the shape of a pumping chamber 212, a heating element 230, and fluid passages 213 and 214. Thus, only differences between the first and second embodiments of the invention will be described in the following paragraphs.

[0046] Referring to FIGS. 6A and 6B, a micro-pump according to a second embodiment of the present invention includes the pumping chamber 212 which is a circular shape. An inner space of the pumping chamber 212 may have a hemispheric or cylindrical shape. Accordingly, the heating element 230 preferably has a circular shape, as shown in FIG. 6A. The fluid passages 213 and 214, i.e., a fluid entrance 213 and a fluid exit 214, are formed extending very long. Thus, it is hard to form the fluid passages 213 and 214 to have a relatively large inclination angle. Therefore, in the present embodiment, unlike in the previous embodiment, the fluid entrance 213 has an increasing cross-sectional area in a direction toward the pumping chamber 212, while the fluid exit 214 has a decreasing cross-sectional area in a direction toward the pumping chamber 212. The fluid entrance 213 and the fluid exit 214 are preferably formed to have a relatively small inclination angle of about $15 \sim 30^\circ$. Due to the existence of the fluid passages 213 and 214, flux resistance in a direction where the cross-sectional area of the fluid passages 213 and 214 gradually increases is smaller than flux resistance in a direction where the cross-sectional area of the fluid passages 213 and 214 gradually decreases, which will be described more fully later.

[0047] The fluid passages 213 and 214 may have different shapes as long as they meet the above-mentioned requirements. In the present embodiment, like in the previous embodiment, it is possible to form only one of the fluid passages 213 and 214 to have a gradually decreasing or gradually increasing cross-sectional area.

[0048] Preferably, the pumping chamber 212, the fluid entrance 213, the fluid exit 214, and the inlet and outlet manifolds 215 and 216 may be formed by etching the surface of the substrate 210 to a predetermined depth, in which case the fluid passages 213 and 214 are preferably formed to have a uniform height but an increasing width in a direction along which a fluid is pumped.

[0049] An insulation layer 220, a heating element 230, a first passivation layer 240, electrodes 251 and 252, a second passivation layer 260, and a heat dissipation layer 270 formed on the substrate 210 are the same as their counterparts in the first embodiment, and thus their description will not be repeated.

[0050] Hereinafter, the operation of the micro-pump according to the present invention will be described in greater detail with reference to FIGS. 7A and 7B. FIG.

7A illustrates fluid pumping mode, and FIG. 7B illustrates fluid supply mode.

[0051] Referring to FIG. 7A, a pulse-type current signal is applied to the heating element 230 via the electrodes 251 and 252. Then, heat is generated by the heating element 230. The heat heats a fluid 280 inside the pumping chamber 212 so that a bubble 290 is generated. Due to expansion of the bubble 290, the fluid 280 in the pumping chamber 212 is discharged from the pumping chamber 212 to the outlet manifold 216 through the fluid exit 214, during which the pulse-type current signal applied to the heating element 230 is removed. As the bubble 290 expands bigger, a flow rate of the fluid 280 is generated in a direction toward the inlet manifold 215 via the fluid entrance 213. In this case, since flux resistance in a direction where the cross-sectional area of the fluid passages 213 and 214 increases is smaller than flux resistance in a direction where the cross-sectional area of the fluid passages 213 and 214 decreases, the amount of fluid 280 discharged from the pumping chamber 212 through the fluid exit 214 is much larger than the amount of fluid 280 discharged from the pumping chamber 212 through the fluid entrance 213.

[0052] Referring to FIG. 7B, when the bubble 280 keeps contracting and finally disappears, pressure affects the pumping chamber 212 in an inward direction from the outside of the pumping chamber 212 to the inside of the pumping chamber 212 so that the fluid 280 flows into the pumping chamber 212 through both the fluid entrance 213 and the fluid exit 214. In this case, flux resistance at the fluid entrance 213 is smaller than flux resistance at the fluid exit 214. Thus, the amount of fluid 280 flowing into the pumping chamber 212 through the fluid entrance 213 is much larger than the amount of fluid 280 flowing into the pumping chamber 212 through the entrance exit 214. During the fluid 280 flows into the pumping chamber 212, heat around the heating element 230 and other elements is dissipated to the substrate 210 or the outside through the heat dissipation layer 270.

[0053] As described above, the micro-pump according to the second embodiment of the present invention provides almost the same pumping effect as the micro-pump according to the first embodiment of the present invention does. In addition, since the micro-pump according to the second embodiment of the present invention does not need a movable element, it is possible to manufacture a micro-pump having a relatively simple structure and enhanced durability, and it is also possible to easily enhance pumping flow rate.

[0054] FIGS. 8A through 8C are graphs illustrating the characteristics of a micro-pump according to a preferred embodiment of the present invention. More specifically, FIG. 8A is a graph illustrating the variation of the amount of fluid passing through a fluid exit in accordance with the passage of time, FIG. 8B is a graph illustrating the variation of the amount of fluid passing through a fluid entrance in accordance with the passage of time, and

FIG. 8C is a graph illustrating the variation of a net flow rate in accordance with the passage of time.

[0055] In experiments whose results are shown in FIGS. 8A through 8C, the fluid entrance and the fluid exit, which are all circular-shaped having an average diameter of $28\text{ }\mu\text{m}$ and a length of $30\text{ }\mu\text{m}$ and whose cross-sectional area decreases in a direction where a fluid is pumped, were used. In addition, in those experiments, the variation of the amount of fluid passing through the fluid entrance or the fluid exit in accordance with the passage of time (s) was measured while carrying out a 20 kHz pumping process for six cycles, i.e., for about 300 μs . In FIGS. 8A through 8C, a positive amount of fluid passing through the fluid entrance or the fluid exit represents the volume of fluid flowing out of a pumping chamber into a manifold, and a negative amount of fluid passing through the fluid entrance or the fluid exit represents the volume of fluid flowing into the pumping chamber from the manifold. In FIGS. 8A through 8C, $1 \times 10^{-14}\text{m}^3$ is equal to 10 pL .

[0056] Referring to FIGS. 8A and 8B, the time when a fluid passes through the fluid entrance matches with the time when the fluid passes through the fluid exit with cycles of bubbles' appearance and then disappearance. However, the amount of the fluid passing through the fluid entrance is different from the amount of the fluid passing through the fluid exit. Here, the sum of the amount of the fluid passing through the fluid entrance and the amount of the fluid passing through the fluid exit is the amount of the fluid flowing into or flowing out of the pumping chamber through the fluid entrance or the fluid exit. Due to the structure of the fluid entrance or the fluid exit whose cross-sectional area varies in a direction where the fluid is pumped, a net flow rate exists along a direction from the fluid entrance to the fluid exit, which is illustrated in FIG. 8C. As shown in FIG. 8C, as much fluid as about 8 pL moves from the fluid entrance to the fluid exit per each cycle. This amount of fluid pumped per each cycle can be increased by adjusting the shape and inclination angle of the fluid entrance and/or the fluid exit. In addition, pumping effects can be maximized by increasing driving frequency.

[0057] As described above, the micro-pump according to the present invention can pump a fluid in accordance with the phase change of the fluid flowing into a pumping chamber. Thus, the micro-pump according to the present invention does not need a movable element. Therefore, according to the present invention, it is possible to realize a micro-pump having a relatively simple structure and enhanced durability. In addition, it is possible to easily enhance pumping efficiency by increasing the area of a heating element provided at one side of the pumping chamber or by increasing the caloric power of the heating element.

[0058] While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and

details may be made therein without departing from the scope of the present invention as defined by the following claims.

Claims

1. A micro-pump comprising:

a pumping chamber which has a predetermined inner space so that it can be filled with a fluid;
at least one fluid entrance and at least one fluid exit which are connected to the pumping chamber;
a heating element which is provided at one side of the pumping chamber to generate bubbles in the pumping chamber by heating the fluid; and
electrodes which apply current to the heating element,

wherein the cross-sectional area of at least one of the fluid entrance and the fluid exit varies along a direction where the fluid flows, the fluid being made to flow into or flow out of the pumping chamber due to expansion and contraction of the bubbles.

2. The micro-pump of claim 1, wherein the fluid entrance has a decreasing cross-sectional area in a direction toward the pumping chamber, and the fluid exit has an increasing cross-sectional area in a direction toward the pumping chamber.

3. The micro-pump of claim 2, wherein the fluid entrance and the fluid exit are respectively formed to have an inclination angle of 50° or larger.

4. The micro-pump of claim 1, 2 or 3, wherein the fluid entrance has an increasing cross-sectional area in the direction toward the pumping chamber, and the fluid exit has a decreasing cross-sectional area in the direction toward the pumping chamber.

5. The micro-pump of claim 4, wherein the fluid entrance and the fluid exit are respectively formed to have an inclination angle of 30° or smaller.

6. The micro-pump of any preceding claim, wherein the fluid entrance is provided at one side of the pumping chamber, and the fluid exit is provided at the other side of the pumping chamber to face the fluid entrance.

7. The micro-pump of any preceding claim, wherein the fluid entrance and the fluid exit are pyramid-shaped.

8. The micro-pump of any of claims 1 to 6, wherein the fluid entrance and the fluid exit are respectively formed to have a regular height but have a varying width in a direction where the fluid flows. 5
9. The micro-pump of any preceding claim, wherein the pumping chamber and the heating element are rectangular-shaped.
10. The micro-pump of any of claims 1 to 8, wherein the pumping chamber and the heating element are circular-shaped. 10
11. The micro-pump of any preceding claim, wherein the heating element is formed of a resistive heating material. 15
12. The micro-pump of any preceding claim, wherein the pumping chamber, the fluid entrance, and the fluid exit are formed by etching a substrate. 20
13. The micro-pump of claim 12, wherein an insulation layer formed on the substrate constitutes an upper wall of the pumping chamber, and the heating element and the electrodes are formed on the insulation layer. 25
14. The micro-pump of claim 13, wherein a passivation layer having insulation characteristics is formed on the heating element and the electrode. 30
15. The micro-pump of claim 14, wherein a heat dissipation layer is formed on the passivation layer for dissipating heat around the heating element and other elements, and the heat dissipation layer is connected to the substrate. 35
16. The micro-pump of claim 15, wherein the heat dissipation layer is formed of a metal. 40
17. Use of a micro-pump according to any preceding claim including generating bubbles in the pumping chamber by heating the fluid and causing fluid to flow in the direction from the fluid entrance to the fluid exit by means of the expansion and contraction of the bubbles. 45

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FIG. 1A (PRIOR ART)

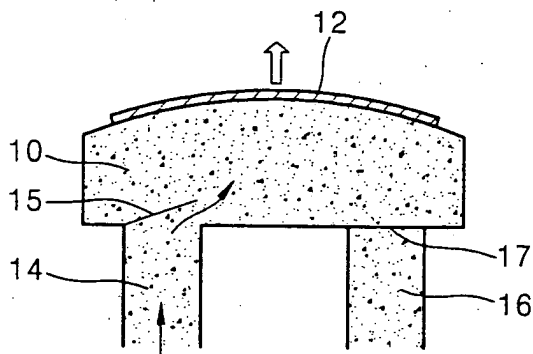


FIG. 1B (PRIOR ART)

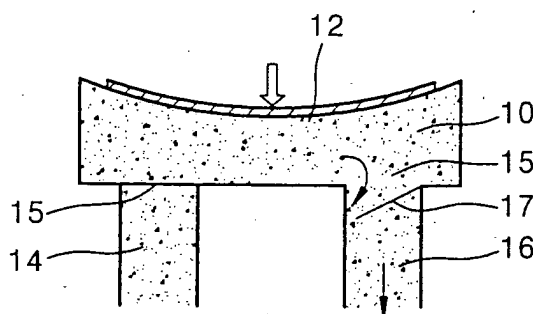


FIG. 2 (PRIOR ART)

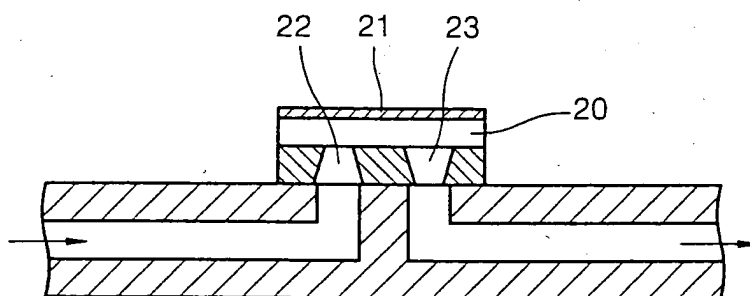


FIG. 3A (PRIOR ART)

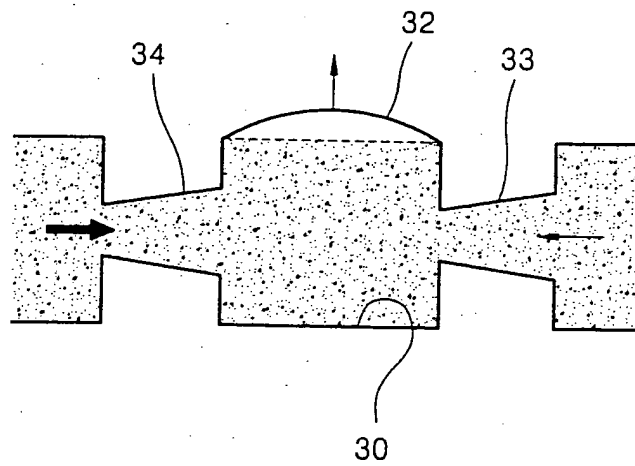


FIG. 3B (PRIOR ART)

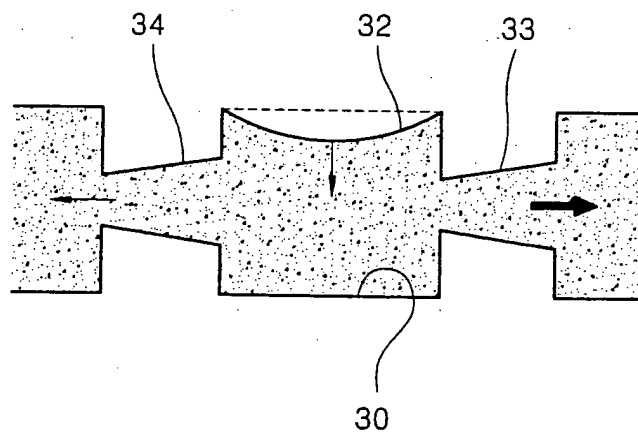


FIG. 4A

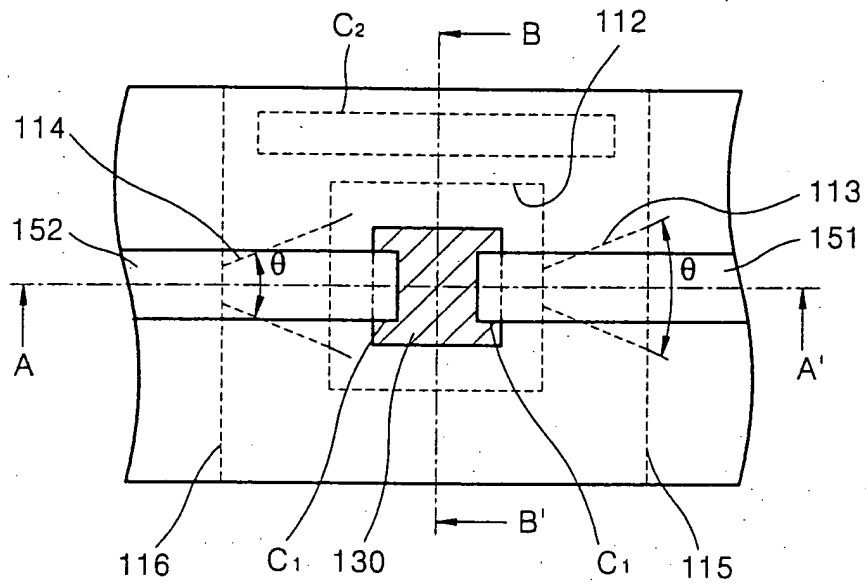


FIG. 4B

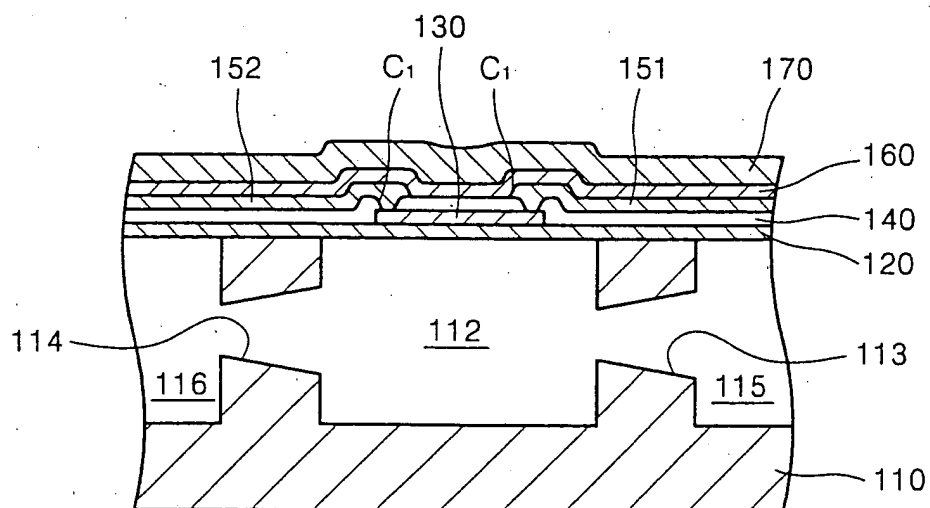


FIG. 4C

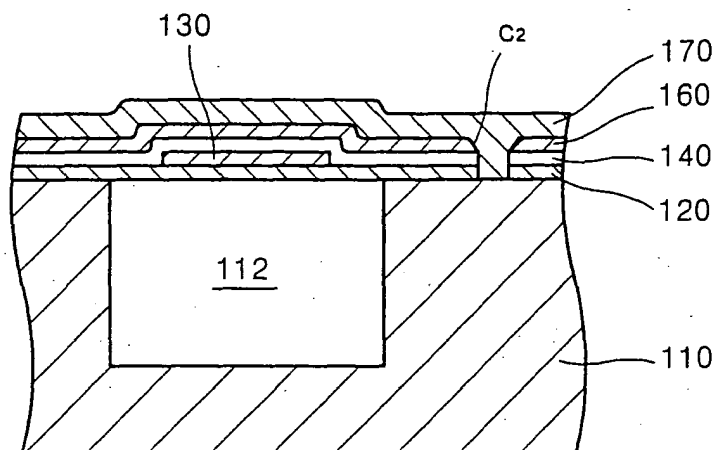


FIG. 5A

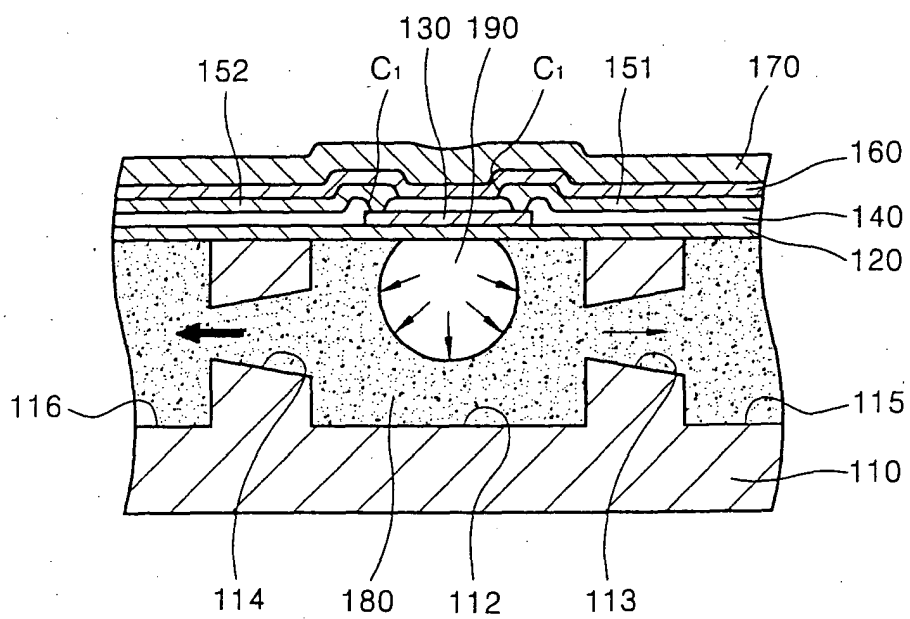


FIG. 5B

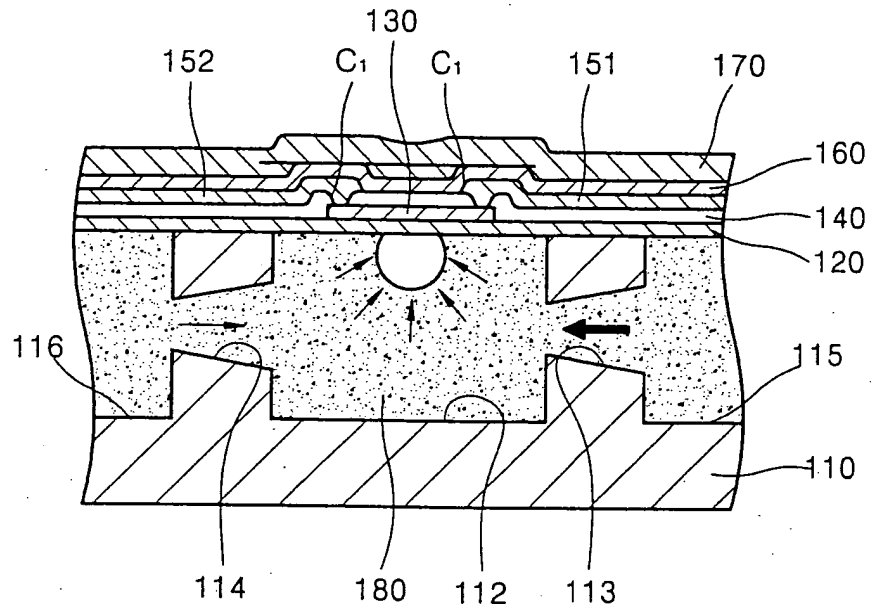


FIG. 6A

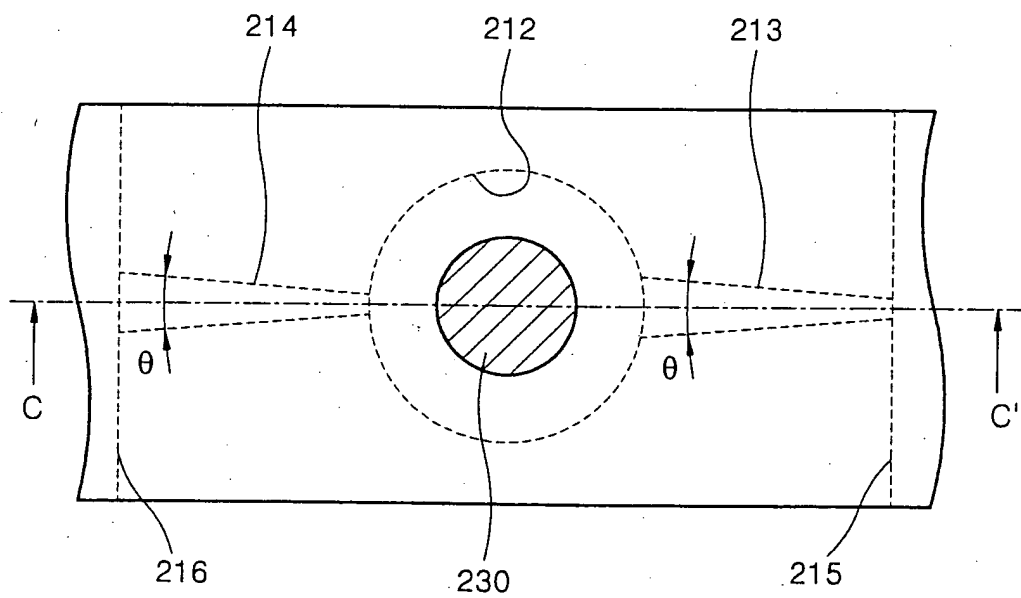


FIG. 6B

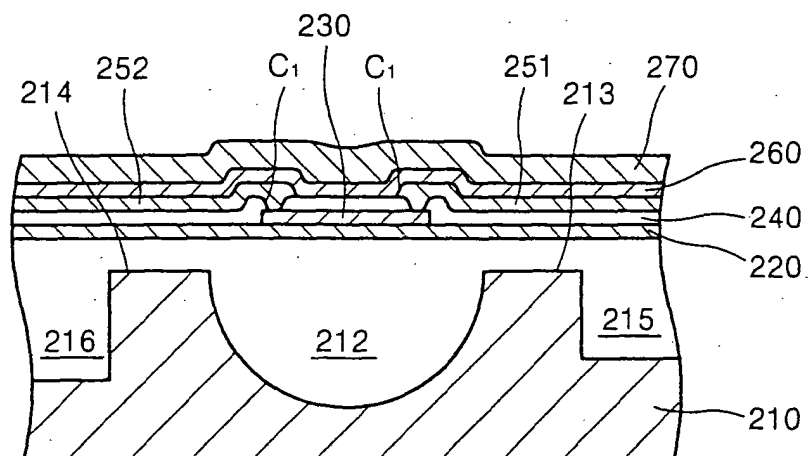


FIG. 7A

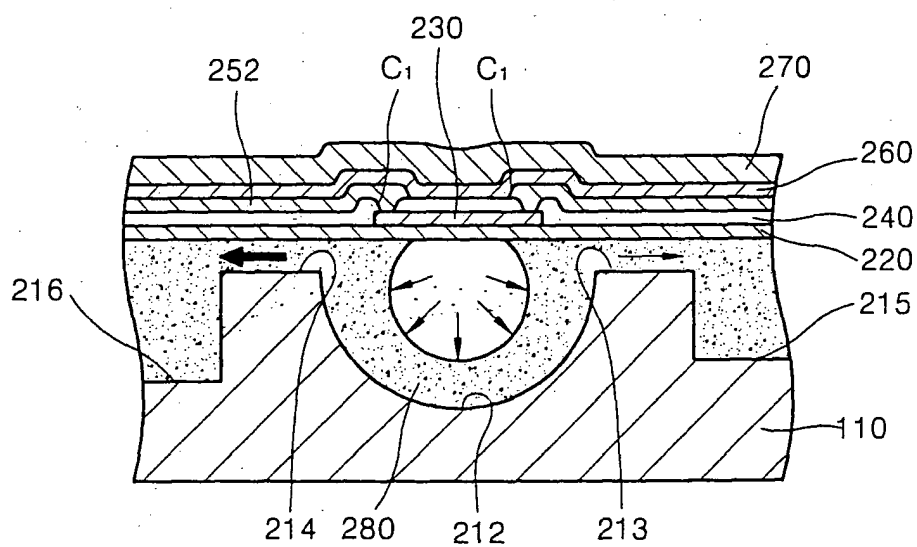


FIG. 7B

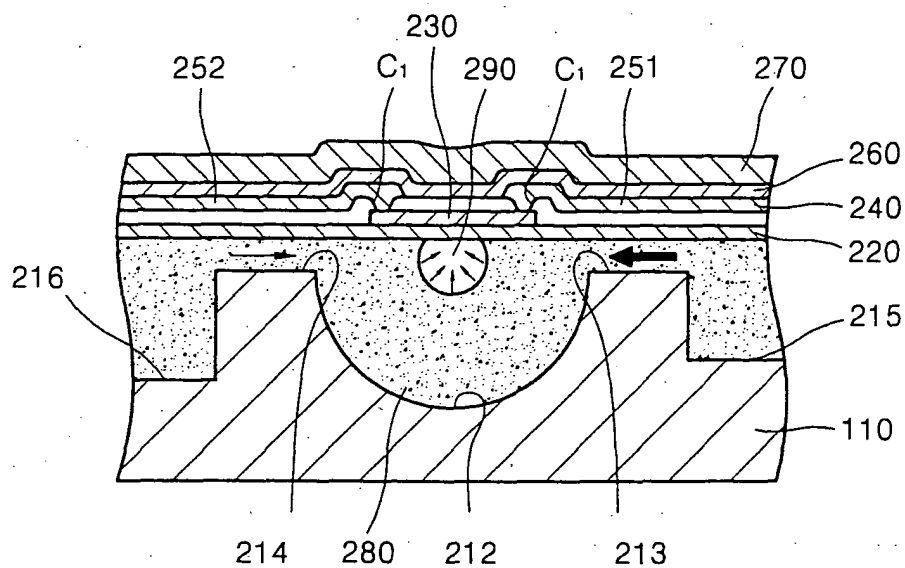


FIG. 8A

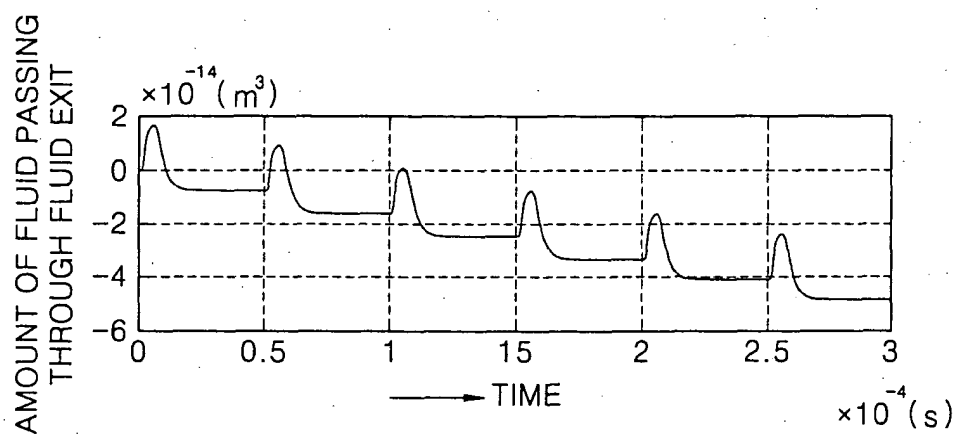


FIG. 8B

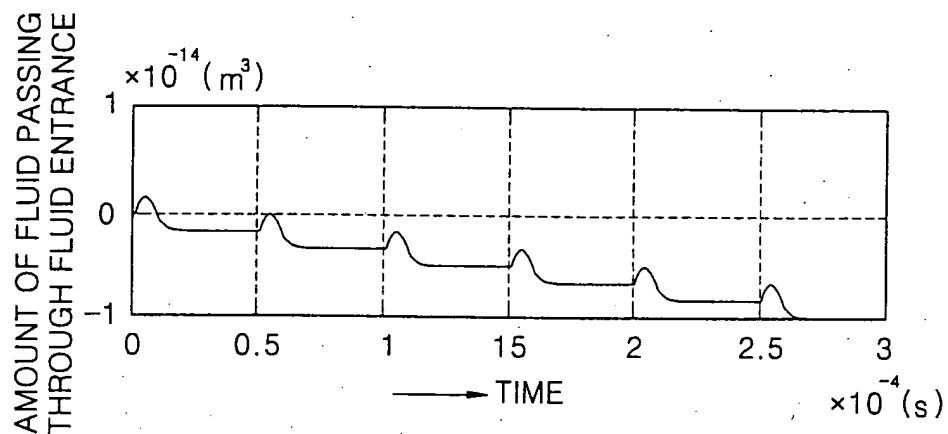
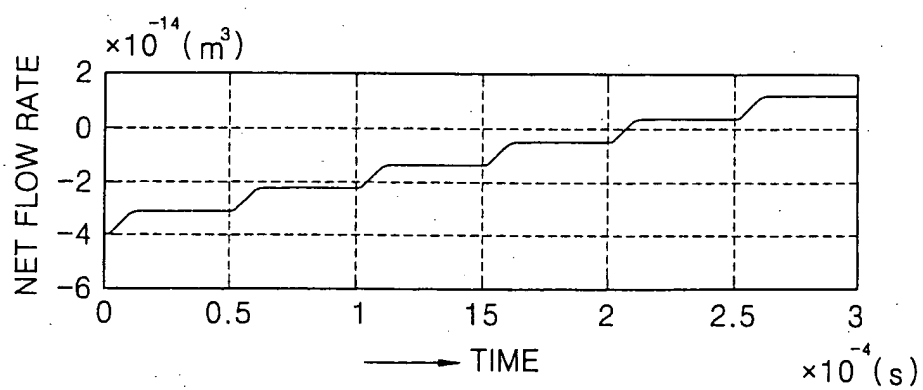


FIG. 8C





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