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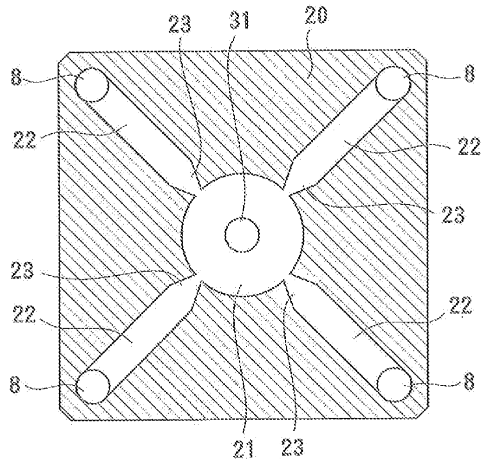
(54) **PIEZOELECTRIC MICROBLOWER**

(57) The object is to provide a piezoelectric micro blower that makes it possible to transport a compressible fluid efficiently without using a check valve and to achieve an increase in the rate of flow.

A blower body 1 includes a first wall 30 and a second wall 10. An opening 31 is formed at a part of the first wall 30 that faces an area of the center of the driver 50. An opening 11 is formed at a part of the second wall 10 that corresponds thereto. A center space 21 that is in communication with the openings 31 and 11 is formed between these walls. Besides the center space 21, inlet passages 22 through which the center space 21 is in communication with the outside are formed between these walls. Bottleneck portions 23 are formed at regions where the inlet passages 22 are connected to the center space 21. A driver 50 vibrates when a voltage is applied to a piezoelectric element 52. The wall 30 vibrates in a sympathetic manner as the driver 50 vibrates. As a result, a large pressure wave is generated from the first opening 31 in an upward direction. Air is forced out of the center space 21 through the second opening 11 to the outside due to the pressure wave. The bottleneck portions 23 reduce pressure energy loss, thereby increasing the rate of flow.

FIG. 4



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Description

Technical Field

[0001] The present invention relates to a piezoelectric micro blower that is suited for transporting a compressible fluid such as air.

Background Art

[0002] A piezoelectric micro pump is used for, for example, a pump for transporting water for cooling a small-sized electronic device such as a notebook computer and a pump for transporting fuel in a fuel cell. On the other hand, a piezoelectric micro blower can be used as a blower that takes the place of a fan for cooling a CPU or the like or as a blower for supplying oxygen that is required for electric power generation in a fuel cell. A piezoelectric micro pump / piezoelectric micro blower is a device that includes a diaphragm that becomes deformed due to flexion when a voltage is applied to a piezoelectric element. The piezoelectric micro pump / piezoelectric micro blower has advantages of a simple structure, a low-profile body, and low power consumption.

[0003] When an incompressible fluid such as liquid is transported, it is common to provide check valves each of which is made of a soft material such as rubber or resin at an inlet port and an outlet port. In addition, it is common to drive a piezoelectric element at a low frequency such as tens of hertz or so. Though the maximum displacement can be obtained when a piezoelectric element is driven approximately at the resonance frequency of a diaphragm (a first-order resonance frequency or a third-order resonance frequency), a check valve fails to operate in response thereto because the resonance frequency has a high frequency in kHz order. Therefore, it is preferable to use a piezoelectric micro blower that does not include any check valve for transporting a compressible fluid.

[0004] A flow generation device is disclosed in a patent Document 1. The flow generation device disclosed therein includes a substrate that has a pressurizing chamber that is filled with a fluid, a nozzle plate that has nozzles that look out on the pressurizing chamber, an opening, and an electric vibrator that is attached to the nozzle plate in such a manner that the nozzles are located approximately at the center of the opening. The nozzle plate and the electric vibrator are attached to the substrate. An alternating current signal that has a frequency that is close to the resonance frequency of the electric vibrator is supplied to the electric vibrator. When such a structure is adopted, a check valve can be omitted. In addition, it is possible to increase the rate of flow by driving the vibrator at a high frequency. In a structure illustrated in Fig. 5 of the patent Document 1, an air chamber into which air flows is provided in front of the nozzle plate. A fluid that is ejected through the nozzles entrains ambient air in the air chamber. The fluid is discharged through an exit port together with the entrained ambient air. However, since the open area of the air chamber is large, the pressure energy of the fluid that is ejected through the nozzles is dissipated into the periphery of the air chamber. For this reason, the structure disclosed therein has a disadvantage in that it is difficult to increase the rate of flow through the exit port.

[0005] A micro blower that includes an ejection unit that sucks air from the outside and ejects the air, a cover that has an exit port for discharging the air ejected from the ejection unit, and a base unit that is connected to the ejection unit is disclosed in a patent Document 2. The following structure is disclosed in Fig. 4 of the patent Document 2. The structure includes an ejection plate that has a suction hole and an ejection hole. A vibration plate that is provided with a magnetic sheet is attached to the back of the ejection plate. A pressurizing chamber is formed between the ejection plate and the vibration plate. A coil is used to vibrate the magnetic sheet. Ejection airflow is generated from a cavity as a result of the vibration of the magnetic sheet. The airflow entrains air in a cover cavity that is located in front of the ejection plate. The fluid ejected is discharged through the exit port together with the entrained air. Since the open area of the cover cavity is larger than that of the pressurizing chamber, the pressure energy of the fluid that is ejected through the ejection hole is dissipated into the cover cavity. For this reason, the structure disclosed therein has the same disadvantage as that of the structure disclosed in the patent Document 1, that is, it is difficult to increase the rate of flow through the exit port.

Patent Document 1: Japanese Examined Patent Application Publication No. S64-2793
Patent Document 2: Japanese Unexamined Patent Application Publication No. 2005-113918

Disclosure of the Invention

Problems to be Solved by the Invention

[0006] An object of the invention is to provide a piezoelectric micro blower that makes it possible to transport a compressible fluid efficiently without using a check valve and to achieve an increase in the rate of flow.

Means for Solving the Problems

[0007] To achieve the above object, the present invention provides a piezoelectric micro blower including a blower body, a driver that has a peripheral part that is fixed to the blower body and further has a piezoelectric element, and a blower chamber that is formed between the blower body and the driver, a voltage being applied to the piezoelectric element to cause the driver to vibrate due to flexion for transporting a compressible fluid. The piezoelectric micro blower includes: a first wall of the blower body, the blower chamber being formed between the driver and the first wall; a first opening that is formed through the first wall, the inside of the blower chamber being in communication with the outside of the blower chamber through the first opening; a second wall that is provided at a side opposite the blower chamber with the first wall being provided between the second wall and the blower chamber, the second wall being provided at a distance from the first wall; a second opening that is formed through the second wall; a center space that is formed between the first wall and the second wall, has an open area that is larger than the first opening and the second opening but smaller than the blower chamber, and is in communication with the first opening and the second opening; and an inlet passage that has an outer end that is in communication with the outside of the piezoelectric micro blower and an inner end that is connected to the center space, wherein a bottleneck portion that has a passage area that is smaller than that of the inlet passage is formed in the inlet passage.

[0008] When a voltage is applied to the piezoelectric element to cause the driver to vibrate due to flexion, a fluid flows at high speed from the first opening to the second opening as the driver becomes displaced. By this means, it is possible to suck a fluid from the inlet passage into the center space. That is, it is possible to suck a fluid from the inlet passage into the center space not only when the driver becomes displaced to form a convex that is oriented downward but also when the driver becomes displaced to form a convex that is oriented upward. The fluid sucked from the inlet passage and the fluid pressed out of the blower chamber flow into each other. The confluent fluids are discharged together through the second opening. Therefore, it is possible to obtain a discharging flow, the quantity of which is larger than the displacement volume of the driver. The inlet passage is connected to the center space between the first opening and the second opening. Since the inlet passage is not directly connected to the blower chamber, the inlet passage is less susceptible to a pressure change in the blower chamber. Even though a check valve is not provided, a fluid that flows at high speed from the first opening to the second opening does not flow backward into the inlet passage. Thus, it is possible to increase the rate of flow effectively. The open area of the center space is larger than the first opening and the second opening but smaller than the blower chamber. The fluid entering from the inlet passage accumulates in the center space temporarily. Entrained by the flow of a fluid that is blown out through the first opening, the fluid that has accumulated in the center space is discharged through the second opening together with the fluid blown out through the first opening.

[0009] When the driver vibrates up and down due to bending as described above, a fluid is sucked from the inlet passage into the center space by utilizing the pressure energy of a fluid pressed out of the blower chamber. The fluid sucked from the inlet passage and the fluid pressed out of the blower chamber flow into each other to be discharged through the second opening. If the inlet passage were directly connected to the center space, the pressure energy of the fluid in the center space would be dissipated into the inlet passage. To avoid such pressure energy dissipation, in the present invention, a bottleneck portion that has a passage area that is smaller than that of the inlet passage is formed in the inlet passage. Since the bottleneck portion is formed in the inlet passage, it is harder for pressure energy that is present inside the center space to be dissipated into the inlet passage. By this means, it is possible to direct the pressure energy toward the second opening efficiently, thereby achieving an increase in the rate of flow of a fluid discharged through the second opening.

[0010] Preferably, the first opening should be formed at a part of the first wall that faces an area of the center of the driver. With such a preferred structure, since the first opening is formed at a position where it faces an area of the center of the driver, which is the area where the displacement of the driver is the largest, it is possible to obtain the maximum rate of flow. In addition, preferably, the second opening should be formed at a part of the second wall that faces the first opening. With such a preferred structure, it is possible for a fluid ejected at high speed from the first opening to pass through the center space and be discharged through the second opening with lower resistance.

[0011] Preferably, the bottleneck portion should be formed at a region of connection of the inlet passage and the center space. The bottleneck portion may be formed anywhere in the inlet passage. However, it is preferable to form the bottleneck portion at a position close to the center space because, with such a structure, it is harder for pressure energy that is present inside the center space to be dissipated into the inlet passage. By this means, it is possible to direct the pressure energy toward the second opening efficiently,

[0012] Preferably, the passage area of the bottleneck portion should gradually decrease in a direction of a flow from the inlet passage to the center space. Since average pressure in the center space is lower than that in the inlet passage, there is a pressure gradient therebetween. Though there occurs pressure loss in a flow channel because of friction between a fluid and wall surfaces, if no bottleneck portion was formed therein, vena contracta would be produced in the vicinity of entrances to the center space because the pressure of the center space is lower than the pressure decreased due to the pressure loss. A vortex would form in the vicinity of the vena contracta, resulting in loss. For this reason, the rate of flow would decrease. To reduce such flow loss, the bottleneck portion is provided in the inlet passage. The passage area of the bottleneck portion gradually decreases in a direction of a flow from the inlet passage to the center space. By this means, it is possible to suppress the forming of a vortex of a fluid that flows from the inlet passage into the center space, thereby further reducing the average pressure in the center space. Therefore, the quantity of a fluid sucked into the center space increases, which makes it possible to further increase the rate of flow of a fluid discharged through the second opening.

[0013] Preferably, the inlet passage should include a plurality of passages extending in radial directions from the center space. In addition, preferably, the outer ends of the plural passages of the inlet passage should be respectively in communication with inlet ports. With such a preferred structure, it is possible to ensure that the inlet passage has a sufficiently large passage area, which can advantageously reduce flow channel resistance. Therefore, it is possible to further increase the rate of flow.

[0014] Preferably, the open area of the center space should be designed in such a manner that the part of the first wall that faces the center space vibrates as the driver vibrates. The vibration of the first wall acts to increase the quantity of a fluid that is caused to flow by the driver. Since the quantity thereof increases because of the displacement of the first wall, it is possible to achieve a further increase in the rate of flow. Especially, it is preferable that the part of the first wall that faces the center space should vibrate in a sympathetic manner as the driver vibrates. That is, it is possible to cause the first wall to vibrate in a sympathetic manner in response to or by following the displacement of the driver by making the natural vibration frequency of the part of the first wall that faces the center space close to the vibration frequency of the driver. When the first wall vibrates in a sympathetic manner, it is not always necessary that the first wall and the driver should vibrate in the same resonance mode. For example, both the first wall and the driver may vibrate in the first-order mode or a higher-order mode (e.g., third-order mode). One of the first wall and the driver only may vibrate in the first-order mode. The other may vibrate in a higher-order mode.

[0015] The driver according to the present invention may be, for example, a unimorph-type driver that has a structure in which a piezoelectric element that stretches and shrinks in a planar direction is attached to one surface of a diaphragm (a resin plate or a metal plate), a bimorph-type driver that has a structure in which piezoelectric elements that stretch and shrink in opposite directions are attached respectively to both surfaces of a diaphragm, or a bimorph-type driver that has a structure in which a multilayer piezoelectric element that becomes deformed due to flexion by itself is attached to one surface of a diaphragm. Alternatively, for example, the entire body of the driver may be configured as a multilayer piezoelectric element. The shape of the piezoelectric element may be a disc, a rectangle, or a ring. An intermediate plate may be sandwiched between the piezoelectric element and the diaphragm. The structure may be modified in various ways as long as the driver vibrates in the direction of its thickness due to flexion when an alternating voltage (which is either a sinusoidal-wave voltage or a rectangular-wave voltage) is applied to the piezoelectric element.

[0016] It is preferable to drive the driver including the piezoelectric element in a first-order resonance mode (at a first-order resonance frequency) because the largest amount of displacement can be obtained in the first-order resonance mode. However, since the first-order resonance frequency is within an audible range, the problem of noise might arise. In contrast, if a third-order resonance mode (a third-order resonance frequency) is used, it is possible to obtain the amount of displacement that is larger than that obtained when a resonance mode is not used at all, although the amount of displacement is smaller than that obtained in the first-order resonance mode. In addition, it is possible to drive the driver at a frequency that is not within the audible range. Therefore, noise will not be generated. The term "first-order resonance mode" means a mode in which the center part of the driver and the peripheral part thereof are displaced in the same direction. The term "third-order resonance mode" means a mode in which the center part of the driver and the peripheral part thereof are displaced in opposite directions.

Advantageous Effects of the Preferred Embodiments of the Invention

[0017] As described above, a piezoelectric micro blower according to the present invention can produce the following advantageous effects. A driver is caused to vibrate due to bending so as to suck a fluid from a center space into a blower chamber through a first opening. The fluid is pressed out of the blower chamber at high speed to be discharged through a second opening. In the course of flowing, the fluid pressed out thereof entrains a fluid that is present inside the center space to be discharged together. Therefore, it is possible to obtain a discharging flow, the quantity of which is larger than the displacement volume of the driver, without any need to provide a check valve. Thus, it is possible to provide a blower that is capable of blowing a large quantity of a fluid. In addition, since a bottleneck portion is formed in an inlet passage, the bottleneck portion makes it harder for the energy of a pressure fluctuation in the center space to be dissipated into the inlet passage. Therefore, it is possible to direct the pressure energy toward the second opening efficiently. Consequently, it is possible to achieve a further increase in the rate of flow.

Brief Description of the Drawings

[0018]

[Fig. 1] Fig. 1 is a perspective view that illustrates an overall configuration of a piezoelectric micro blower according to a first embodiment of the present invention;
[Fig. 2] Fig. 2 is an exploded perspective view of the piezoelectric micro blower illustrated in Fig. 1;
[Fig. 3] Fig. 3 is a sectional view taken along the line III-III of Fig. 1;
[Fig. 4] Fig. 4 is a sectional view taken along the line IV-IV of Fig. 3;
[Fig. 5] Fig. 5 is a diagram that illustrates the operation of the piezoelectric micro blower illustrated in Fig. 3;
[Fig. 6] Fig. 6 is a sectional view of a piezoelectric micro blower according to a variation example;
[Fig. 7] Fig. 7 is a diagram that illustrates flow rate characteristics relative to an applied voltage and flow rate characteristics relative to power consumption that were obtained from samples in which the material and thickness of separators are different from each other; and
[Fig. 8] Fig. 8 is a sectional view of a micro blower having bottleneck portions according to another example.

Reference Numerals

[0019]

A	piezoelectric micro blower
8	inlet ports
10	top plate (second wall)
11	discharging port (second opening)
20	flow channel formation plate
21	center hole (center space)
22	inlet passages
23	bottleneck portions
30	separator (first wall)
31	communication hole (first opening)
40	blower frame member
41	blower chamber
50	driver
51	diaphragm
52	piezoelectric element
60	bottom plate

Best Mode for Carrying Out the Invention

[0020] With reference to the accompanying drawings, preferred embodiments of the present invention will now be explained.

First Embodiment

[0021] A piezoelectric micro blower according to a first embodiment of the present invention is shown in Figs. 1 to 4. A piezoelectric micro blower A according to the present embodiment of the invention is an air blower that is used for cooling electronic equipment. The piezoelectric micro blower A includes a top plate (second wall) 10, a flow channel formation plate 20, a separator (first wall) 30, a blower frame member 40, a driver 50, and a bottom plate 60, which are fixed to form a layered structure in this order as viewed from the top. The peripheral part of the driver 50 is fixed by bonding between the blower frame member 40 and the bottom plate 60. The members mentioned above except the driver 50, that is, 10, 20, 30, 40, and 60, are components that make up a blower body 1. Each of them is made of a flat material having rigidity such as a metal plate or a hard resin plate.
[0022] The top plate 10 is a quadrangular flat plate. A discharging port (second opening) 11 is formed as a through hole at the center of the top plate 10.
[0023] The flow channel formation plate 20 is also a flat plate that has the same outer shape as that of the top plate 10. As illustrated in Fig. 4, a center hole (center space) 21 that has a diameter larger than that of the discharging port 11 is formed at the center of the flow channel formation plate 20. A plurality of inlet passages (in the illustrated example, four inlet passages) 22 extending in radial directions toward four corners is formed in the flow channel formation plate

20. The outer ends of the inlet passages 22 are respectively in communication with inlet ports 8, which will be explained later. In the present embodiment of the invention, the inlet passages 22 are in communication with the center hole 21 from four directions. Because of such a structure, a fluid can be sucked into the center hole 21 without substantial fluid resistance when the driver 50 performs pumping operation. Therefore, it is possible to increase the rate of flow. Each of the inlet passages 22 has a bottleneck portion 23. The bottleneck portion 23 is the tapered part of the inlet passage 22 at which the width thereof becomes smaller toward the center hole 21. In the present embodiment of the invention, the bottleneck portions 23 are formed at regions where the inlet passages 22 are connected to the center hole 21. However, the regions where the bottleneck portions 23 are formed are not limited thereto. The bottleneck portions 23 may be formed anywhere in the inlet passages 22.

[0024] The separator 30 is also a flat plate that has the same outer shape as that of the top plate 10. A communication hole (first opening) 31 is formed at the center of the separator 30, specifically, at a position corresponding to the position of the discharging port 11. The communication hole 31 has a diameter that is substantially the same as that of the discharging port 11. The diameter of the communication hole 31 may be exactly the same as that of the discharging port 11. The diameter of the communication hole 31 may be different from that of the discharging port 11. It is required that, however, said diameter is smaller than that of the center hole 21. Inlet holes 32 are formed near four corners of the separator 30, specifically, at positions corresponding to the outer ends of the inlet passages 22, respectively. In an assembled state in which the top plate 10 and the separator 30 are attached to the flow channel formation plate 20, the center of the discharging port 11, the center of the center hole 21, and the center of the communication hole 31 are aligned on the same axis. The center of the aligned openings 11, 21, and 31 corresponds to the center of the driver 50, which will be explained later. As will be explained later, preferably, the separator 30 should be made of a thin metal plate so that a part of the separator 30 that is located at an area corresponding to the center hole 21 can be vibrated in a sympathetic manner.

[0025] The blower frame member 40 is also a flat plate that has the same outer shape as that of the top plate 10. A circular cavity 41 having a large diameter is formed at the center of the blower frame member 40. Inlet holes 42 are formed near four corners of the blower frame member 40, specifically, at positions corresponding to the positions of the inlet holes 32, respectively. Since the blower frame member 40 is fixed by bonding between the separator 30 and the driver 50, the cavity 41 of the blower frame member 40 is formed as a blower chamber. The blower chamber 41 is not limited to an enclosed space. The blower chamber 41 may be a partially open space.

[0026] The bottom plate 60 is also a flat plate that has the same outer shape as that of the top plate 10. A cavity 61 is formed at the center of the bottom plate 60. The two-dimensional shape of the cavity 61 is substantially the same as that of the blower chamber 41. The bottom plate 60 has a thickness that is greater than the sum of the thickness of a piezoelectric element 52 and the amount of displacement of a diaphragm 51. With such a structure, when the piezoelectric micro blower A is mounted on, for example, a substrate, it is possible to avoid the contact of the piezoelectric element 52 with the substrate. The wall of the cavity 61 surrounds the piezoelectric element 52 of the driver 50, which will be explained later. Inlet holes 62 are formed near four corners of the bottom plate 60, specifically, at positions corresponding to the positions of the inlet holes 32 and 42, respectively.

[0027] The driver 50 includes the diaphragm 51 and the piezoelectric element 52. The piezoelectric element 52 which has a circular shape is attached to the lower surface of the diaphragm 51 at the center area thereof. Besides various metal materials such as stainless or brass, resin can be used as the material of the diaphragm 51. For example, a resin plate that is made of glass epoxy resin may be used as the diaphragm 51. The piezoelectric element 52 has the shape of a disc having a diameter smaller than that of the cavity 41 of the blower frame member 40. In the present embodiment of the invention, single-plate piezoelectric ceramics having electrodes on both surfaces is used as the piezoelectric element 52. The piezoelectric element 52 is attached to the back of the diaphragm 51 (i.e., one surface of the diaphragm 51 that is opposite to the other surface facing the blower chamber 41). That is, the driver 50 is configured as a unimorph driver. When an alternating voltage (either a sinusoidal wave or a rectangular wave) is applied to the piezoelectric element 52, the piezoelectric element 52 extends and contracts in a planar direction. As a result, the displacement of the entire body of the driver 50 in the direction of its thickness occurs due to bending. The alternating voltage applied to the piezoelectric element 52 causes the driver 50 to become displaced either in a first-order resonance mode or in a third-order resonance mode due to bending, Since such a voltage is applied thereto, it is possible to significantly increase the displacement volume of the driver 50 as compared with a case where a voltage having any frequency other than the above is applied thereto. Consequently, it is possible to significantly increase the rate of flow.

[0028] Inlet holes 51 a are formed near four corners of the diaphragm 51, specifically, at positions corresponding to the positions of the inlet holes 32, 42, and 62, respectively. The inlet holes 32, 42, 51 a, and 62 are aligned in such a manner that they make up each of the inlet ports 8. One end of the inlet port 8 is formed as a downward open end. The other end of the inlet port 8 is in communication with the inlet passage 22.

[0029] As illustrated in Fig. 3, the inlet ports 8 of the piezoelectric micro blower A are open at the bottom of the blower body 1. In addition, the discharging port 11 is open at the top of the blower body 1. A compressible fluid can be sucked into the inlet ports 8 through the open ends thereof, which are formed at the reverse side of the piezoelectric micro blower A, and then can be discharged from the discharging port 11, which is formed at the front side of the piezoelectric micro blower A. Such a structure is suited for use as a blower for supplying air to a fuel cell or a blower for cooling a CPU by means of air. It is not always necessary that the open ends of the inlet ports 8 be oriented downward. They may be open at the sides.

[0030] Though the driver 50 illustrated in Fig. 3 is made up of the diaphragm 51 and the piezoelectric element 52, the structure of the driver 50 is not limited to the illustrated example. For example, as illustrated in Fig. 6, the driver 50 may further include an intermediate plate 53 that is sandwiched between the diaphragm 51 and the piezoelectric element 52. A plate that is made of metal such as SUS can be used as the intermediate plate 53. Since the intermediate plate 53 is sandwiched between the diaphragm 51 and the piezoelectric element 52, a neutral plane at the time of the displacement of the driver 50 due to bending is located inside the intermediate plate 53, which results in greater displacement efficiency. Therefore, it is possible to provide a piezoelectric micro blower that can offer a high flow rate with a low voltage.

[0031] Fig. 5 is a diagram that schematically illustrates an example of the operation of the piezoelectric micro blower A. To facilitate understanding, displacement is shown in an exaggerated manner. An initial state (when no voltage is applied thereto) is shown in Fig. 5(a). Figs. 5(b) to 5(e) illustrate the displacement of the driver 50 and the separator 30 at intervals of 1/4 in a cycle of a voltage (e.g., sinusoidal wave) applied to the piezoelectric element 52. As a result of the application of an alternating voltage to the piezoelectric element 52, operations shown in Figs. 5(b) to 5(e) are repeated in a cycle. As illustrated therein, the vibration of the driver 50 causes the sympathetic vibration of the separator 30. The vibration of the separator 30 occurs with a delay of a predetermined phase (in this example, approximately 90°) with respect to the vibration of the driver 50. Because of the sympathetic vibration of the separator 30, a large pressure wave is generated from the first opening 31 in an upward direction. Air is forced out of the center space 21 through the second opening 11 to the outside due to the pressure wave. Therefore, it is possible to increase the rate of flow as compared with a case where the separator 30 is not vibrated in a sympathetic manner. Since the air is forced out of the center space 21, new air is sucked from the inlet passages 22 into the center space 21, thereby generating a continuous airflow exiting from the second opening 11.

[0032] In Fig. 5, an example of the displacement of the driver 50 in a first-order resonance mode is illustrated. The same principle holds true for displacement in a third-order resonance mode. In the illustrated example, it is assumed that the amount of displacement of the separator 30 is larger than that of the driver 50. Depending on the dimensions of the center space 21, the Young's modulus of the separator 30, the thickness of the separator 30, and the like, however, there is a possibility that the amount of displacement of the separator 30 is smaller than that of the driver 50. The phase delay of the separator 30 with respect to the driver 50 is not limited to 90°. In short, the above structure may be modified as long as the vibration of the separator 30 occurs with a certain delay with respect to the vibration of the driver 50, and, for this reason, an actual change in the distance between the driver 50 and the separator 30 is greater than a change that would occur if the separator 30 did not vibrate at all.

[0033] Flow-rate measurement was conducted with the use of the piezoelectric micro blower A having the following specifications.

Driver: A unimorph element that includes a diaphragm, a single-plate piezoelectric ceramic element, and an intermediate plate that is sandwiched between the diaphragm and the piezoelectric ceramic element was used as the driver. The diaphragm is made of a 42Ni plate having a thickness of 0.08 mm. The intermediate plate is an SUS430 plate having a thickness of 0.15 mm and a diameter of 11 mm. The piezoelectric ceramic element has a thickness of 0.2 mm and a diameter of 11 mm.

Blower chamber: 0.15 mm in height, 16 mm in diameter
Blower body: 20 mm in length, 20 mm in width, 2.4 mm in height
Separator: SUS430 having a thickness of 0.05 mm
First opening: 0.6 mm in diameter
Second opening: 0.8 mm in diameter
Center space: 6 mm in diameter, 0.5 mm in height
Inlet passages: 2.5 mm in width, 0.5 mm in height, four passages
Bottleneck portions: 1 mm in width

[0034] A voltage having a sinusoidal waveform of 24 kHz and 20 Vp-p was applied to the piezoelectric micro blower A having the above specifications. As a result of the measurement, the rate of flow was 0.9 Umin under 100 Pa condition. In the above measurement, the driver was energized in the third-order mode. The driver may be energized in the first-order mode. Another experiment was conducted for comparison with the use of a piezoelectric micro blower having the same specifications as above except that it does not have any bottleneck portion. As a result of the measurement, the rate of flow was 0.77 L/min under 100 Pa condition. From the above results, it was found that the bottleneck portions contribute to an increase in the rate of flow.

[0035] It can be inferred that there are the following reasons (1), (2), and (3) why the quantity of flow is relatively large in the above structure in which the inlet passages have the bottleneck portions.

[0036] (1) When the driver 50 vibrates, a pressure wave having high energy is generated from the first opening 31.

Because of the pressure wave, air is forced out of the center space 21 through the second opening 11. As the driver 50 vibrates, a part of the separator 30 that constitutes the bottom wall of the center space 21 also vibrates (refer to Fig. 5). The vibration of the separator 30 generates a large pressure fluctuation in the center space 21. The energy of pressure acts to be dissipated not only through the second opening 11 but also into the inlet passages 22. If the sectional area of the inlet passage 22 is configured to be large for reducing air resistance, pressure energy loss is large. In contrast, since the inlet passages 22 have the bottleneck portions 23, it is harder for pressure energy that is present inside the center space 21 to be dissipated into the inlet passages 22. By this means, it is possible to direct the pressure energy that is present inside the center space 21 toward the second opening 11 efficiently, thereby achieving an increase in the rate of flow.

[0037] (2) Since there is a high-speed flow inside the center space 21, its average pressure is lower than pressure in the inlet passages 22. For this reason, a pressure gradient is produced in a flow channel. The pressure gradient generates a flow from the inlet passages 22 toward the center space 21. Though there occurs pressure loss in the inlet passages 22 because of friction between air and wall surfaces, if no bottleneck portion was formed in the flow channel, vena contracta would be produced in the vicinity of entrances to the center space 21 because the pressure of the center space 21 is lower than the pressure decreased due to the pressure loss. Therefore, loss due to the forming of a vortex would occur in the vicinity of the vena contracta. Consequently, the rate of flow of the blower would decrease. In contrast, since the bottleneck portions 23 are formed in the vicinity of entrances to the center space 21, the conformity of the shape of the flow channel to the shape of the flow increases. With the increased conformity, it is possible to suppress the forming of a vortex and thus reduce flow loss. Consequently, the rate of flow of the blower increases.

[0038] (3) The separator 30 is attached to the flow channel formation plate 20. The center area of the separator 30 that corresponds to the center space 21 is configured as a regional part that can vibrate. As illustrated in Fig. 5, the vibration of the center area of the separator 30 has a strong bearing on the rate of flow. In view of the above, the size of the center space 21 (open area) is designed to have an appropriate diameter that makes it easier for the center area of the separator 30 to vibrate. However, it is impossible to restrain the separator 30 at regions where the inlet passages 22 are connected to the center space 21. In the flow channel formation plate 20 having the bottleneck portions 23, since the front end of each of the bottleneck portions 23 has a tapered structure, the area where the sidewalls of the center space 21 exist is relatively large. That is, as compared with a case where there is not any bottleneck portion, it is possible to increase the area where the separator 30 is supported. The shape of the area where the separator 30 is supported is close to a circle. Having the bottleneck portions 23, the flow channel formation plate 20 can support the center area of separator 30 more securely, which contributes to an increase in the rate of flow.

[0039] Table 1 shows the rate of flow obtained when the drive frequency of the driver 50 and the diameter of the center space 21 are changed. The unit of the rate of flow is L/min. A diaphragm (42Ni plate) having a thickness of 0.08 mm was used for a drive frequency of 24.4 kHz. A diaphragm (42Ni plate) having a thickness of 0.1 mm was used for a drive frequency of 25.5 kHz.

[0040] Table 1

		Diameter of Center Space	
		ϕ 5 mm	ϕ 6 mm
Frequency	24.4 kHz	0.7 Umin.	0.8 Umin.
	25.5 kHz	0.78 Umin.	0.71 Umin.

[0041] As can be understood from Table 1, the rate of flow increases as the frequency increases when the diameter of the center space 21 is 5 mm, whereas the rate of flow increases as the frequency decreases when the diameter of the center space 21 is 6 mm. As described above, it can be understood that the vibration of the center area of the separator 30 that corresponds to the center space 21 has a strong bearing on the rate of flow. The reason can be inferred as follows. The natural vibration frequency of the driver 50 differs depending on the material of the diaphragm 51 and the thickness thereof. It is possible to make the natural vibration frequency of the center area of the separator 30 that corresponds to the center space 21 close to the natural vibration frequency of the driver 50 by adjusting the diameter of the center space 21, thereby causing the sympathetic vibration of the separator 30. By this means, the rate of flow increases.

[0042] Fig. 7 shows the result of an experiment conducted on a piezoelectric micro blower B having a structure in which the driver 50 includes the diaphragm 51, the piezoelectric element 52, and the intermediate plate 53 that is sandwiched between the diaphragm 51 and the piezoelectric element 52. As shown in Table 2, the experiment was conducted to compare the rate of flow obtained when the material of the separator 30 and the thickness thereof are changed. A plate that is made of phosphor bronze and has a thickness of 0.05 mm was used as a separator in a first sample. A plate that is made of SUS304 and has a thickness of 0,1 mm was used as a separator in a second sample. Except for the above component, the specifications of the piezoelectric micro blower B are the same as those of the piezoelectric micro blower A. The specifications of the first sample are the same as those of the second sample except for the separator. The drive frequency of 24.4 kHz was used for both the first sample and the second sample.

[0043] Table 2

	First Sample	Second Sample
Material of Separator	phosphor bronze	SUS304
Thickness of Separator (mm)	0.05	0.1
Diameter of First Opening (mm)	0.6	0.6
Material of Top Plate	nickel silver	nickel silver
Diameter of Second Opening (mm)	0.8	0.8
Material of Blower Chamber	nickel silver	nickel silver
Height of Blower Chamber (mm)	0.15	0.15
Diameter of Blower Chamber (mm)	16	16
Material of Diaphragm	42Ni	42ni
Thickness of Diaphragm (mm)	0.08	0.08
Thickness of Intermediate Plate (mm)	0.15	0.15
Diameter of Intermediate Plate (mm)	11	11
Thickness of Piezoelectric Element (mm)	0.20	0.20
Diameter of Piezoelectric Element (mm)	11	11
Diameter of Center Space (mm)	6	6
Height of Center Space (mm)	0.5	0.5

[0044] Generally, a plate that is made of SUS304 and has a certain thickness is one and a half times as rigid as a plate that is made of phosphor bronze and has the same thickness. Since the separator of the second sample is twice as thick as the separator of the first sample, the rigidity of the separator of the second sample is far greater than the rigidity of the separator of the first sample. In other words, presumably, a regional part of the separator of the first sample that faces the center space can vibrate, whereas a regional part of the separator of the second sample that faces the center space can hardly vibrate. The purpose of the experiment is to measure the influence of the vibration of a regional part of the separator that faces the center space on the rate of flow.

[0045] As illustrated in Fig. 7(a), for example, the rate of flow of the second sample obtained when a voltage of 20 Vp-p was applied thereto was approximately 0.42 L/min. The rate of flow of the first sample obtained when the same voltage of 20 Vp-p was applied thereto was approximately 0.78 L/min. Therefore, the rate of flow of the first sample is roughly twice as high as the rate of flow of the second sample. That is, it can be understood that the vibration of the above part of the separator contributes much to an increase in the rate of flow. Fig. 7(b) shows the result of comparison of the rate of flow based on power consumption. Though power consumption changes due to a change in impedance, it can be understood that the first sample is advantageous when compared on the basis of the same power consumption.

Second Embodiment

[0046] Fig. 8 illustrates the shape of bottleneck portions according to another embodiment of the invention. Since the structure of the flow channel formation plate 20 according to the present embodiment of the invention is the same as that of the first embodiment of the invention (refer to Fig. 4) except for the shape of bottleneck portions, the same reference numerals are used for the components described earlier. The components described earlier are not explained below. In the present embodiment of the invention, bottleneck portions 24 that are not tapered are formed at regions where the inlet passages 22 are connected to the center space 21. As in the foregoing structure, the bottleneck portions

24 make it harder for the energy of a pressure fluctuation in the center space 21 to be dissipated into the inlet passages 22. By this means, it is possible to achieve an increase in the rate of flow.

[0047] In the foregoing embodiments of the invention, a part of a separator (first wall) that corresponds to a center space vibrates in a sympathetic manner as a driver vibrates. However, it is not always necessary for the separator to vibrate in a sympathetic manner. Any alternative structure in which the vibration of a driver excites a separator, and, in addition, the separator vibrates in response to or by following the vibration of the driver makes it possible to achieve an increase in the rate of flow. The shape of an inlet passage is not limited to a linear passage extending in a radial direction as shown in Fig. 4. That is, the shape of the inlet passage may be selected arbitrarily. The number of inlet passages may also be selected arbitrarily depending on the rate of flow and the level of noise.

[0048] In the foregoing embodiments of the invention, a plurality of plate members is fixed in layers to form a blower body. However, the structure of the blower body is not limited thereto. For example, the top plate 10 and the flow channel formation plate 20 may be molded integrally as a single component that is made of resin or metal. The same applies for, for example, the separator 30 and the blower frame member 40, or the flow channel formation plate 20 and the separator 30.

Claims

1. A piezoelectric micro blower including a blower body, a driver that has a peripheral part that is fixed to the blower body and further has a piezoelectric element, and a blower chamber that is formed between the blower body and the driver, a voltage being applied to the piezoelectric element to cause the driver to vibrate due to bending for transporting a compressible fluid, the piezoelectric micro blower comprising:

    a first wall of the blower body, the blower chamber being formed between the driver and the first wall;
    a first opening that is formed through the first wall, the inside of the blower chamber being in communication with the outside of the blower chamber through the first opening;
    a second wall that is provided at a side opposite the blower chamber with the first wall being provided between the second wall and the blower chamber, the second wall being provided at a distance from the first wall;
    a second opening that is formed through the second wall; a center space that is formed between the first wall and the second wall, has an open area that is larger than the first opening and the second opening but smaller than the blower chamber, and is in communication with the first opening and the second opening; and
    an inlet passage that has an outer end that is in communication with the outside of the piezoelectric micro blower and an inner end that is connected to the center space,
    wherein a bottleneck portion that has a passage area that is smaller than that of the inlet passage is formed in the inlet passage.

2. The piezoelectric micro blower according to Claim 1, wherein the first opening is formed at a part of the first wall that faces an area of the center of the driver.

3. The piezoelectric micro blower according to Claim 1 or Claim 2, wherein the second opening is formed at a part of the second wall that faces the first opening.

4. The piezoelectric micro blower according to any of Claims 1, 2, and 3, wherein the bottleneck portion is formed at a region of connection of the inlet passage and the center space.

5. The piezoelectric micro blower according to any of Claims 1 to 4, wherein the passage area of the bottleneck portion gradually decreases in a direction of a flow from the inlet passage to the center space.

6. The piezoelectric micro blower according to any of Claims 1 to 5, wherein the open area of the center space is designed in such a manner that the facing part of the first wall vibrates as the driver vibrates.

7. The piezoelectric micro blower according to any of Claims 1 to 6, wherein the inlet passage includes a plurality of passages extending in radial directions from the center space.

FIG. 1

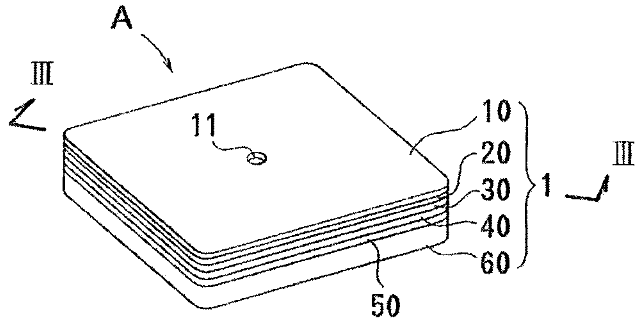

FIG. 2

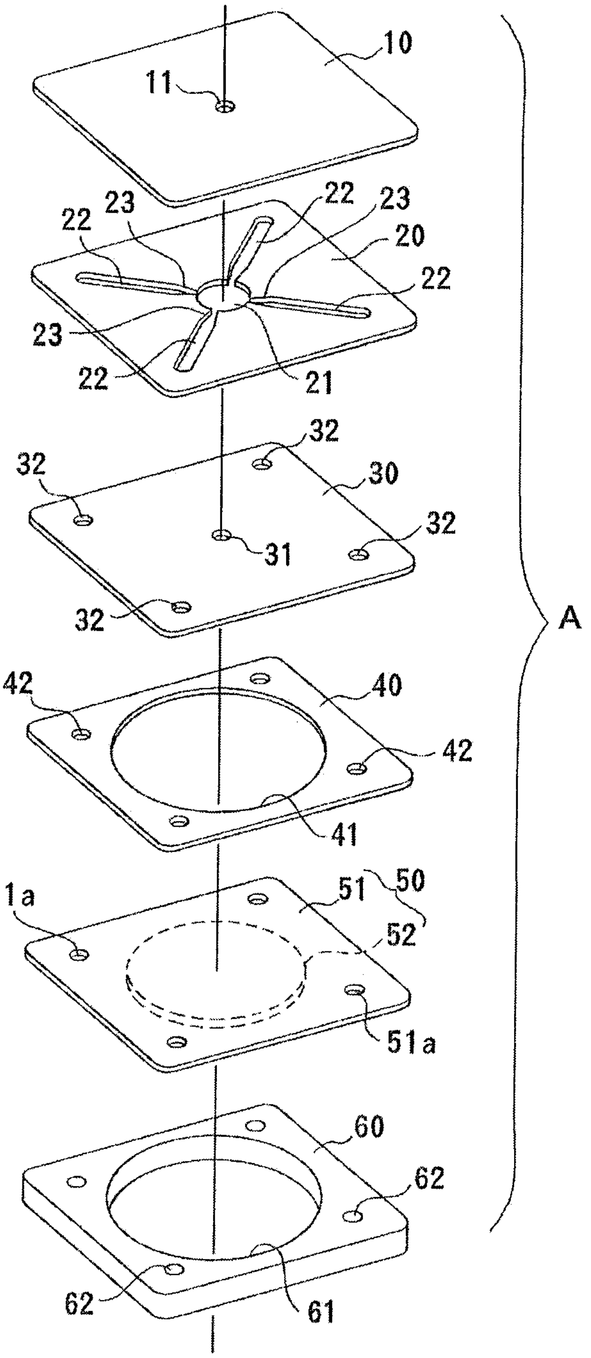
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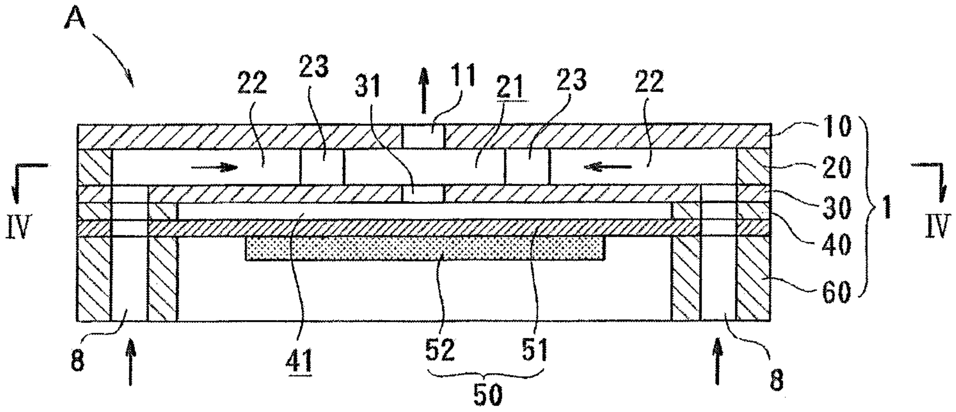
FIG. 3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8

FIG. 4

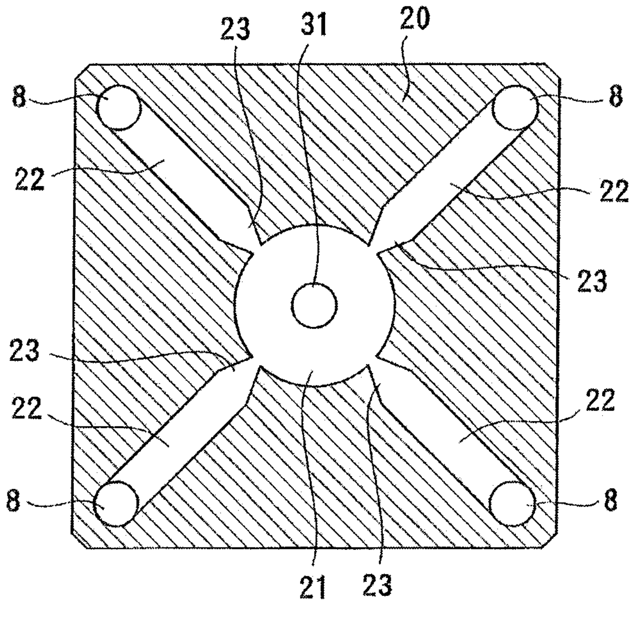
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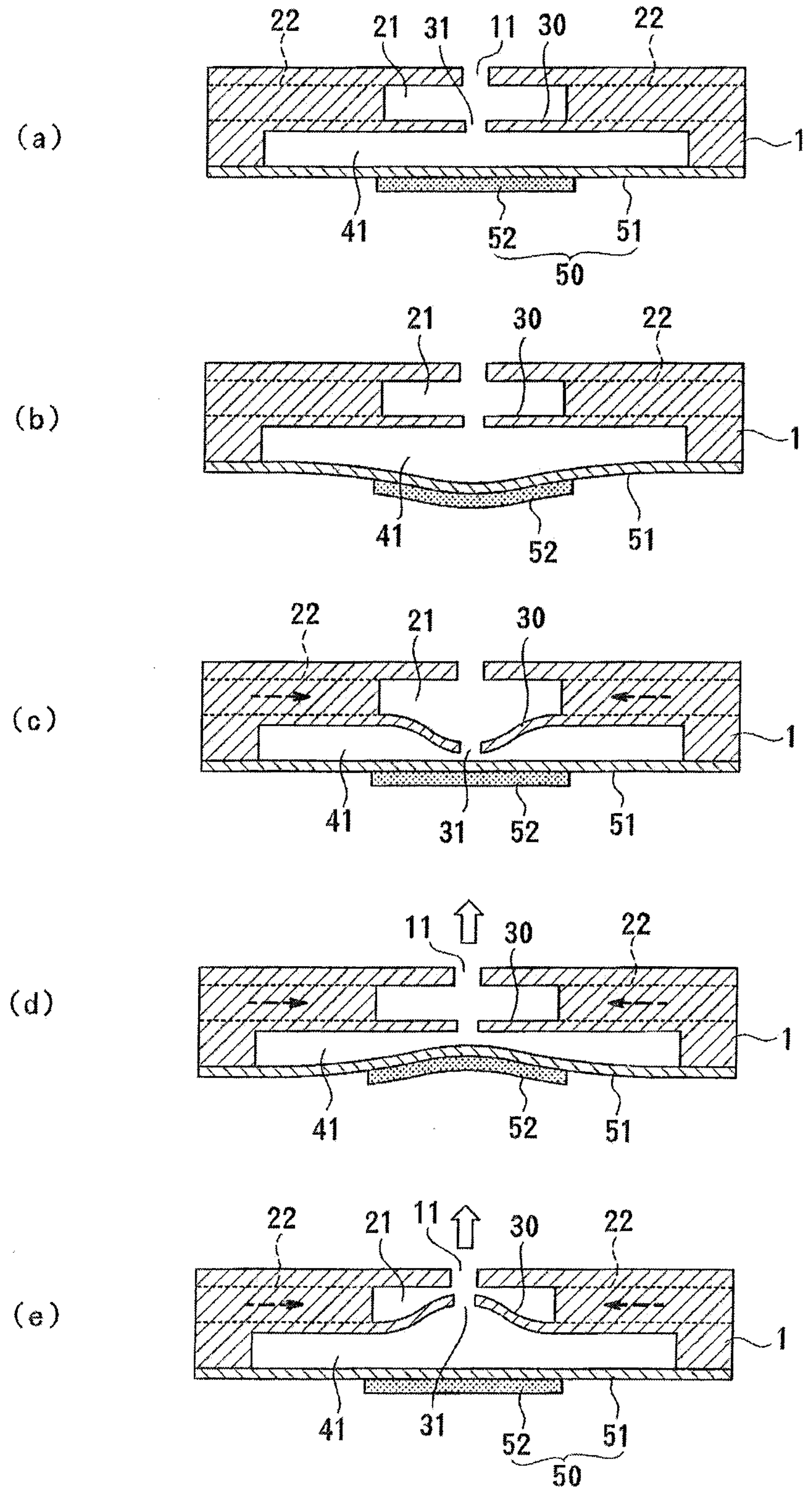
FIG. 5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(b)
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(d)
11
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FIG. 6

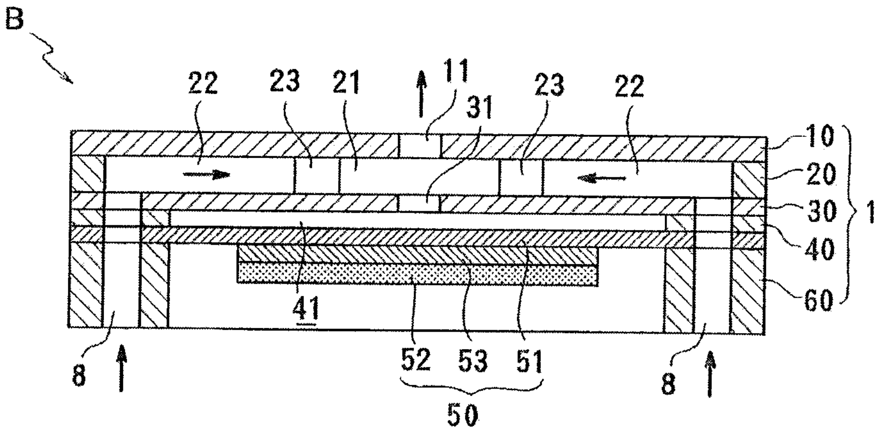
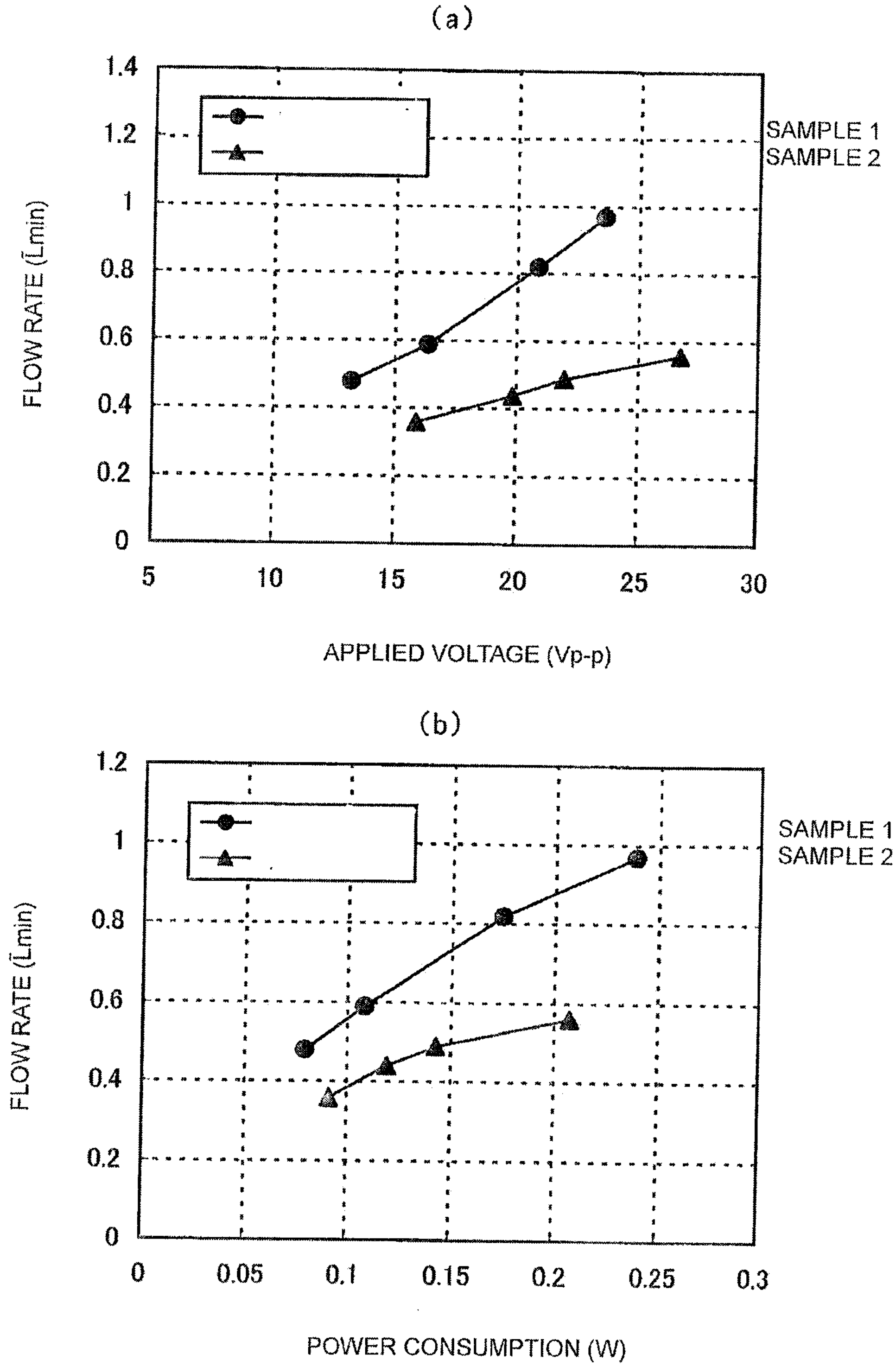


FIG. 7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0.8
0.6
0.4
0.2
0
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10
15
20
25
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FLOW RATE (L/min)
APPLIED VOLTAGE (Vp-p)
SAMPLE 1
SAMPLE 2
(b)
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
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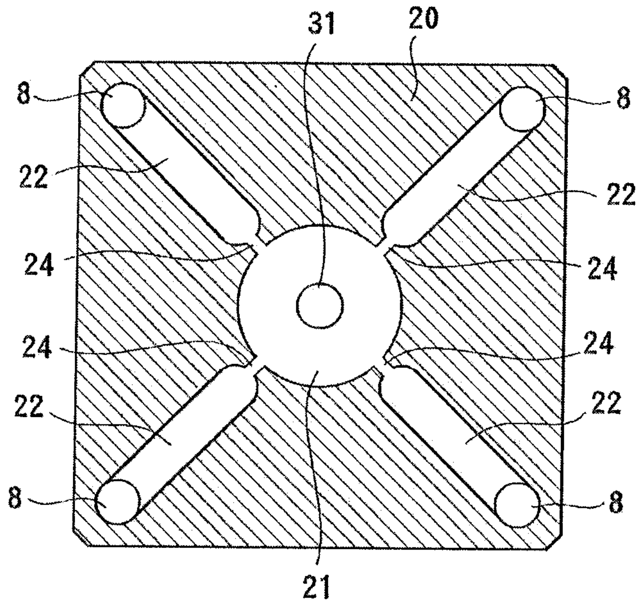
0.2
0.25
0.3
FLOW RATE (L/min)
POWER CONSUMPTION (W)
SAMPLE 1
SAMPLE 2

FIG. 8



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2009/058968

A. CLASSIFICATION OF SUBJECT MATTER
F04B45/047(2006.01)i, *F04B45/04*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04B45/047, F04B45/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2009
Kokai Jitsuyo Shinan Koho	1971-2009	Toroku Jitsuyo Shinan Koho	1994-2009

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	JP 2005-113918 A (Samsung Electronics Co., Ltd.), 28 April, 2005 (28.04.05), Par. Nos. [0029] to [0050], [0059]; Figs. 3 to 8 & US 2005/0074662 A1 & EP 1523038 A2 & KR 10-2005-0034777 A	1-4 5,7 6
Y A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 125639/1978(Laid-open No. 041584/1980) (Toyota Motor Co., Ltd.), 17 March, 1980 (17.03.80), Page 2, line 11 to page 5, line 2; Figs. 1, 2 (Family: none)	5,7 6

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 June, 2009 (08.06.09)	16 June, 2009 (16.06.09)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2009/058968

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 58-140491 A (Matsushita Electric Industrial Co., Ltd.), 20 August, 1983 (20.08.83), Page 2, upper left column, line 15 to page 3, upper left column, line 5; Figs. 4, 5 (Family: none)	1-7

Form PCT/ISA/210 (continuation of second sheet) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

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- JP S642793 B **[0005]**
- JP 2005113918 A **[0005]**