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Fig. 1

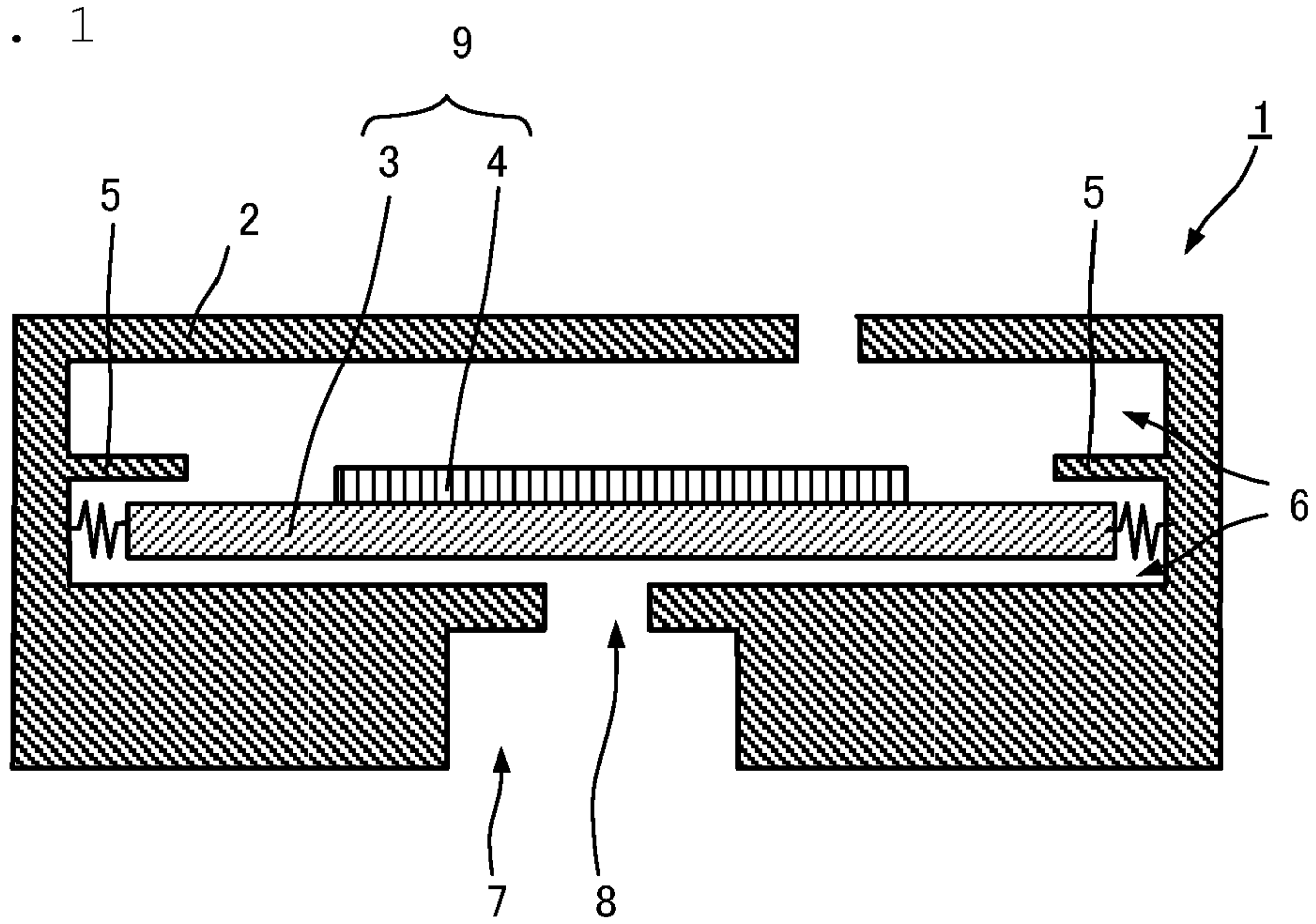


Fig. 2

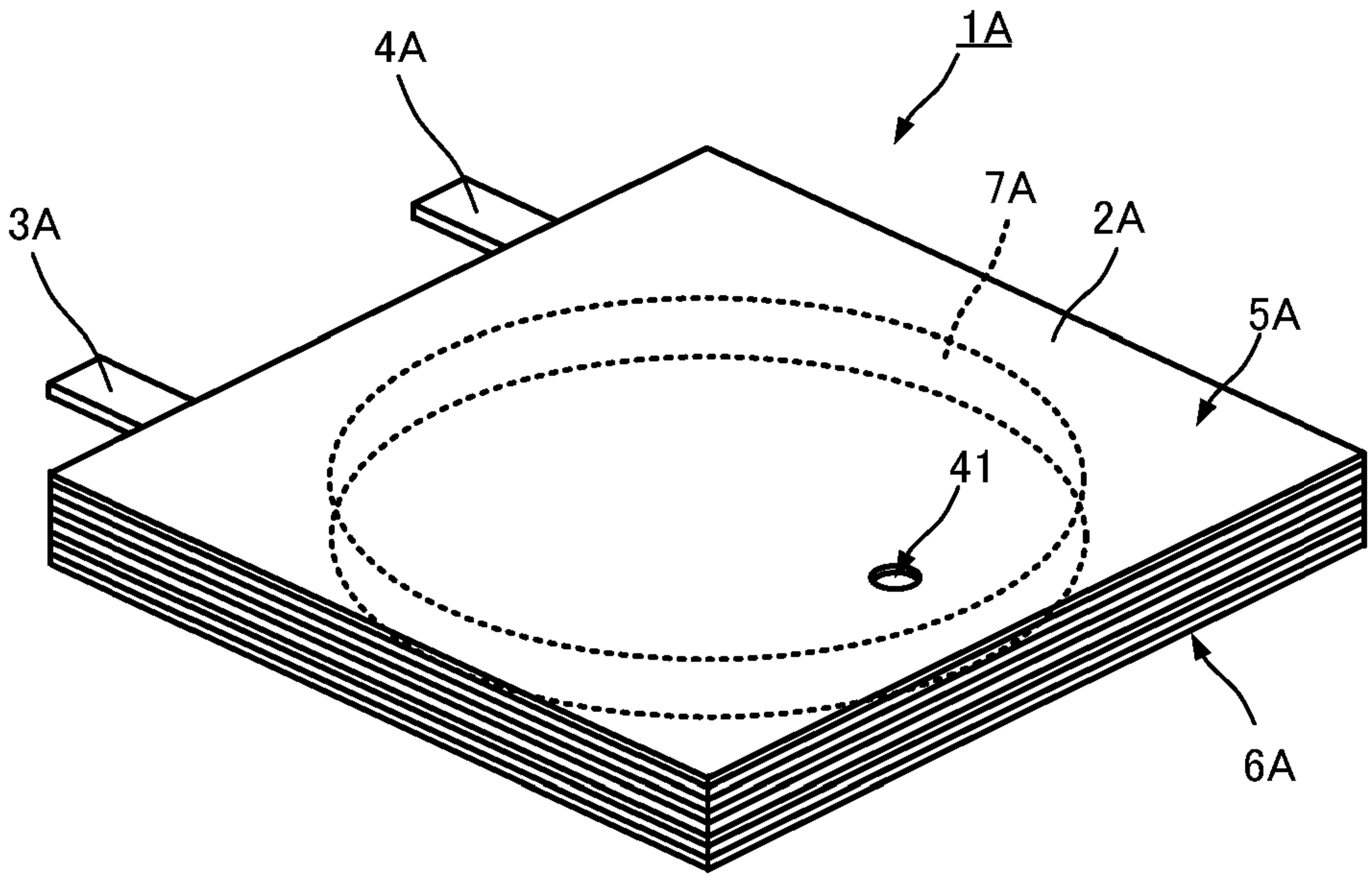
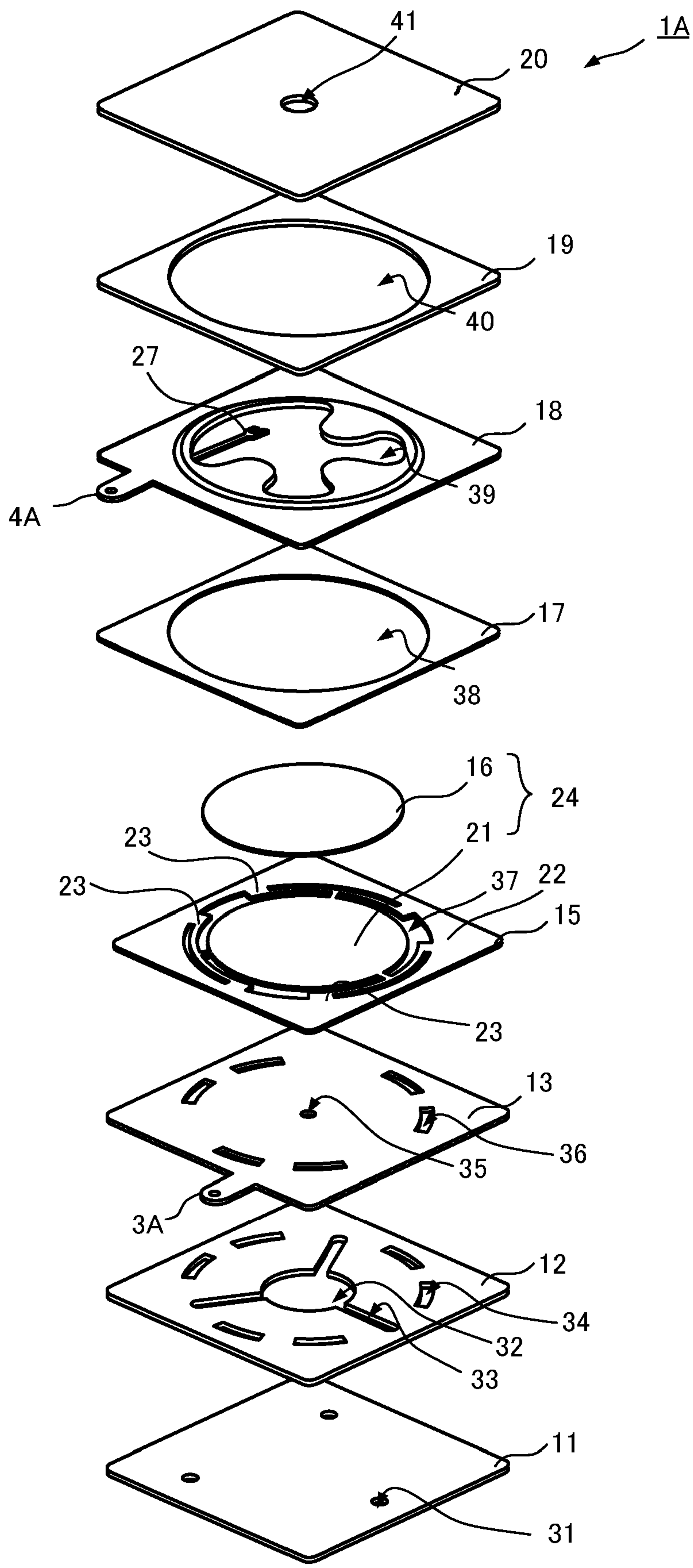


Fig. 3



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1A
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4A
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3A
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Fig. 4A

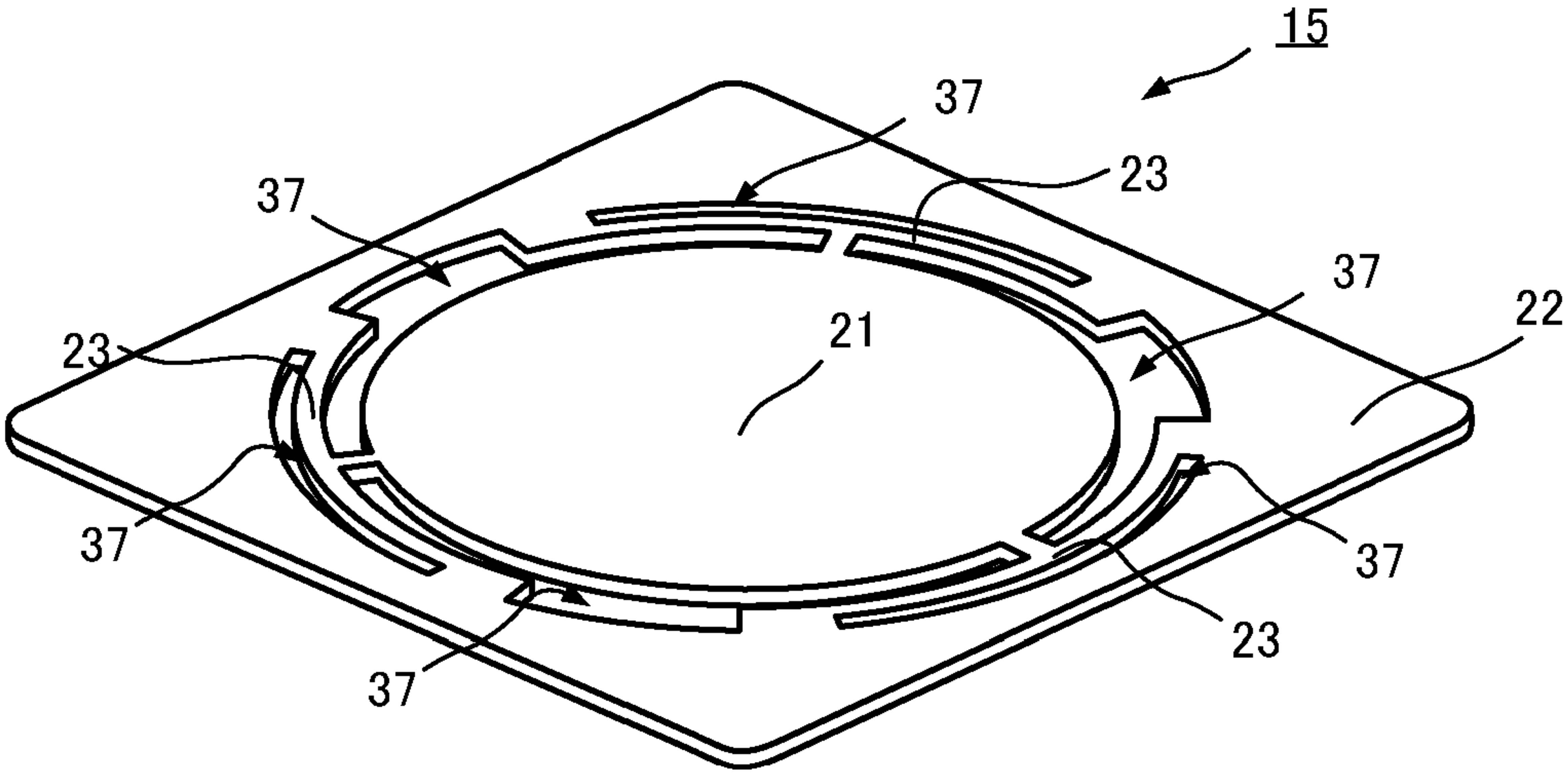
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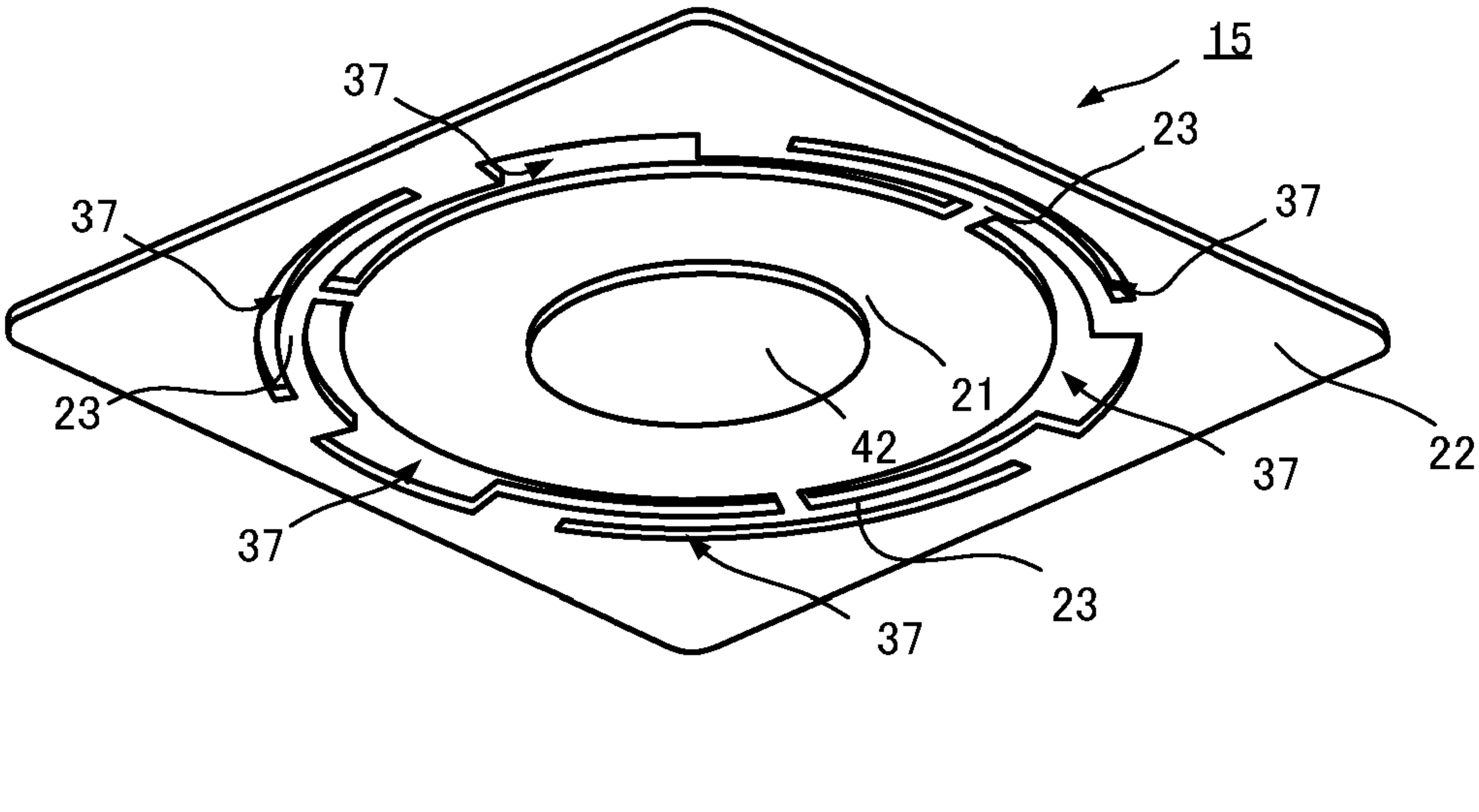
Fig. 4B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37

Fig. 5A

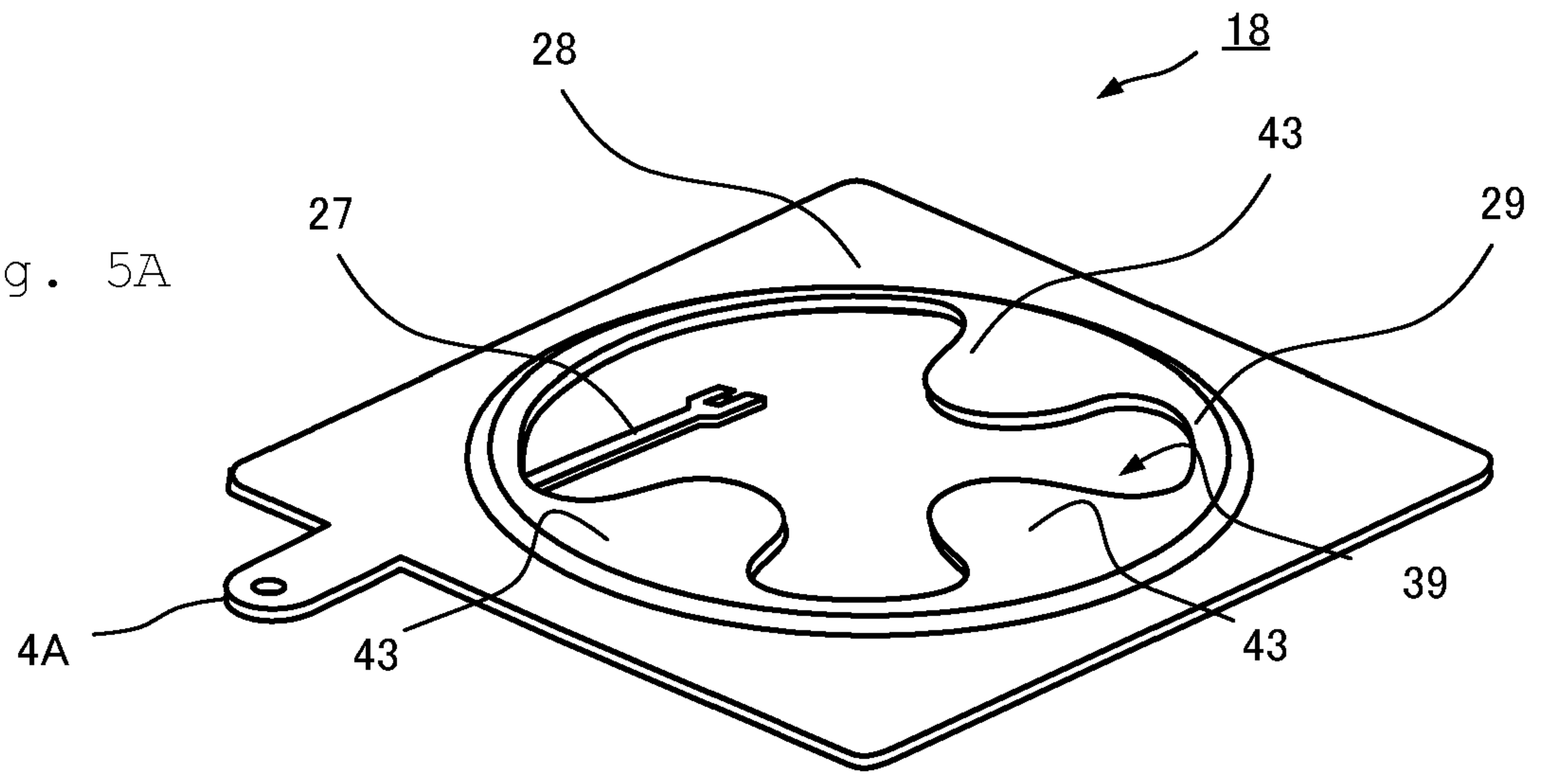


Fig. 5B

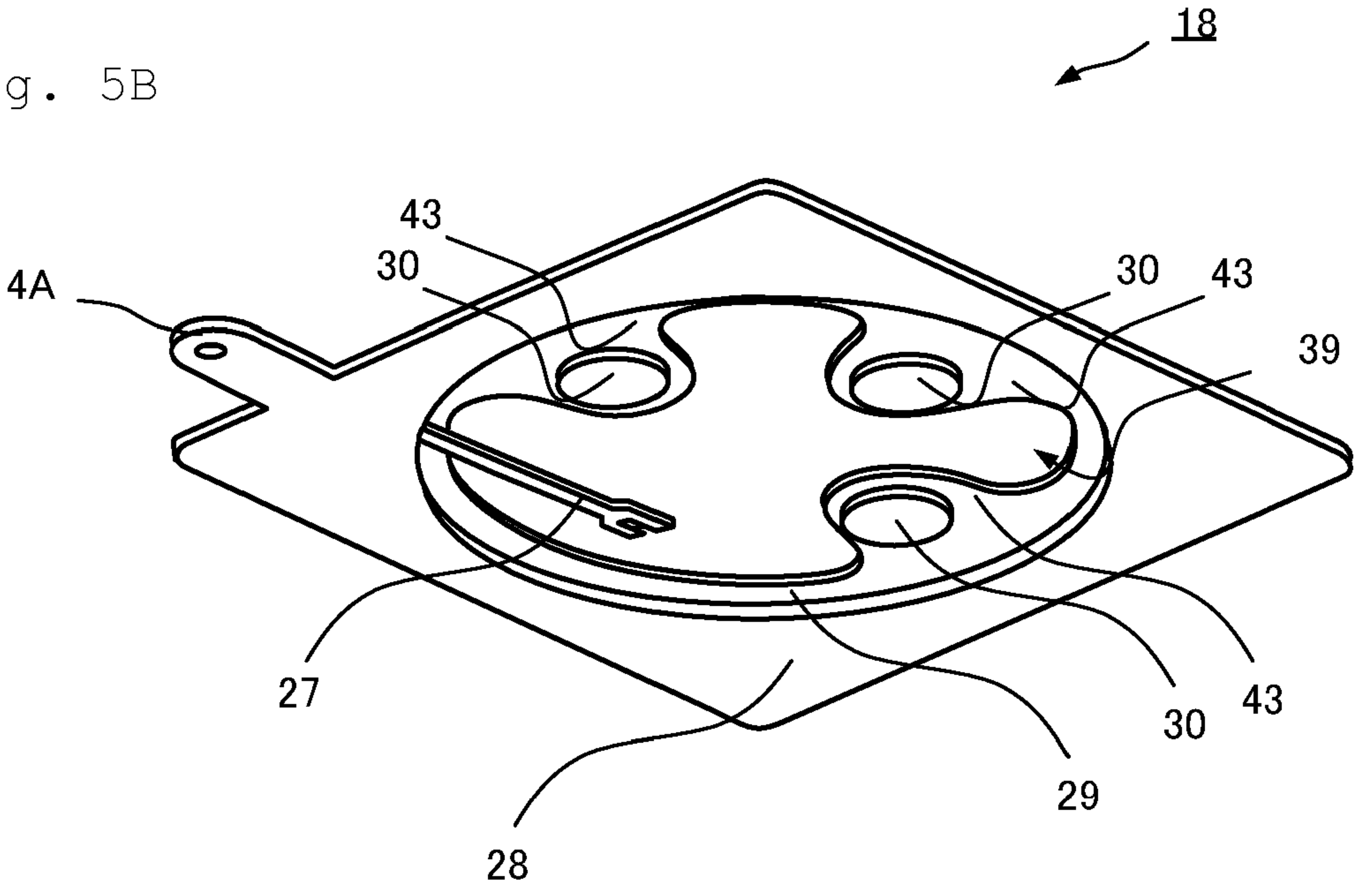
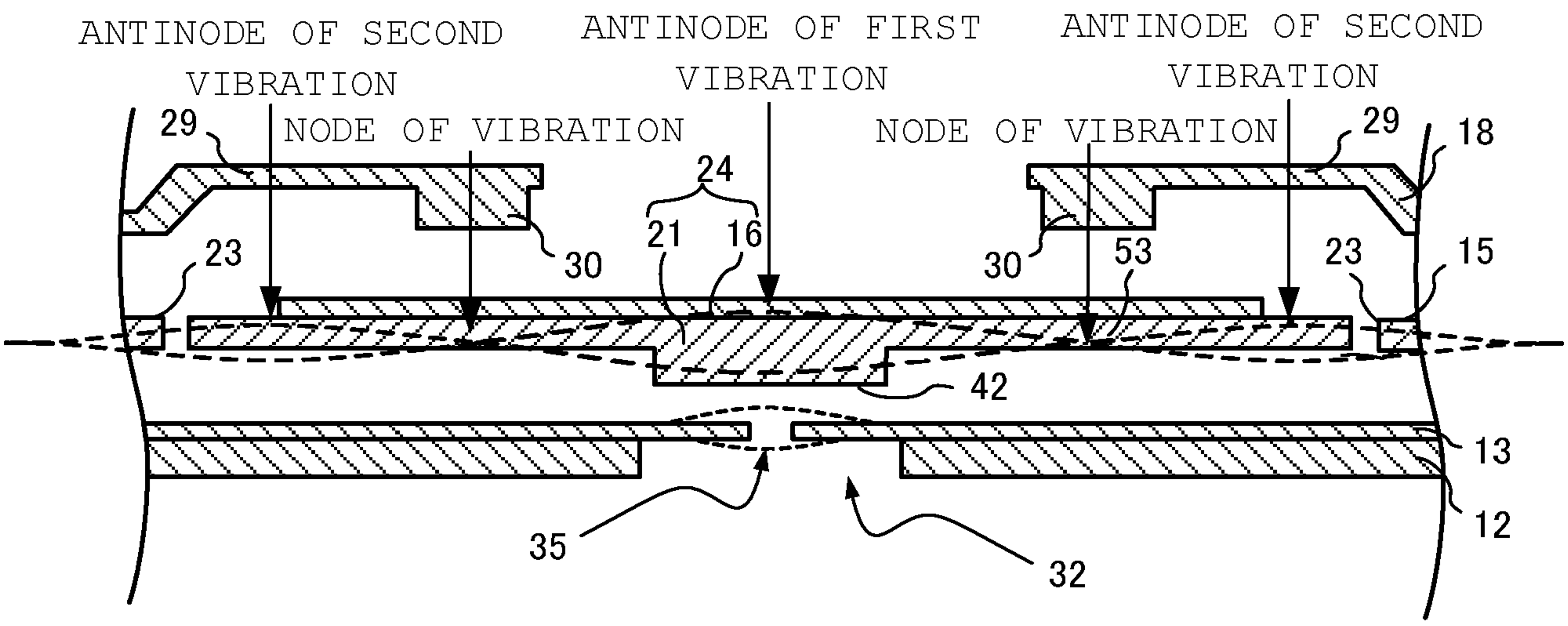


Fig. 6A


ANTINODE OF SECOND VIBRATION
NODE OF VIBRATION
ANTINODE OF FIRST VIBRATION
NODE OF VIBRATION
ANTINODE OF SECOND VIBRATION
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24
21
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53
42
18
15
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12
35
32

Fig. 6B

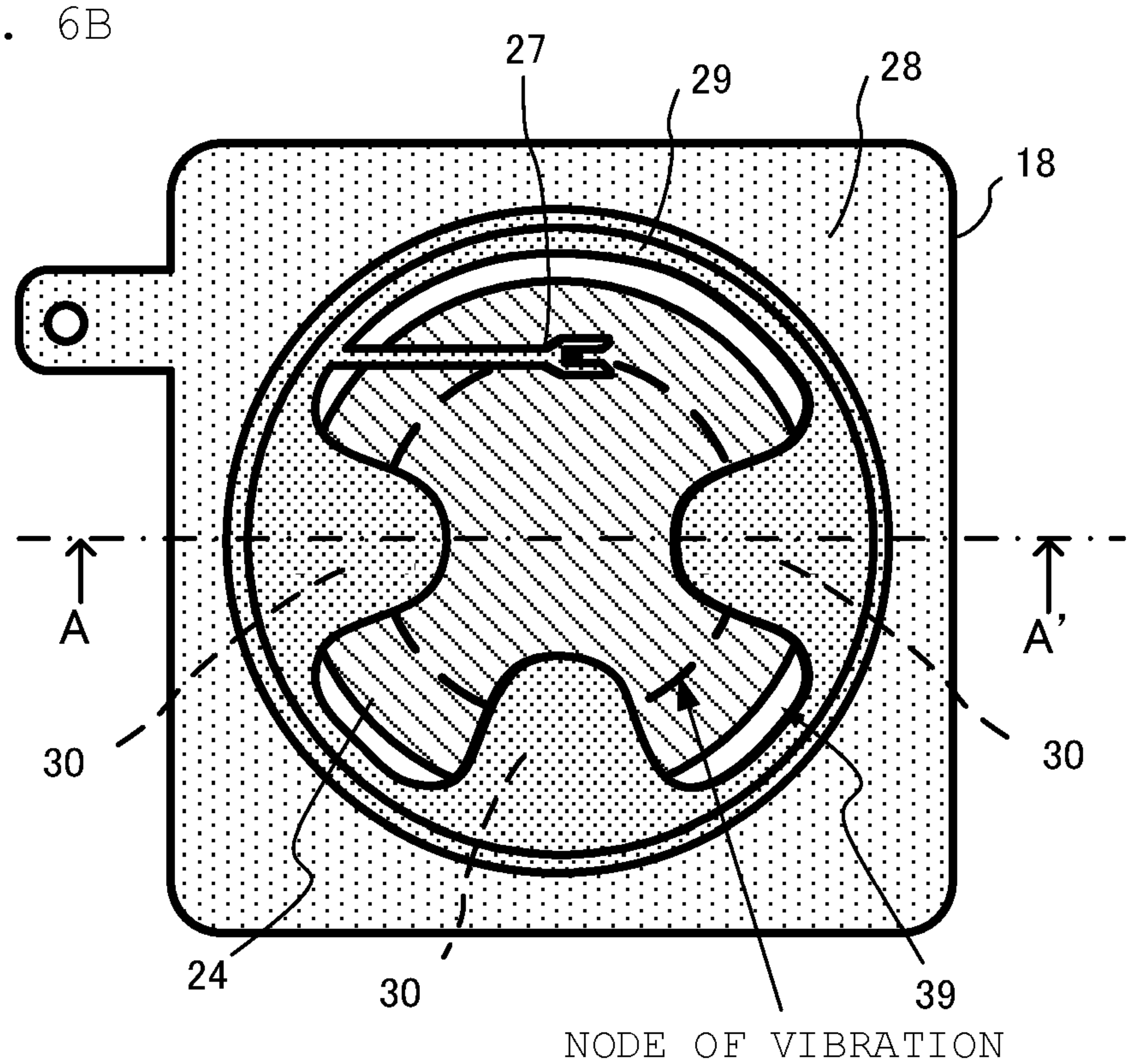

27
29
28
18
A
A'
30
30
30
24
39
NODE OF VIBRATION

Fig.7

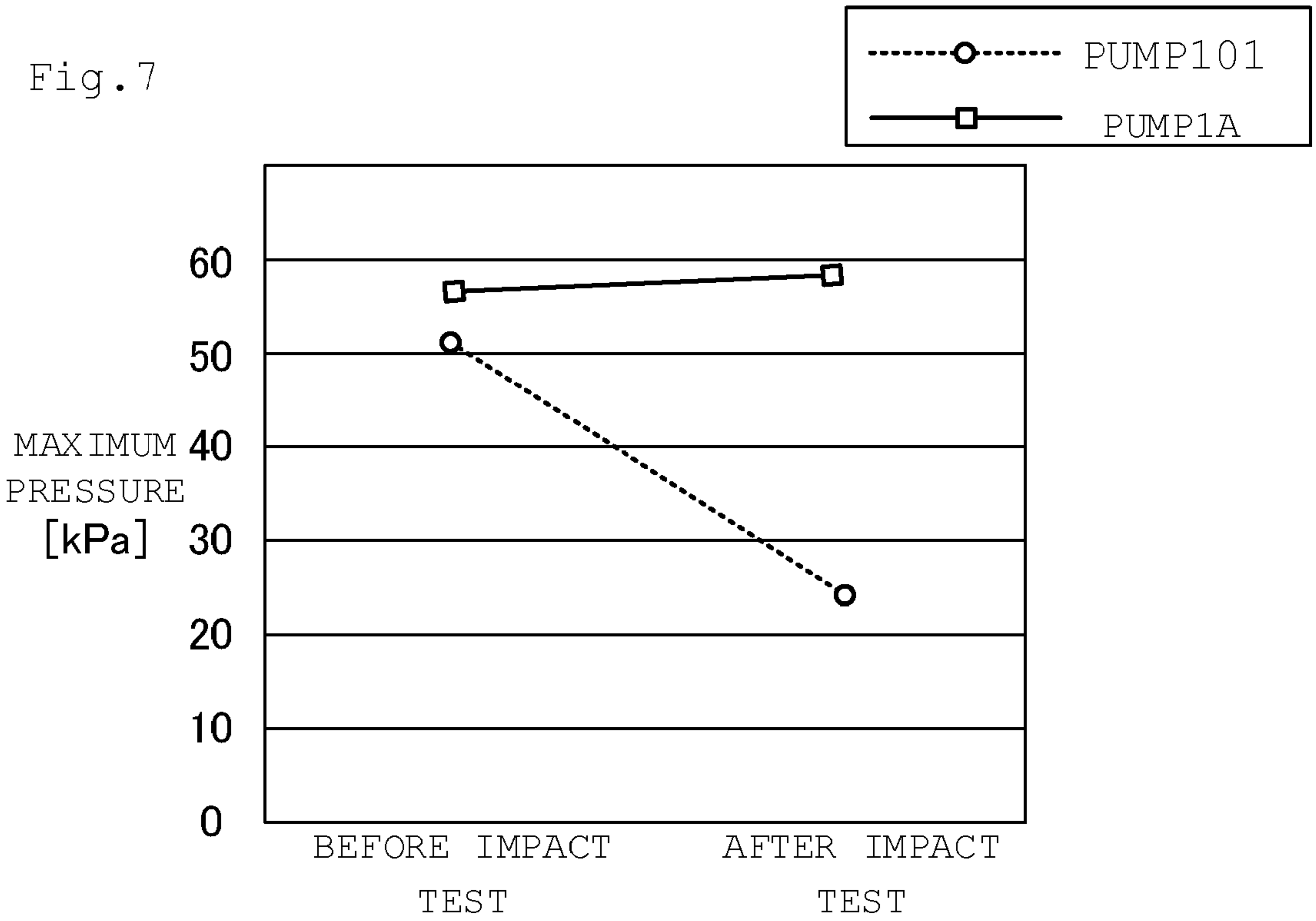
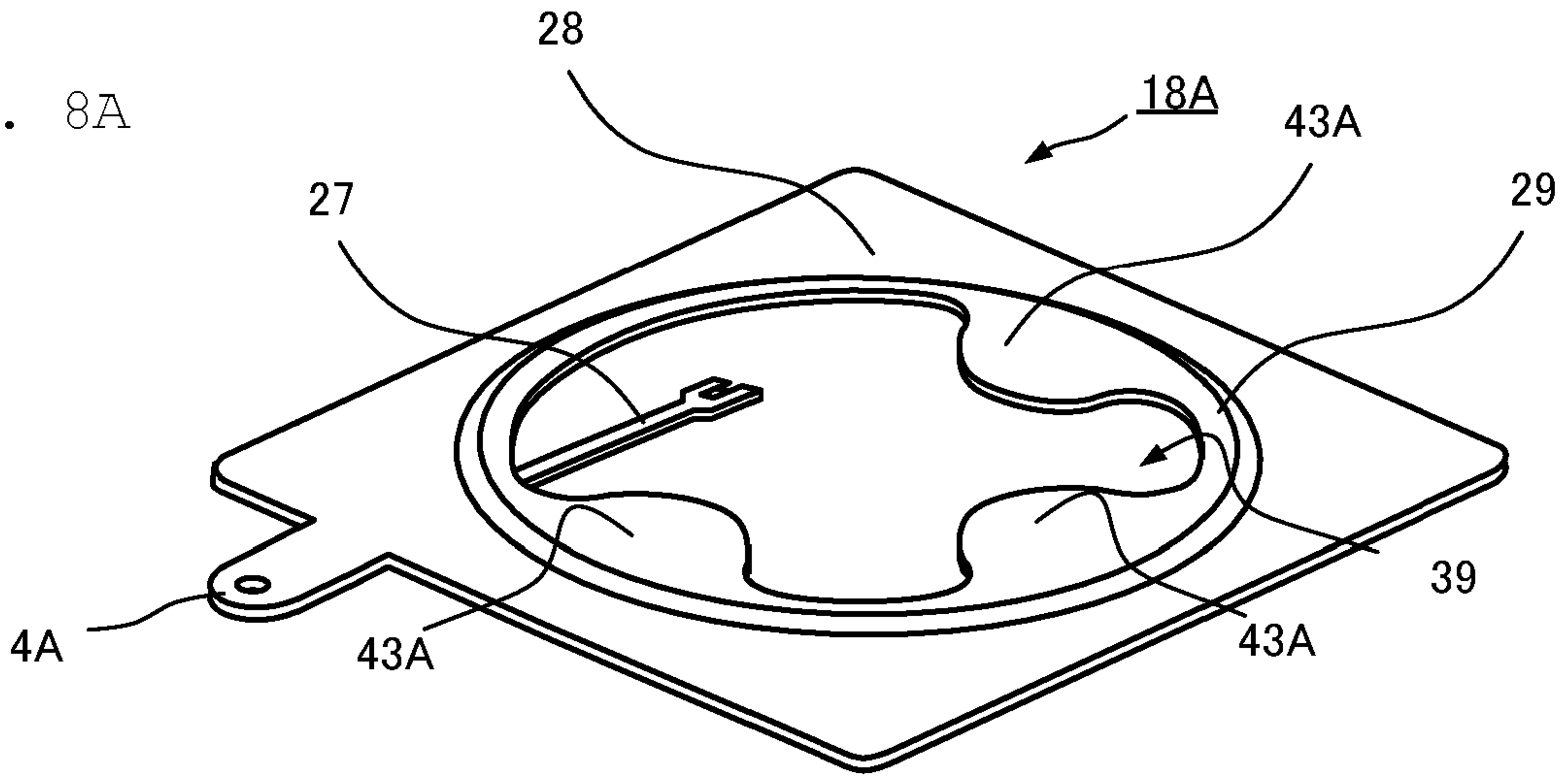

PUMP101
PUMP1A
MAXIMUM PRESSURE [kPa]
60
50
40
30
20
10
0
BEFORE IMPACT TEST
AFTER IMPACT TEST

Fig. 8A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18A
43A
27
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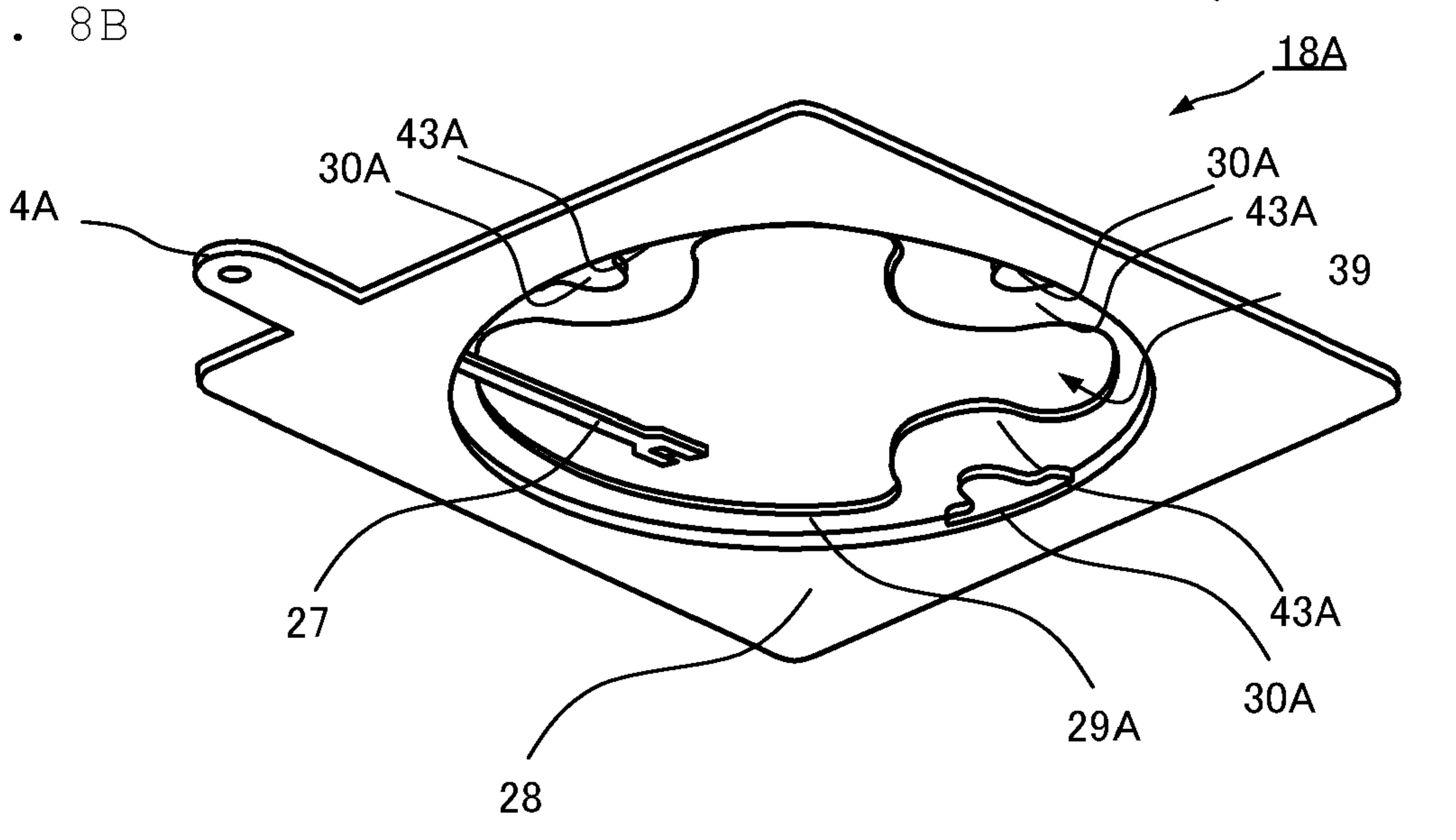
39
4A
43A
43A

Fig. 8B


18A
43A
30A
4A
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39
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43A
30A
29A
28

Fig. 9

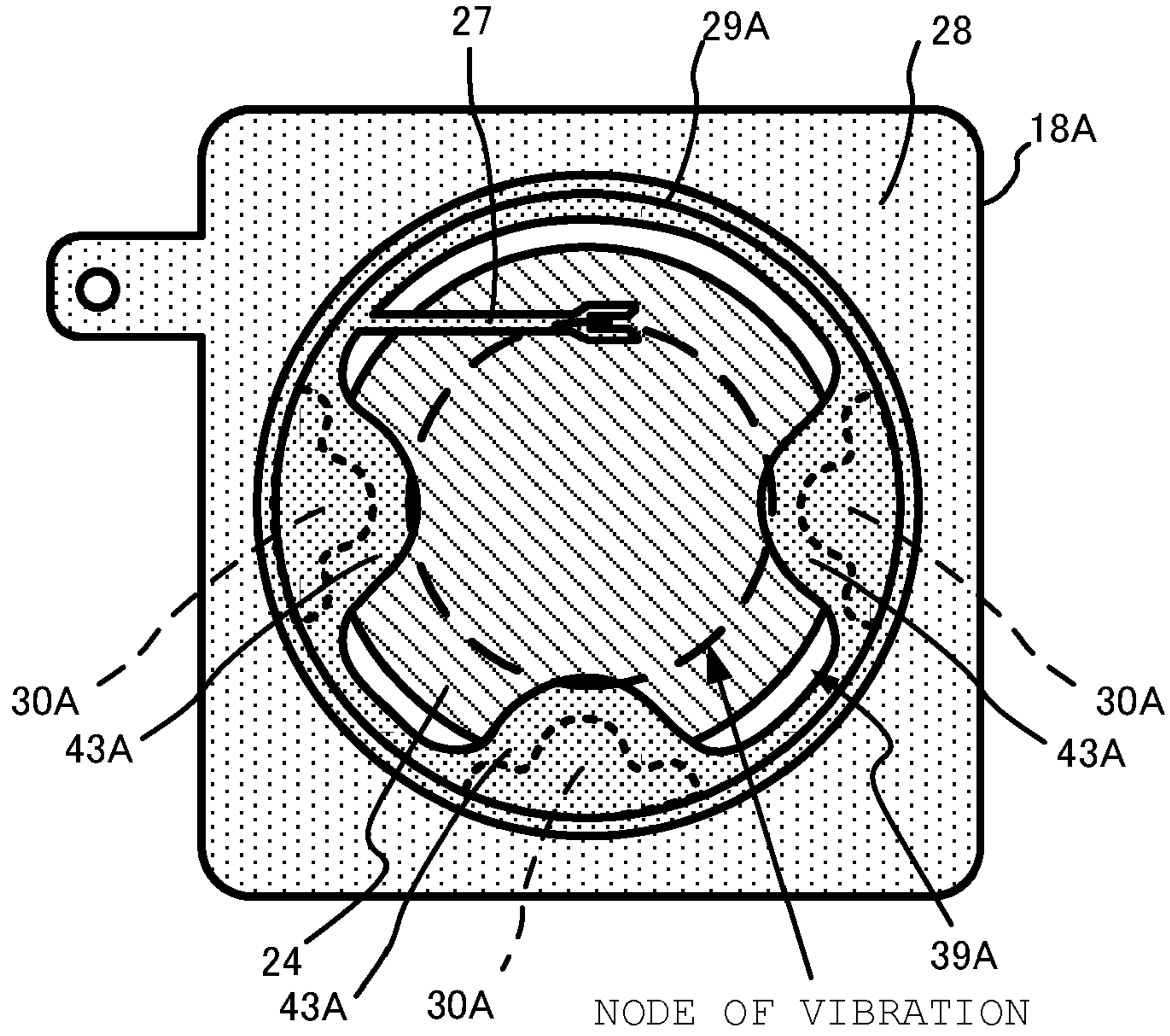
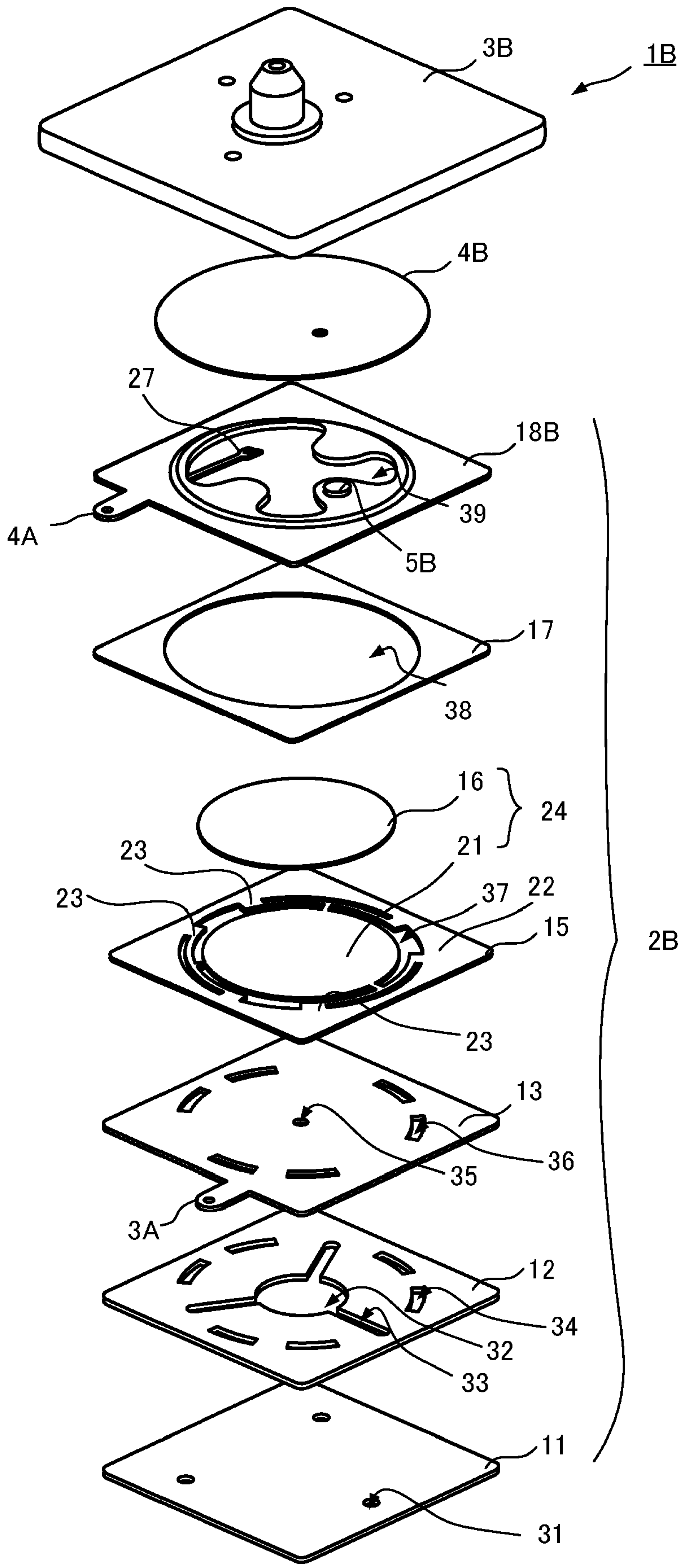


Fig. 10



3B
1B
4B
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18B
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Fig. 11A

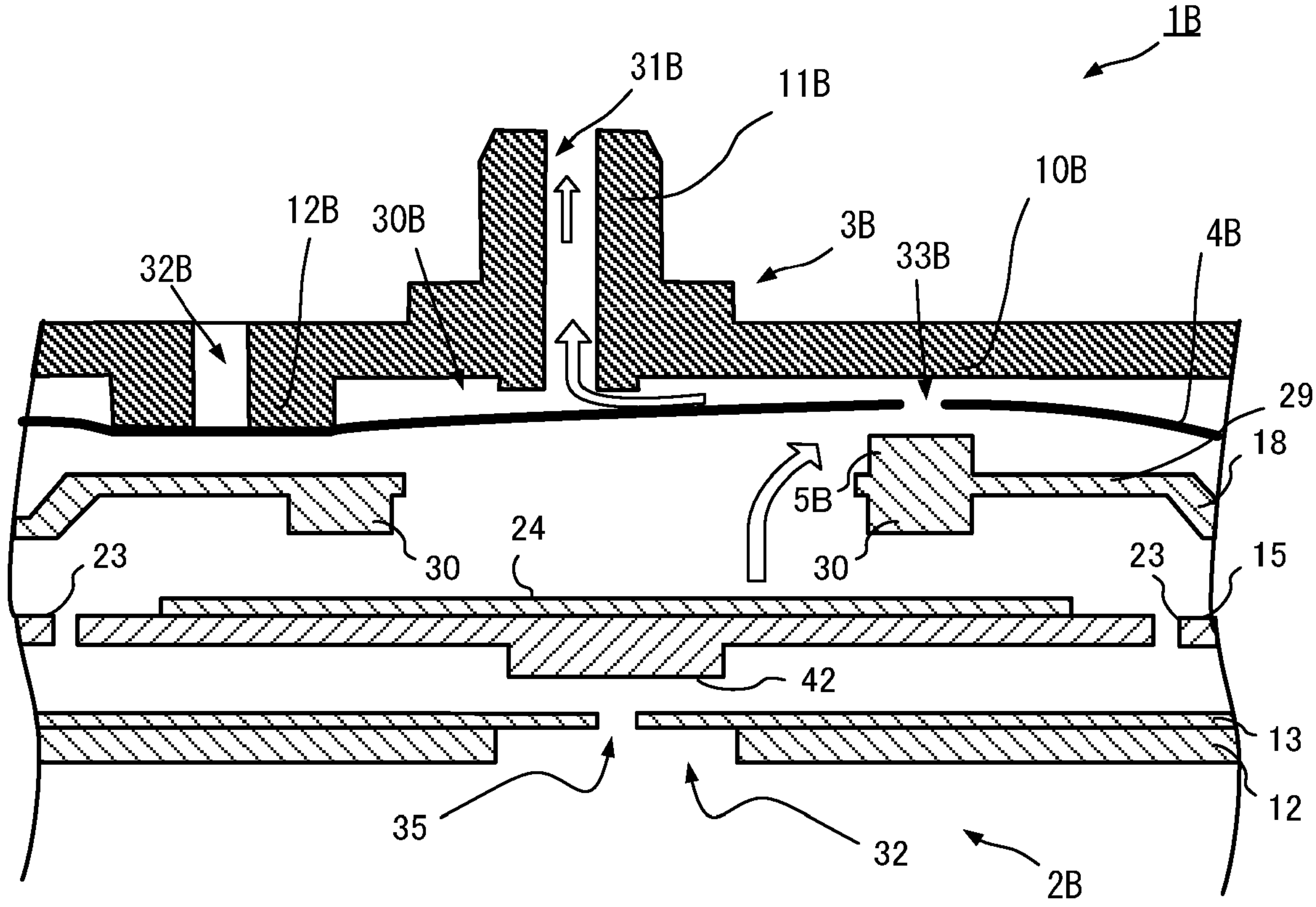


Fig. 11

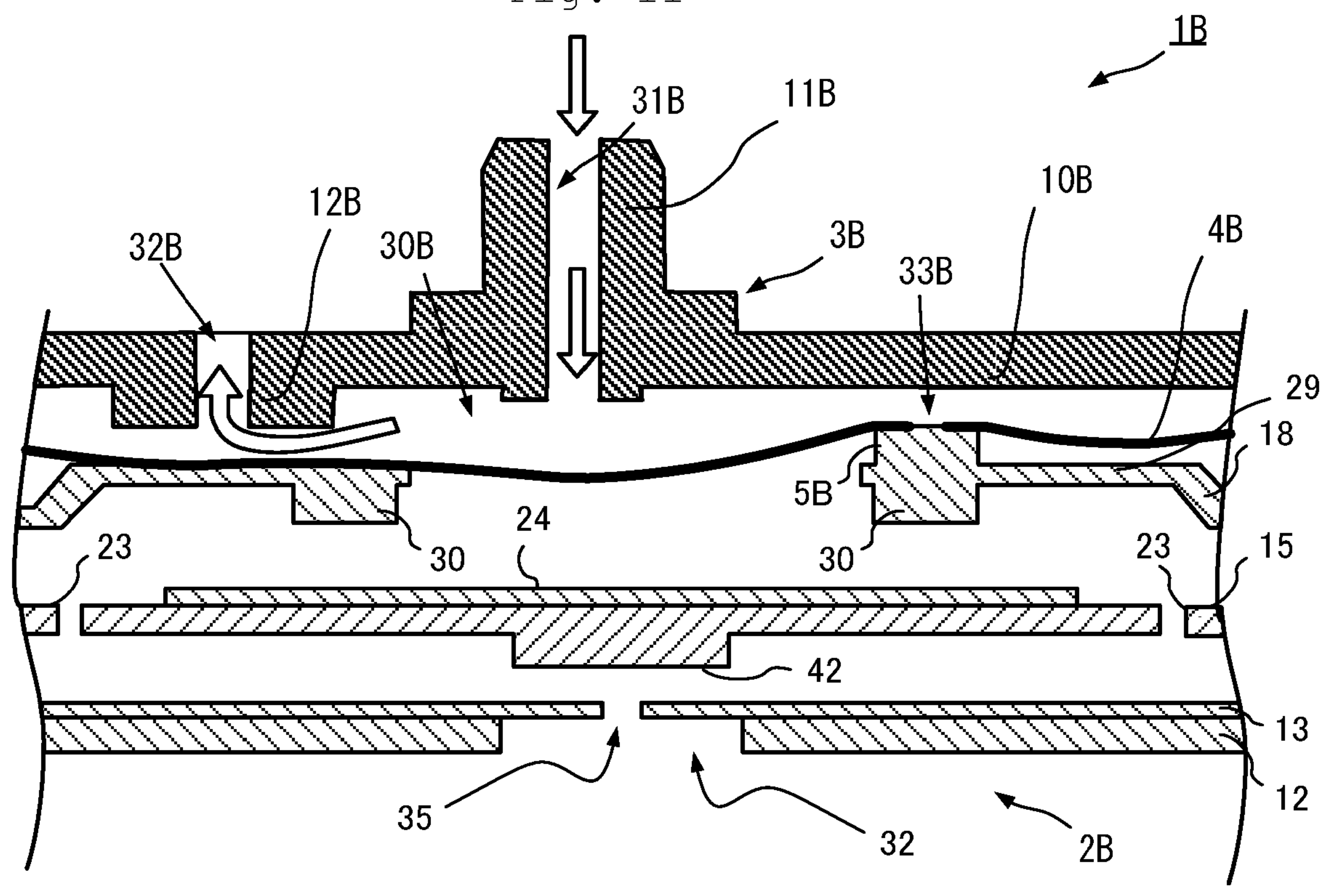
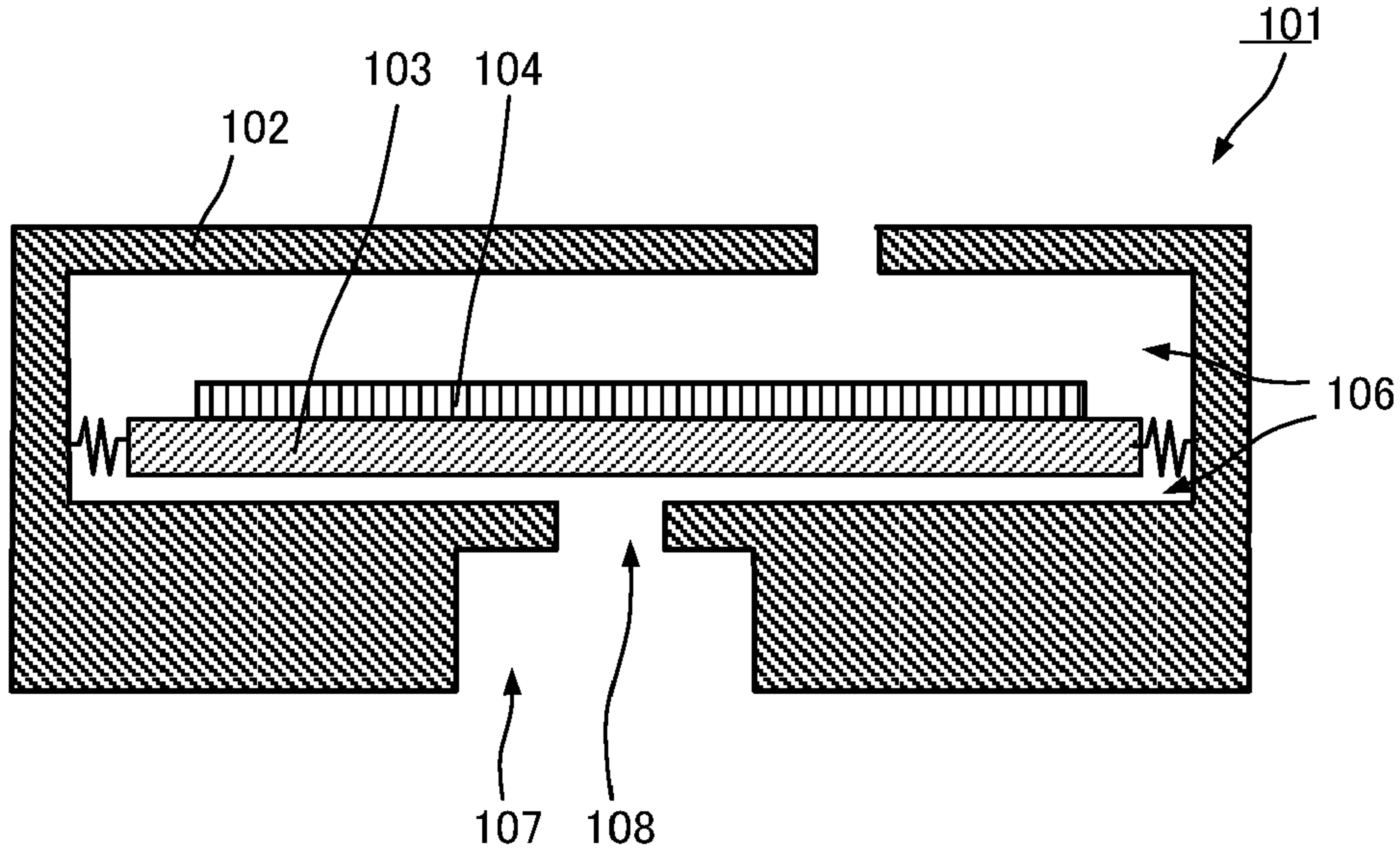


Fig. 12



Prior Art

PUMP

Technical Field

Preferred embodiments of the present invention relate to a pump that sucks and discharges fluid.

Background Art

Fig. 12 is a conceptual view of a conventional pump (see Japanese Unexamined Patent Application Publication No. 2013-068215, for example).

A pump 101 shown in Fig. 12 is provided with a pump housing 102 and a vibrating portion 103. The pump housing 102 interiorly has a pump chamber 106 and a flow path 107. The vibrating portion 103 is housed in the pump chamber 106, faces a connection portion (opening) 108 of the flow path 107 to the pump chamber 106 with a spacing between each other, and is adjacent to the opening 108. The vibrating portion 103 is elastically coupled to the pump housing 102 so as to vibrate in a direction opposite to the opening 108. The vibrating portion 103 is provided with a driving portion 104, and the driving portion 104 vibrates the vibrating portion 103 in the direction opposite to the opening 108.

In the conventional pump 101, an impact load is added to the pump housing 102, so that inertial force works on the vibrating portion 103 and thus excessive displacement has sometimes occurred in the vibrating portion 103. Then, tensile stress exceeding a yield point acts on the vibrating portion 103, and the vibrating portion 103 has sometimes been plastically deformed. Accordingly, in the pump 101, when the impact load is applied, a failure or characteristic degradation might have occurred.

In particular, in a case of a biological information acquisition device that is often carried and used, there is a high possibility that the biological information acquisition device is dropped out of carelessness and the impact load is then applied to a pump provided in the biological information acquisition device. The biological information acquisition device is, for example, a wrist type sphygmomanometer

In view of the foregoing, preferred embodiments of the present invention are directed to provide a pump with improved impact resistance.

SUMMARY OF INVENTION

A pump according to preferred embodiments of the present invention includes: a pump housing internally including a pump chamber; a vibrating portion being supported against the pump housing in the pump chamber, dividing the pump chamber into a first pump chamber and a second pump chamber each including an inner wall, and being driven so as to bend and vibrate in a predetermined direction; and a displacement regulating portion projecting from the inner wall of the first pump chamber and facing the vibrating portion. The vibrating portion is configured by a driving portion and a vibrating plate, for example. The driving portion may be a piezoelectric element, for example. The displacement regulating portion faces an outer peripheral portion of the vibrating portion without facing a center portion of the vibrating portion

In this configuration, even when the vibrating portion is about to be excessively displaced by the impact load or the like, displacement of the vibrating portion is regulated by the displacement regulating portion. Therefore, the vibrating portion is able to be prevented from being displaced excessively, and thus the failure of the pump or a large reduction in pump efficiency due to large plastic deformation of the vibrating portion are able to be prevented. Accordingly, the impact resistance of the pump is improved.

The pump of this configuration is able to prevent the displacement regulating portion from blocking the flow of fluid near the central portion of the vibrating portion. Moreover, the pump of this configuration is able to make the supporting portion provided with the displacement regulating portion comparatively short and hard to vibrate. Therefore, the pump of this configuration is able to prevent the flow of fluid being blocked due to the vibration of the displacement regulating portion.

It is to be noted that the pump according to the present invention may be provided with a displacement regulating portion projecting from the inner wall of the second pump chamber and facing the vibrating portion.

The displacement regulating portion may preferably be positioned in a space in which the vibrating portion is able to be positioned when the vibrating portion elastically deforms. This elastic deformation, for example, is deformation also including unintended movement due to physical impact. In this configuration, the vibrating portion is able to be reliably prevented from plastically deforming. The displacement regulating portion may not preferably be positioned in a space in which the vibrating portion is able to be positioned when the vibrating portion bends and vibrates. This space is a space in which, when the driving portion drives and the vibrating plate deforms by the driving portion, both the driving portion and the vibrating plate are able to move. In this configuration, it is possible to prevent (reduce) the displacement regulating portion from interfering in the vibrating portion that bends and vibrates.

The pump may preferably include: a flat plate-shaped member configuring the displacement regulating portion, and the pump is configured as a laminate of a plurality of flat plate-shaped members; and the flat plate-shaped member includes: a supporting portion projecting from the side of the pump housing to the pump chamber; and a projecting portion projecting from the supporting portion to the side of the vibrating portion. In this configuration, since the flat plate-shaped members are stacked to configure a pump, it is easy to manufacture a pump and it is possible to make the pump thin.

The flat plate-shaped member may preferably further include an internal connection terminal extending and projecting from the side of the pump housing to the pump chamber and having a tip connected to the vibrating portion. In this configuration, the flat plate-shaped member configuring the displacement regulating portion serves as a member for performing power supply to the vibrating portion, so that it is possible to reduce the number of flat plate-shaped members and further make the pump thin.

The vibrating portion may preferably bend and vibrate in a high-order resonance mode. In this configuration, it is possible to reduce the amplitude of vibration in the outer peripheral portion of the vibrating portion and to make the vibration of the vibrating portion hard to leak to the pump housing.

In addition, the displacement regulating portion may preferably face a position to be a node of the bending vibration of the vibrating portion without facing the center portion of the vibrating portion. In this configuration, even when the vibrating portion bends and vibrates, a distance between the displacement regulating portion and the vibrating portion is almost unchanged and is able to be kept constant. Therefore, it is possible to reliably prevent the flow of fluid from being blocked due to changes in the distance between the displacement regulating portion and the vibrating portion.

Alternatively, the displacement regulating portion may preferably face a position to be an antinode of the bending vibration of the vibrating portion without facing the center portion of the vibrating portion. In this configuration, even when abnormal drive power works on the driving portion and the vibrating portion is about to be excessively displaced, the displacement of the vibrating portion is regulated by the displacement regulating portion. Therefore, the pump of this configuration is able to prevent the vibrating portion from being displaced excessively, and thus the failure of the pump or a large reduction in pump efficiency due to large plastic deformation of the vibrating portion are able to be prevented. Accordingly, the pump of this configuration is able to increase a rated input.

The rated input is the maximum value of the input with which the pump does not fail. For example, in a case in which the pump is driven with a voltage, the rated input is the maximum value of the voltage with which the pump does not fail.

The pump, as the displacement regulating portion, may preferably include a plurality of displacement regulating portions that are aligned at intervals from each other. In this configuration, when the displacement regulating portion and the vibrating portion are in contact with each other, it is possible to prevent (reduce) the inclination of the vibrating portion. In addition, it is also possible to reduce an area in which the displacement regulating portion and the vibrating portion face each other and to more reliably prevent the flow of fluid being blocked by the displacement regulating portion.

The pump may preferably be provided with three or more displacement regulating portions as the displacement regulating portion. Since the vibrating portion becomes in parallel with a plane connecting the three or more displacement regulating portions when contacting the displacement regulating portion, the pump of this configuration is able to more reliably prevent the vibrating portion from inclining.

Furthermore, the center of gravity of the vibrating portion may preferably fall inside the three or more displacement regulating portions. Since at least one or more of the displacement regulating portions regulate the inclination of the vibrating portion, the pump of this configuration is able to more reliably prevent the inclination of the vibrating portion.

According to various preferred embodiments of the present invention, it is possible to prevent a vibrating portion from being displaced excessively by a displacement regulating portion when an impact load or the like acts on a pump and to improve the impact resistance of the pump.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross-sectional view of a pump 1 according to a first preferred embodiment of the present invention.

Fig. 2 is an external perspective view of a pump 1A according to a second preferred embodiment of the present invention.

Fig. 3 is an exploded perspective view of the pump 1A.

Fig. 4A is a perspective view of the top surface side of a vibrating plate 15. Fig. 4B is a perspective view of the bottom surface side of the vibrating plate 15.

Fig. 5A is a perspective view of the top surface side of a power feeding plate 18. Fig. 5B is a perspective view of the bottom surface side of the power feeding plate 18.

Fig. 6A is a sectional side elevational view of the pump 1 viewed from the power feeding plate 18 to a flow path plate 12, and shows a cross-section taken along a line A-A' in Fig. 6B. Fig. 6B is a plan view of a vibrating portion 24 and the power feeding plate 18.

Fig. 7 is a graph showing a change of pump characteristics (the maximum pressure force) before and after an impact test in which samples of the pump 1A according to the second preferred embodiment of the present invention and a pump 101 (see Fig. 12) according to a conventional configuration are dropped from the height of 50 cm is performed.

Fig. 8A is a perspective view of the top surface side of a power feeding plate 18A with which a pump according to a third preferred embodiment is provided. Fig. 8B is a perspective view of the bottom surface side of the power feeding plate 18A.

Fig. 9 is a plan view of the power feeding plate 18A and the vibrating portion 24.

Fig. 10 is an exploded perspective view of a pump 1B according to a fourth preferred embodiment of the present invention.

Fig. 11A and Fig. 11B are schematic cross-sectional views of a main portion of the pump 1B. Fig. 11A shows a case in which fluid flows in a forward direction, and Fig. 11B shows a case in which fluid flows in a reverse direction.

Fig. 12 is a conceptual view of a conventional pump (see JP 2013-068215, for example).

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Hereinafter, a plurality of preferred embodiments of a pump according to the present invention will be described by taking a case in which an air pump that sucks and discharges gas is configured as an example. It is to be noted that the pump according to the present invention is able to configure not only an air pump but also a pump that generates a flow of proper fluid such as liquid, vapor-liquid mixed fluid, gas-solid mixed fluid, solid-liquid mixed fluid, gel, or gel mixing fluid.

<u>First Preferred Embodiment</u>

First, a description will be made of the schematic configuration of a pump according to the present invention.

Fig. 1 is a schematic cross-sectional view of a pump 1 according to a first preferred embodiment of the present invention.

The pump 1 is provided with a pump housing 2, a vibrating plate 3, a driving portion 4, and a displacement regulating portion 5. The pump housing 2 internally has a pump chamber 6 and a flow path 7. The flow path 7 has an opening 8 connected to the pump chamber 6. The vibrating plate 3 and the driving portion 4 are integrally stacked and configure a vibrating portion 9. The vibrating portion 9 is housed in the pump chamber 6, and is adjacent to and faces the opening 8 with a spacing between the vibrating portion 9 and the opening 8. The vibrating portion 9 is elastically linked to the pump housing 2 so as to be displaceable in a direction facing the opening 8, and generates vibration in the direction facing the opening 8 when a drive voltage is applied to the driving portion 4. The vibrating portion 9 divides the pump chamber 6 into a first pump chamber and a second pump chamber. The displacement regulating portion 5 projects from the inner wall of the pump chamber 6 and faces the vibrating portion 9 with a spacing between the displacement regulating portion 5 and the vibrating portion 9, on a side opposite to the opening 8.

Therefore, inertial force works on the vibrating portion 9 by the action of an impact load or the like, and, even when the vibrating portion 9 is about to be excessively displaced to the side opposite to the opening 8, excessive displacement of the vibrating portion 9 is regulated by the displacement regulating portion 5. Accordingly, it is possible to reduce large plastic deformation of the vibrating portion 9 and achieve the high impact resistance of the pump 1.

It is to be noted that the displacement regulating portion 5 is positioned in a space of the pump chamber 6 in which the vibrating portion 9 is able to be positioned when the vibrating portion 9 elastically deforms. This elastic deformation, for example, is deformation also including unintended movement due to physical impact. Accordingly, tensile stress exceeding a yield point does not act on the vibrating plate 3, so that the plastic deformation of the vibrating plate 3 is able to be reliably prevented.

The displacement regulating portion 5 is not positioned in the space of the pump chamber 6 in which the vibrating portion 9 is able to be positioned when the vibrating portion 9 bends and vibrates. This space is a space in which, when the driving portion 4 drives and the vibrating plate 3 deforms by the driving portion 4, both the driving portion 4 and the vibrating plate 3 are able to move. Accordingly, the displacement regulating portion 5 does not interfere in (contact) the vibrating portion 9 that vibrates by the normal drive of the driving portion 4, which can prevent (reduce) the vibration of the vibrating portion 9 from being blocked.

Therefore, this pump 1 has a high impact resistance, and, even when an impact load or the like acts on the pump 1, a failure or characteristic degradation is unlikely to occur.

As shown in Fig. 1, the displacement regulating portion 5 may preferably be closer to the vibrating plate 3 than to the driving portion 4. This is because, while the driving portion 4 is generally made of an impact-sensitive material such as a piezoelectric body, the vibrating plate 3 has a spring property and is often made of an impact-resistant metal material. Thus, the pump 1 is able to more reliably prevent the breakage of the vibrating portion 9.

It is to be noted that, in a case in which the displacement regulating portion 5 is adjacent to the driving portion 4, as shown in Fig. 1, the vibrating plate 3 may preferably be attached to the entire lower principal surface of the driving portion 4. Accordingly, the pump 1 is able to more reliably prevent the breakage of the vibrating portion 9. Hereinafter, a description is made of a more detailed configuration example of the pump according to the second preferred embodiment of the present invention.

<u>Second Preferred Embodiment</u>

Fig. 2 is an external perspective view of a pump 1A according to a second preferred embodiment of the present invention.

The pump 1A is provided with a pump housing 2A and external connection terminals 3A and 4A. The external connection terminals 3A and 4A are connected to an external power source, and an alternating current drive signal is applied to the external connection terminals 3A and 4A. The pump housing 2A has a principal surface (upper principal surface) 5A and a principal surface (lower principal surface) 6A, and is a hexahedron having a thin body between the upper principal surface 5A and the lower principal surface 6A. In addition, the pump housing 2A internally has a pump chamber 7A, has a flow path hole 41 leading to the pump chamber 7A on the upper principal surface 5A, and has a flow path hole 31 (see Fig. 3) leading to the pump chamber 7A on the lower principal surface 6A.

Fig. 3 is an exploded perspective view of the pump 1A. The pump 1A is provided with components including a cover plate

11, a flow path plate 12, a facing plate 13, an adhesive layer 14 (not shown), a vibrating plate 15, a piezoelectric element 16, an insulating plate 17, a power feeding plate 18, a spacer plate 19, and a lid plate 20, and has a structure in which the above components are stacked from the lower principal surface 6A to the upper principal surface 5A in order.

The cover plate 11, the flow path plate 12, and the facing plate 13 include a flow path leading to the flow path hole 31 of the lower principal surface 6A (see Fig. 2). The pump chamber 7A (Fig. 2) is formed in contact with the adhesive layer 14 (not shown), the vibrating plate 15, the insulating plate 17, the power feeding plate 18, and the spacer plate 19. The lid plate 20 includes a flow path leading to the flow path hole 41 of the upper principal surface 5A (Fig. 2).

The cover plate 11 has three flow path holes 31. Each of the flow path holes 31 is circle-shaped, and functions as an air intake hole that opens to the lower principal surface 6A of the pump housing 2 and sucks gas from an external space, in the second preferred embodiment of the present invention. In addition, the three flow path holes 31 are positioned away from the center position of the cover plate 11 in a plan view. More specifically, each of the flow path holes 31 is arranged so that the angles formed by a line segment, connecting each of the flow path holes 31 and the center position may be equal angles.

The flow path plate 12 has one opening 32, three flow paths 33, and six adhesive sealing holes 34. The opening 32 is provided in a circular shape with a comparatively large area around the center position of the flow path plate 12. The opening 32 is covered with the cover plate 11 from a bottom surface side and in communication with a flow path hole 35 of the facing plate 13 to be described below at a top surface side.

The three flow paths 33 each extend from a first end to a second end in a radial direction from the opening 32 provided near the center of the flow path plate 12. The first end of each of the flow paths 33 is in communication with the opening 32. The second end of each of the flow paths 33 is in communication with each of the three flow path holes 31 of the cover plate 11. The upper side of each of the three flow path holes 33 except for the second end 332 is covered with the facing plate 13. The lower sides of each of the flow paths 33 except for the second end covered with the cover plate 11.

The six adhesive sealing holes 34 are arranged with a spacing between each other along the outer periphery of the pump chamber 7A (see Fig. 2). More specifically, each of the adhesive sealing holes 34 extends along the outer periphery of the pump chamber 7A so as to face a position in which a frame portion 22 of the vibrating plate 15 and a link portion 23 to be described below are connected to each other. Each of the adhesive sealing holes 34 is covered with the cover plate 11 from a bottom surface side and in communication with an adhesive sealing hole 36 of the facing plate 13 to be described below at a top surface side.

The facing plate 13 is made of metal, and is provided with an external connection terminal 3A so as to project outward. In addition, the facing plate 13 has one flow path hole 35 and six adhesive sealing holes 36.

The flow path hole 35 is provided in a circular shape with a diameter smaller than the opening 32 of the flow path plate 12, around the center position of the facing plate 13. The flow path hole 35 is in communication with the opening 32 of the flow path plate 12 at a bottom surface side and a top surface side in communication with the pump chamber 7A (see Fig. 2) at a top surface side.

The six adhesive sealing holes 36 are arranged with a spacing between each other along the outer periphery of the pump chamber 7A (see Fig. 2). More specifically, each of the adhesive sealing holes 36 extends along the outer periphery of the pump chamber 7A so as to face a position in which the frame portion 22 of the vibrating plate 15 and the link portion 23 to be described below are connected to each other. Each of the adhesive sealing holes 36 is in communication with each of the adhesive sealing holes 34 of the flow path plate 12 at a bottom surface side and facing the adhesive layer 14 (not shown) at a top surface side.

The adhesive sealing holes 34 and 36 are provided in order to prevent the adhesive layer 14 (not shown) in an uncured state from overflowing into the pump chamber 7A (see Fig. 2) and adhering to the link portion 23 of the vibrating plate 15. When the adhesive layer 14 in an uncured state adheres to the link portion 23, the vibration of the link portion 23 is blocked and thus variation in the characteristics of each product is caused. Accordingly, the adhesive sealing holes 34 and 36 are provided so as to cause overflowing adhesives to flow into the adhesive sealing holes 34 and 36, which prevents the adhesive layer 14 from overflowing into the pump chamber 7A and also reduces the variation in the characteristics of each product.

The adhesive layer 14 (not shown) is provided in a frame shape having a circular opening in a plan view so as to overlap with the frame portion 22 of the vibrating plate 15 to be described below. The space surrounded by the frame of the adhesive layer 14 configures a portion of the pump chamber 7A (see Fig. 2). The adhesive layer 14 is configured by containing a plurality of conductive particles each having a substantially uniform particle diameter in a thermosetting resin such as an epoxy resin. Each of the conductive particles is configured as silica or resin coated with a conductive metal, for example. In this manner, since the adhesive layer 14 contains the plurality of conductive particles, the thickness of the entire circumference of the adhesive layer 14 is substantially matched with the particle diameter of the conductive particle, and is able to be made uniform. Therefore, the adhesive layer 14 is able to cause the facing plate 13 and the vibrating plate 15 to face each other with a constant spacing between the facing plate 13 and the vibrating plate 15. In addition, the facing plate 13 and the vibrating plate 15 are able to be made electrically connected to each other through the conductive particles of the adhesive layer 14.

The vibrating plate 15 may be made of metal such as SUS 430, for example. Fig. 4A is a perspective view of the top surface side of the vibrating plate 15. Fig. 4B is a perspective view of the bottom surface side of the vibrating plate 15.

The vibrating plate 15 is provided with a circular plate portion 21, a frame portion 22, and three link portions 23, and has a plurality of openings 37 surrounded by the circular plate portion 21, the frame portion 22, and the link portions 23. The plurality of openings 37 configure a portion of the pump chamber 7A (see Fig. 2). The circular plate portion 21 has a circular shape in a plan view. The frame portion 22 has a frame shape provided with a circular opening in a plan view, and surrounds the circular plate portion 21 with a spacing between the frame portion 22 and the circular plate portion 21. Each of the link portions 23 links the circular plate portion 21 and the frame portion 22. The circular plate portion 21 is supported against the link portions 23 in a state of floating inside the pump chamber 7A (see Fig. 2).

The bottom surface (see Fig. 4B) of the circular plate portion 21 has a convex portion 42 in which a circular region is configured in a convex shape in the vicinity of or adjacent to the central portion of the bottom surface of the circular plate portion 21. By providing the convex portion 42 on the bottom surface of the circular plate portion 21, the convex portion 42 is adjacent to the flow path hole 35 of the facing plate 13, which is able to increase the pressure fluctuation of fluid that is generated accompanying vibration of the circular plate portion 21. In addition, in a region in which the convex portion 42 is not provided, the spacing between the circular plate portion 21 and the facing plate 13 is increased. Since the region in which the convex portion 42 is not provided is a region that does not contribute to a pump operation directly, by increasing the space between the circular plate portion 21 and the facing plate 13 in this region, the driving load of the piezoelectric element 16 is able to be reduced and the pressure of fluid and the flow amount that are generated by the pump operation, and a pump efficiency are able to be improved. It is to be noted that, while, in the second preferred embodiment of the present invention, an example in which the convex portion 42 is provided on the bottom surface of the circular plate portion 21 is shown, the bottom surface of the circular plate portion 21 may be made into a flat shape, and the circumference of the flow path hole 35 may be made into a convex shape with respect to the facing plate 13 facing the circular plate portion 21.

The link portions 23 are each approximately T-shaped, and are arranged with a spacing in an equiangular direction. Specifically, each of the link portions 23 has an end on the side of the center of the vibrating plate 15, the end being linked with the circular plate portion 21, and extends from the circular plate portion 21 in a radial direction, splits into two forks, extends along the outer periphery of the pump chamber 7A, bends towards the frame portion 22, reaches the frame portion 22, and is linked with the frame portion 22. Since each of the link portions 23 has such a shape, the edge of the circular plate portion 21 is supported against the frame portion 22 so as to be displaceable in the vertical direction and hardly be displaced in a plane direction.

The piezoelectric element 16 as shown in Fig. 3 is configured by providing electrodes on the top and bottom surfaces of a circular plate made of a piezoelectric material. The electrode on the top surface of the piezoelectric element 16 is electrically connected to an external connection terminal 4A through the power feeding plate 18. The electrode on the bottom surface of the piezoelectric element 16 is electrically connected to an external connection terminal 3A through the vibrating plate 15, the adhesive layer 14, and the facing plate

13. It is to be noted that the electrode on the bottom surface of the piezoelectric element 16 may not be provided and may be replaced by the vibrating plate 15 made of metal. This piezoelectric element 16, when an electric field is applied in the thickness direction of the piezoelectric element 16, has a piezoelectric property such that an area may be increased or reduced in the in-plane direction. The use of the piezoelectric element 16 is able to make the vibrating portion 24 to be described below thin and is also able to downsize the pump 1.

The piezoelectric element 16 is attached to the circular plate portion 21 with a not shown adhesive or the like, and configure the vibrating portion 24. The vibrating portion 24 has a unimorph structure of the piezoelectric element 16 and the circular plate portion 21, and is configured so as to generate bending vibration in the vertical direction when the area vibration of the piezoelectric element 16 is restrained by the circular plate portion 21. Since the outer peripheral portion of the circular plate portion 21 is supported vertically by the link portion 23 to be displaceable as described above, the bending vibration that is generated in the vibrating portion 24 is hardly blocked by the link portion 23. It is to be noted that, since the vibrating portion 24 is able to be displaced in the vertical direction, when an impact load or acceleration acts on the pump 1A, displacement in the vertical direction will occur in the vibrating portion 24.

The insulating plate 17 has a frame shape having a circular opening 38 in a plan view. The opening 38 configures a portion of the pump chamber 7A (see Fig. 2). The insulating plate 17 is made of an insulating resin and insulates electrically between the power feeding plate 18 and the vibrating plate 15. This makes it possible to apply a driving voltage to the electrodes of the top and bottom surfaces of the piezoelectric element 16 through the power feeding plate 18 and the vibrating plate 15. It is to be noted that the power feeding plate 18 and the vibrating plate 15 may be insulated, other than by providing the insulating plate 17, by coating the surface of the vibrating plate 15 or the power feeding plate 18 with an insulating material or by providing an oxide layer on the surface of the vibrating plate 15 or the power feeding plate 18.

The power feeding plate 18 is metal. Fig. 5A is a perspective view of the top surface side of the power feeding plate 18. Fig. 5B is a perspective view of the bottom surface side of the power feeding plate 18.

The power feeding plate 18 is provided with an external connection terminal 4A, an internal connection terminal 27, a frame portion 28, a supporting portion 29, and a displacement regulating portion 30, and has an opening 39 surrounded by the supporting portion 29. The opening 39 configures a portion of the pump chamber 7A (see Fig. 2). The internal connection terminal 27 is provided so as to project from the frame portion 28 to the opening 39, and has a tip soldered to the electrode of the top surface of the piezoelectric element 16.

The supporting portion 29 has a circular outside shape in a plan view and has a frame shape that surrounds the opening 39. The frame portion 28 has a frame shape that surrounds the supporting portion 29 in a plan view. In the second preferred embodiment of the present invention, the power feeding plate 18 has a level difference between the supporting portion 29 and the frame portion 28, the supporting portion 29 is recessed more than the frame portion 28 on the bottom surface of the power feeding plate 18, and the frame portion 28 is recessed from the supporting portion 29 on the top surface of the power feeding plate 18. Since, when the top surface of the piezoelectric element 16 excessively approaches the supporting portion 29, the amplitude of oscillation is reduced due to air resistance, the supporting portion 29 is caused to be recessed more than the frame portion 28 on the bottom surface of the power feeding plate 18 in order to prevent the piezoelectric element 16 from excessively approaching the supporting portion 29.

The supporting portion 29 has three wave-shaped portions 43 that project to the opening 39, in other words, that project toward the center of the supporting portion 29. Each of the wave-shaped portions 43 is continuously arranged in a wavelike manner in a plan view. The three wave-shaped portions 43 are provided in three regions, respectively, out of the regions obtained by dividing the opening 39 into four regions at equal angles. It is to be noted that the tip of the internal connection terminal 27 is positioned in one remaining region of the regions obtained by dividing the opening 39 into four regions at equal angles.

Each of the wave-shaped portions 43 includes the displacement regulating portion 30 provided on the bottom surface (see Fig. 5B) of the wave-shaped portions 43. Each of the displacement regulating portions 30 corresponds to a projecting portion, has a circular shape in a plan view, and projects downward from the bottom surface of each of the wave-shaped portions 43. Each of the displacement regulating portions 30 is provided in order to prevent the link portion 23 of the vibrating plate 15 from excessively extending, by contacting the top surface of the piezoelectric element 16 at the time of the action of the impact load or the like. It is to be noted that the bottom surface of each of the displacement regulating portions 30 is provided in height that does not interfere with the bending vibration of the vibrating portion 24.

The displacement regulating portion 30, as shown in Fig. 5B, compared with a pointed shape, may preferably have a planar shape. When the excessive displacement of the vibrating portion

24 is regulated by the displacement regulating portion 30, the impact load is able to be received by a plane, so that the stress concentrated on both the displacement regulating portion 30 and the vibrating portion 24 is relieved. Therefore, the displacement regulating portion 30 having a plane shape is able to prevent both the displacement regulating portion 30 and the vibrating portion 24 from being damaged.

In addition, the spacer plate 19 as shown in Fig. 3 is made of a resin and is in a substantially frame shape having a circular opening 40 in a plan view. The opening 40 configures a portion of the pump chamber 7A (see Fig. 2).

The lid plate 20 closes the top surface of the pump chamber 7A (see Fig. 2). In the second preferred embodiment of the present invention, the lid plate 20 has a flow path hole 41 that opens to the upper principal surface 5A of the pump housing 2. The flow path hole 41 has a circular shape in a plan view, and is in communication with the external space and also in communication with the opening 40 of the spacer plate 19, that is, the pump chamber 7A. The flow path hole 41 is an exhaust air hole that discharges gas to the external space in the second preferred embodiment of the present invention. It is to be noted that, while the flow path hole 41 is provided in the center position of the lid plate 20 in the second preferred embodiment of the present invention, the flow path hole 41 may be provided in a position away from the center position of the lid plate 20.

Fig. 6A is a sectional side elevational view of the pump 1 viewed from the power feeding plate 18 to the flow path plate 12, and shows a cross-section taken along a line A-A' in Fig. 6B.

In the pump 1A, an alternating current drive signal is applied to the external connection terminals 3A and 4A, so that an alternating electric field is applied in the thickness direction of the piezoelectric element 16. Then, the piezoelectric element 16 tends to evenly expand and contract in the in-plane direction, and thus the bending vibration in the thickness direction is generated concentrically in the vibrating portion 24 of the piezoelectric element 16 and the circular plate portion 21.

In the second preferred embodiment of the present invention, the alternating current drive signal applied to the external connection terminals 3A and 4A is set so as to have the frequency that generates in the vibrating portion 24 a bending vibration in a third-order resonance mode. In a case in which the vibrating portion 24 bends and vibrates in the third-order resonance mode, an antinode of a first vibration occurs in the central portion of the vibrating portion 24, an antinode of a second vibration of which the phase is different by 180 degrees from the phase of the first vibration occurs at the outer edge portion of the vibrating portion 24, and a node of vibration occurs in the intermediate portion between the central portion and the outer edge portion of the vibrating portion 24. Thus, if the vibrating portion 24 is bent and vibrated in the high-order (and odd number-order) resonance mode, compared with a case of being bent and vibrated in a first-order resonance mode, vibration such that the vibrating portion 24 does not bend but vibrates in the vertical direction becomes unlikely to occur, and the amplitude of oscillation in the outer peripheral portion of the vibrating portion 24 becomes smaller and the vibration becomes unlikely to leak to the pump housing 2A (see Fig. 2).

The bending vibration occurs in the vibrating portion 24 as described above, so that, in the vibrating portion 24, the convex portion 42 is repeatedly displaced up and down, and the convex portion 42 is repeatedly beaten against a thin fluid layer of a gap between the convex portion 42 and the facing plate 13. Accordingly, repeated pressure fluctuation occurs in the fluid layer that faces the convex portion 42, and the pressure fluctuation is transmitted through fluid to the region (hereinafter will be referred to as a movable portion 44) of the facing plate 13 that faces the convex portion 42. The movable portion 44, since facing the opening 32 of the flow path plate 12, is thin, and is configured so as to bend and vibrate. Therefore, the movable portion 44, in response to the bending vibration of the vibrating portion 24, generates bending vibration having the same frequency as and a different phase from the bending vibration of the vibrating portion 24.

The vibration of the vibrating portion 24 and the vibration of the movable portion 44 that are generated in this manner are coupled to each other, and thus, inside of the pump chamber 7A, a distance of the gap between the convex portion 42 and the movable portion 44 varies from a vicinity to an outer periphery side of the flow path hole 35 in the form of traveling waves. Accordingly, fluid comes to flow from the vicinity to the outer periphery side of the flow path hole 35 inside of the pump chamber 7A. Thus, a negative pressure occurs around the flow path hole 35 inside of the pump chamber 7A, the fluid is sucked from the flow path hole 35 to the pump chamber 7A, and then the fluid of the pump chamber 7A is to be discharged outside through the flow path hole 41 provided in the lid plate 20.

Fig. 6B is a plan view of a vibrating portion 24 and the power feeding plate 18.

The displacement regulating portion 30 of the power feeding plate 18 is provided so as to face the top surface side of the vibrating portion 24 with a spacing. More specifically, in the second preferred embodiment of the present invention, the displacement regulating portion 30 is not provided so as not to face a position in which the antinode of the first vibration or the antinode of the second vibration of the vibrating portion 24 occurs but so as to face a position in which a node of vibration occurs. Therefore, even when the bending vibration occurs in the vibrating portion 24, the distance between the vibrating portion 24 and the displacement regulating portion 30 is not changed and a constant distance is kept. Accordingly, even when the displacement regulating portion 30 is provided, the vibration of the vibrating portion 24 is hardly blocked and thus a good pump efficiency is able to be achieved.

In addition, the displacement regulating portion 30 includes a plurality of displacement regulating portions 30 that are dispersedly provided, and three displacement regulating portions 30 are provided in the second preferred embodiment of the present invention. Therefore, when the vibrating portion 24 is displaced due to an impact load or the like and the vibrating portion 24 comes into contact with the displacement regulating portion 30, it is possible to prevent inclination so that the vibrating portion 24 may come into contact with the plurality of displacement regulating portions 30. In addition, it is also possible to reduce an area in which the displacement regulating portions 30 and the vibrating portion 24 face each other and to more reliably prevent the flow of fluid being blocked by the displacement regulating portions 30.

It is to be noted that the tip of the internal connection terminal 27 is soldered to a position being the node of vibration in the vibrating portion 24. In addition, the internal connection terminal 27, with respect to a concentric circular area in which the node of vibration of the piezoelectric element 16 occurs, extends in the tangential direction of the concentric circular area. As a result, it is possible to significantly reduce or prevent the vibration from leaking from the piezoelectric element 16 to the internal connection terminal 27, to achieve further improvement in pump efficiency, and also to prevent breakage of the internal connection terminal 27 due to vibration.

In the pump 1A according to the second preferred embodiment with the above configuration, as is the case with the first preferred embodiment, even when an impact load or the like acts, it is also possible to regulate excessive displacement of the vibrating portion 24 by the displacement regulating portion 30 and to significantly reduce or prevent large plastic deformation of the link portion 23, and thus the impact resistance of the pump 1A becomes high. Fig. 7 is a graph showing a change of pump characteristics (the maximum pressure force) before and after an impact test in which samples of the pump 1A according to the second preferred embodiment of the present invention and a pump 101 (see Fig. 12) according to a conventional configuration are dropped from the height of 50 cm is performed. In the pump 1A according to the second embodiment of the present invention, while specific degradation in the pump characteristics before and after the impact test has not occurred, in the pump 101 according to a conventional configuration, serious degradation in the pump characteristics has occurred by the impact test. Thus, the pump 1A according to the second preferred embodiment of the present invention has a high impact resistance, and, even when an impact load or the like acts on the pump 1A, a failure or characteristic degradation is unlikely to occur.

Third Preferred Embodiment

Subsequently, a description will be made of a pump according to a third preferred embodiment of the present invention.

Fig. 8A is a perspective view of the top surface side of a power feeding plate 18A with which the pump according to the third preferred embodiment of the present invention is provided. Fig. 8B is a perspective view of the bottom surface side of the power feeding plate 18A.

The power feeding plate 18A is provided with an external connection terminal 4A, an internal connection terminal 27, a frame portion 28, a supporting portion 29A, and a displacement regulating portion 30A, and has an opening 39A surrounded by the supporting portion 29A. In the third preferred embodiment of the present invention, the configuration of the external connection terminal 4A, the internal connection terminal 27, and the frame portion 28 is almost the same as the configuration according to the second preferred embodiment, and the configuration of the supporting portion 29A, the displacement regulating portion 30A, and the opening 39A is different from the configuration according to the second preferred embodiment. Specifically, the displacement regulating portion 30A is mountain-shaped and is provided along the outer peripheral portion of the supporting portion 29A. The supporting portion 29A is provided with three wave-shaped portions 43A, and the wave-shaped portions 43A have smaller unevenness as compared with the configuration according to the second preferred embodiment of the present invention. The opening 39A has an area that is enlarged by only a portion in which the unevenness of the wave-shaped portion 43A is smaller.

Fig. 9 is a plan view of the power feeding plate 18A and the vibrating portion 24.

The displacement regulating portion 30A of the power feeding plate 18A is provided so as to face the top surface side of the vibrating portion 24 with a spacing, so as not to face a position in which the antinode of the first vibration or the node of vibration of the vibrating portion 24, and so as to face the outer peripheral portion of the vibrating portion 24 outside the node of vibration of the vibrating portion 24. In this configuration, since the displacement regulating portion 30A is provided at a position outside the position of the second preferred embodiment, the unevenness of the wave-shaped portion 43A is able to be reduced. In other words, the dimension of the wave-shaped portion 43A in the radial direction of the power feeding plate 18A is able to be shortened. Accordingly, the vibration in the thickness direction of the wave-shaped portion 43A that blocks the flow of fluid is significantly reduced or prevented, and the flow of fluid is facilitated.

It is preferable to determine whether the displacement regulating portion is caused to face the outer peripheral portion of the vibrating portion as in the configuration according to the present third preferred embodiment or whether the displacement regulating portion is caused to face the node of vibration in the vibrating portion as in the configuration according to the previous second preferred embodiment of the present invention, depending on which one of the effect of blocking the flow of fluid by vibration of the wave-shaped portion (supporting portion) and the effect of blocking the flow of fluid by variation of a distance between the displacement regulating portion and the vibrating portion is larger.

In the pump according to the third preferred embodiment of the present invention, the pump having the above configuration, as in the first preferred embodiment of the present invention, since excessive displacement of the vibrating portion 24 is also regulated by the displacement regulating portion 30A even when an impact load or the like acts on the pump, the impact resistance of the pump becomes high and, even when such an impact load or the like acts on the pump, a failure or characteristic degradation is unlikely to occur.

<u>Fourth Preferred Embodiment</u>

Subsequently, a description will be made of a fourth preferred embodiment of the present invention.

Fig. 10 is an exploded perspective view of a pump 1B according to the fourth preferred embodiment of the present invention.

The pump 1B is provided with a pump housing 2B, a valve housing 3B, and a diaphragm 4B. The pump housing 2B has a configuration in which the members (the power feeding plate, the lid plate, and the spacer plate) that are closer to the top plate than to the power feeding plate of the pump 1 according to the second preferred embodiment of the present invention are removed and a power feeding plate 18B is provided. The power feeding plate 18B has a configuration in which a valve convex portion 5B that cylindrically projects to the top surface side of one of the wave-shaped portions 43 is added to the configuration of the above described second preferred embodiment of the present invention. The pump housing 2B discharges the fluid that is sucked from a lower principal surface side, to a top surface side.

The valve housing 3B is provided on the top surface side of the pump housing 2B, and has a function of preventing the fluid that the pump housing 2B, with the diaphragm 4B, discharges from flowing backward to the pump housing 2B. The diaphragm 4B has a flat film shape and has flexibility, and is held between the valve housing 3B and the pump housing 2B.

Fig. 11A and Fig. 11B are schematic cross-sectional views of a main portion of the pump 1B. Fig. 11A shows a case in which fluid flows in a forward direction, and Fig. 11B shows a case in which fluid flows in a reverse direction.

The valve housing 3B is provided with a top plate 10B, an external connecting portion 11B that projects upward from the top plate 10B, and a valve seat 12B that projects downward from the top plate 10B. The external connecting portion 11B is provided with a first flow path hole 31B that ventilates an internal space 30B of the valve housing 3B and the external space. The valve seat 12B is provided with a second flow path hole 32B that ventilates the internal space 30B of the valve housing 3B and the external space. The diaphragm 4B is provided with an opening 33B at a position facing the valve convex portion 5B provided in the power feeding plate 18B.

The diaphragm 4B includes a portion around the opening

33B, and the portion comes into contact with the valve convex portion 5B as the diaphragm 4B is pressurized from the internal space 30B of the valve housing 3B and the portion separates from the valve convex portion 5B as the diaphragm 4B is pressurized from the side of the pump housing 2B. In addition, the diaphragm 4B includes a portion facing the valve seat 12B, and the portion separates from the valve seat 12B as the diaphragm 4B is pressurized from the internal space 30B of the valve housing 3B and the portion comes into contact with the valve seat 12B as the diaphragm 4B is pressurized from the side of the pump housing 2B.

Accordingly, as shown in Fig. 11A, in a case in which fluid flows in the forward direction, the opening 33B of the diaphragm 4B is separated from the valve convex portion 5B and is opened, and the fluid flows from the side of the pump housing 2B into the internal space 30B of the valve housing 3B. Then, since the second flow path hole 32B is closed by the diaphragm 4B, the fluid is discharged to the outside through the first flow path hole 31B.

In addition, as shown in Fig. 11B, in a case in which fluid flows in the backward direction and flows from the outside into the internal space 30B of the valve housing 3B through the first flow path hole 31B, since the opening 33B of the diaphragm 4B contacts the valve convex portion 5B and is closed and the diaphragm 4B is separated and the second flow path hole 32B is open, the fluid is discharged to the outside through the second flow path hole 32B.

Thus, in the pump 1B according to the fourth preferred embodiment of the present invention, even when the discharged fluid flows backward, the fluid does not reach the side of the pump housing 2B and is able to be discharged to the outside through another flow path hole.

While the pump 1B according to the fourth preferred embodiment of the present invention has a configuration in which the pump housing 2B, the valve housing 3B, and the diaphragm 4B are integrally formed, the pump housing 2B, the valve housing 3B, and the diaphragm 4B may be completely separately configured. The pump housing 2B, the valve housing 3B, and the diaphragm 4B are integrally configured, so that even the pump 1B that has a valve function is able to be downsized. In particular, in the pump 1B according to the fourth preferred embodiment of the present invention, since the power feeding plate 18B provided with the displacement regulating portion 30 configured to regulate the displacement of the vibrating portion 24 due to an impact load additionally includes the valve convex portion 5B for achieving a valve function, the pump 1B that has the valve function is able to be made extremely small.

While the present invention is able to be implemented as shown in each of the above preferred embodiments, the present invention is also able to be implemented in a preferred embodiment other than the preferred embodiment. For example, while each of the above preferred embodiments of the present invention shows an example of using the piezoelectric element in which expansion and contraction occurs in the in-plane direction, the present invention is not limited to this example. For example, the vibrating plate may be bent and vibrated electromagnetically.

In addition, while each of the above preferred embodiments of the present invention shows an example of providing the displacement regulating portion on the power feeding plate and making the displacement regulating portion project to the bottom surface side, the present invention is not limited to this example. For example, the displacement regulating portion may project from a lid plate or the like. Moreover, the displacement regulating portion may be provided on the lower side (the second pump chamber) of the vibrating portion 24, and may be provided on both the lower side (the second pump chamber) and the upper side (the first pump chamber) of the vibrating portion 24.

Furthermore, while each of the above preferred embodiments of the present invention shows an example of providing three cylindrical displacement regulating portions, the number of displacement regulating portions, the shape of the displacement regulating portion, and the arrangement of the displacement regulating portions are not limited to the above mentioned example. For example, the displacement regulating portion may be made into the shape of a square pillar or the shape of a circular ring. In addition, the displacement regulating portion may be made into the shape of a circular ring that has the outer shape slightly smaller than the outer shape of the vibrating portion 24. Moreover, the displacement regulating portion may be provided at one location, two locations, or four or more locations.

Furthermore, while each of the above preferred embodiments shows an example of determining the frequency of an alternating current drive signal so that the vibrating plate may be vibrated in the third-order resonance mode, the present invention is not limited to this example. For example, the frequency of an alternating current drive signal may be determined so that the vibrating plate may be vibrated in a first-order resonance mode or in a fifth-order resonance mode.

In addition, while each of the above preferred embodiments shows an example of using gas as fluid, the present invention is not limited to this example. For example, the fluid may be liquid, vapor-liquid mixed fluid, gas-solid mixed fluid, or solid-liquid mixed fluid. Moreover, while each of the above preferred embodiments shows an example of sucking fluid to the pump chamber through the flow path hole provided in the facing plate, the present invention is not limited to this example. For example, the fluid may be discharged from the pump chamber through the flow path hole provided in the facing plate. Whether fluid is to be sucked or discharged through the flow path hole provided in the facing plate may be determined according to the direction of the traveling waves in the difference in vibration between the convex portion and the movable portion.

Lastly, the foregoing preferred embodiments are illustrative in all points and should not be construed to limit the present invention. The scope of the present invention is defined not by the foregoing preferred embodiment but by the following claims. Further, the scope of the present invention is intended to include all modifications within the scopes of the claims and within the meanings and scopes of equivalents.

Reference Signs List

1, 1A, 1B Pump

2, 2A, 2B Pump housing

3 Vibrating plate

4 Driving portion

5 Displacement regulating portion

6 Pump chamber

7 Flow path

8 Opening

9 Vibrating portion

3A, 4A External connection terminal

5A, 6A Principal surface

7A Pump chamber

11 Cover plate

12 Flow path plate

13 Facing plate

14 Adhesive layer

15 Vibrating plate

16 Piezoelectric element

17 Insulating plate

18, 18A, 18B Power feeding plate

19 Spacer plate

20 Lid plate

21 Circular plate portion

22 Frame portion

23 Link portion

24 Vibrating portion

27 Internal connection terminal

28 Frame portion

29, 29A Supporting portion

30, 30A Displacement regulating portion

31 Flow path hole

32 Opening

33 Flow path

35 Flow path hole

42 Convex portion

43, 43A Wave-shaped portion

44 Movable portion

3B Valve housing

4B Diaphragm

5B Valve convex portion

10B Top plate

11B External connecting portion

12B Valve seat

33B Opening

CLAIMS

1. A pump comprising:

a pump housing internally including a pump chamber;

a vibrating portion being supported against the pump housing in the pump chamber, dividing the pump chamber into a first pump chamber and a second pump chamber each including an inner wall;

a driving portion arranged on the vibrating portion and configured to drive the vibrating portion so as to bend and vibrate the vibrating portion in a predetermined direction; and

a displacement regulating portion projecting from the inner wall of the first pump chamber and facing the vibrating portion;

wherein the displacement regulating portion faces an outer peripheral portion of the vibrating portion without facing a center portion of the vibrating portion.

2. The pump according to claim 1, wherein the displacement regulating portion is positioned in a space in which the vibrating portion is able to be positioned when the vibrating portion elastically deforms.

3. The pump according to claim 1 or 2, wherein the displacement regulating portion is not positioned in a space in which the

vibrating portion is able to be positioned when the vibrating portion bends and vibrates.

4. The pump according to any one of claims 1 to 3, further comprising

a flat plate-shaped member forming the displacement regulating portion comprising:

a supporting portion projecting from a side of the pump housing to the pump chamber; and

a projecting portion projecting from the supporting portion to a side of the vibrating portion.

5. The pump according to claim 4, wherein the flat plate-shaped member comprises an internal connection terminal projecting and extending from the side of the pump housing to the pump chamber and having a tip connected to the vibrating portion.

6. The pump according to claim 4 or 5, wherein the vibrating portion bends and vibrates in a high-order resonance mode.

7. The pump according to claim 6, wherein the displacement regulating portion faces a position to be a node of bending vibration of the vibrating portion without facing a center portion of the vibrating portion.

8. The pump according to any one of claims 1 to 7, further comprising a projecting portion projecting from the inner wall of the second pump chamber and facing the vibrating portion.

9. The pump according to any one of claims 1 to 8, comprising, as the displacement regulating portion, a plurality of projecting portions that are aligned at intervals from each other.

10. The pump according to claim 9, comprising, as the displacement regulating portion, three projecting portions.

11. The pump according to claim 4, wherein the pump is configured as a laminate of a plurality of flat plate-shaped members that are stacked in the predetermined direction.