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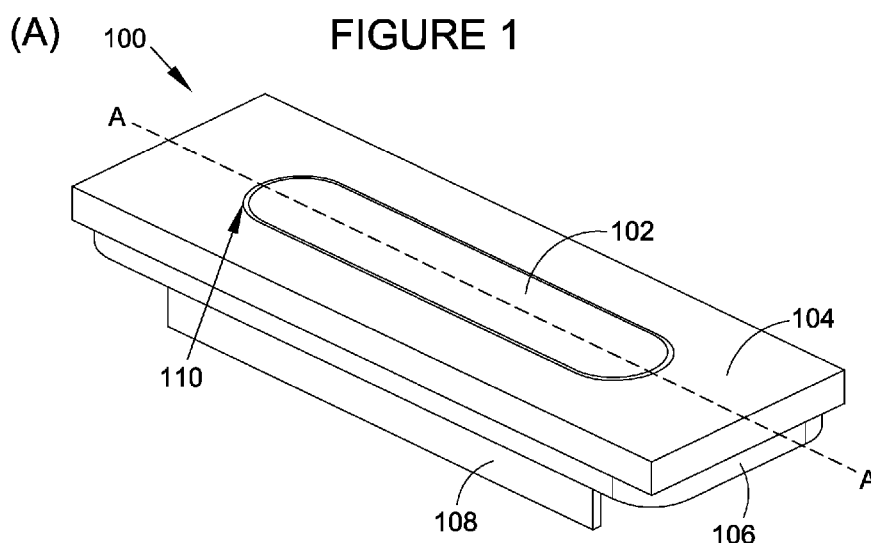
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(57) Abstract: Broadly speaking, embodiments of the present techniques provide haptic feedback devices which comprise sealing mechanisms to minimise, limit or prevent liquid and/or dirt/dust ingress into the device such that the functionality of the haptic feedback device is maintained over its lifetime. The haptic feedback devices are operated using shape memory alloy (SMA) actuators.

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Seals for Haptic Feedback Devices

The present techniques generally relate to apparatus and methods for providing haptic feedback to a user, and in particular, relate to haptic feedback devices which are waterproof.

Consumer electronics devices, such as laptops and smartphones, may employ different types of controls to give users of the devices some feedback indicating that they have, for example, successfully pressed a button or input data into the device. This is generally known as haptic feedback, and haptic buttons or controls on a device may provide a tactile sensation to the user to confirm that they have successfully pressed the button/control/switch. A haptic button may be provided as a module or assembly for incorporation within an electronic device by a device manufacturer.

There is an increasing need for electronic devices to be waterproof and/or dustproof, or to at least be resistant to submersion in water for a reasonable period of time.

In a first approach of the present techniques, there is provided a haptic feedback device comprising: a housing comprising a cavity; a moveable component provided within the cavity and moveable relative to the cavity; an actuator for moving the moveable component to provide haptic feedback; and a sealing mechanism for limiting liquid and/or dust ingress into the device.

The actuator may comprise at least one length of shape memory alloy (SMA) actuator wire arranged to, on contraction, move the moveable component within the cavity. The at least one length of SMA actuator wire may directly or indirectly move the moveable component. For example, in embodiments, the at least one length of SMA actuator wire may be coupled to the moveable component such that when the actuator wire contracts, the moveable component is caused to move. This is an example of direct movement. In embodiments, the at least one length of SMA actuator wire may be coupled to a further moveable component, such that when the actuator wire contracts, the further moveable component is

caused to move and the movement of the further moveable component causes the moveable component to move. This is an example of indirect movement.

In a second approach of the present techniques, there is provided an apparatus comprising any haptic feedback device described herein for delivering a haptic sensation to a user of the apparatus.

The apparatus may be any one of: a smartphone, a camera, a foldable smartphone, a foldable image capture device, a foldable smartphone camera, an a foldable consumer electronics device, a camera with folded optics, image capture device, an array camera, a 3D sensing device or system, a servomotor, a consumer electronic device (including domestic appliances such as vacuum cleaners, washing machines and lawnmowers), a mobile or portable computing device, a mobile or portable electronic device, a laptop, a tablet computing device, an e-reader (also known as an e-book reader or e-book device), a computing accessory or computing peripheral device (e.g. mouse, keyboard, headphones, earphones, earbuds, etc.), an audio device (e.g. headphones, headset, earphones, etc.), a security system, a gaming system, a gaming accessory (e.g. controller, headset, a wearable controller, etc.), a robot or robotics device, an augmented reality system, an augmented reality device, a virtual reality system, a virtual reality device, a wearable device (e.g. a watch, a smartwatch, a fitness tracker, etc.), and a vehicle. It will be understood that this is a non-exhaustive list of possible apparatus.

Preferred features are set out in the appended dependent claims.

Implementations of the present techniques will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1A is a perspective view of a haptic feedback device comprising a labyrinth sealing mechanism;

Figure 1B is a perspective view of a cross section through the haptic feedback device of Figure 1A;

Figure 1C is a perspective view of a cross section through a portion of the haptic feedback device of Figure 1A;

5 Figure 1D is a perspective view of a further cross section through the haptic device of Figure 1A;

Figure 2A shows a cross section along an axis of a haptic device comprising a gasket sealing mechanism;

10 Figure 2B shows a cross section along another axis of the haptic device of Figure 2A;

Figure 3A shows a plan view of a haptic feedback device comprising a gasket sealing mechanism;

15 Figure 3B shows a cross section along an axis of the device of Figure 3A;

Figure 4 shows a cross-sectional view of a haptic feedback device comprising an external sealing mechanism;

20 Figure 5 shows a cross-sectional view of an alternative haptic feedback device comprising an external sealing mechanism;

Figure 6 shows a cross-sectional view of a haptic feedback device comprising an internal sealing mechanism;

25 Figures 7A and 7B respectively show a plan view and a cross-sectional view of a sealing mechanism for sealing a haptic feedback device, and Figure 7C shows a cross-sectional view of a modified sealing mechanism;

30 Figures 8A to 8C show cross-sectional views of three mechanisms for sealing a haptic feedback device;

Figures 9A and 9B show cross-sectional views of two further mechanisms for sealing a haptic feedback device;

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Figure 10 shows a cross-sectional view of a further mechanism for sealing a haptic feedback device;

5 Figure 11 shows a cross-sectional view of a haptic feedback device and a sealing mechanism;

Figure 12 shows a cross-sectional view of a haptic feedback device and a sealing mechanism;

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Figure 13A shows a cross-sectional view along an axis of a haptic device comprising a flexible sealing element;

15 Figure 13B shows a cross-sectional view along another axis of the haptic device of Figure 13A;

Figure 14 shows a cross-sectional view of a haptic feedback device comprising a continuous casing;

20 Figure 15 shows schematic diagrams of casings comprising mechanical edge constraints; and

Figures 16A to 16E show cross-sectional schematic views of further haptic devices comprising flexible sealing mechanisms.

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Broadly speaking, embodiments of the present techniques provide haptic feedback devices which comprise sealing mechanisms to minimise, limit or prevent liquid and/or dirt/dust ingress into the device such that the functionality of the haptic feedback device is maintained over its lifetime.

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Generally speaking, the present techniques provide haptic feedback devices comprising a sealing mechanism for limiting liquid and/or dust ingress into the device. The haptic feedback device may further comprise a housing comprising a cavity; a moveable component provided within the cavity and moveable relative to the cavity; and an actuator for moving the moveable component to provide

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haptic feedback. The haptic feedback device may be incorporated into any device/apparatus in which it may be useful to provide a user of the device with haptic feedback. For example, the haptic feedback devices may be incorporated into an electronic device or a consumer electronics device, such as a computer, laptop, portable computing device, smartphone, computer keyboard, gaming system, portable gaming device, gaming equipment/accessory (e.g. controllers, wearable controllers, etc.), medical device, user input device, etc. It will be understood that this is a non-limiting, non-exhaustive list of possible devices which may incorporate any of the haptic feedback devices described herein. The haptic feedback device may be, for example, incorporated into or otherwise provided along an edge of a smartphone or on a surface of a smartphone (e.g. on the front face of the smartphone, or under a display screen of the smartphone). The haptic feedback devices described herein may be provided as standalone modules that may be incorporated into an electronic device during manufacture, and may be adapted to suit the device specifications such that it fits into a casing or external surface of the electronic device. Alternatively, some or all of the components of the haptic feedback devices may be integrally formed in an electronic device. For example, the housing or seal of a haptic feedback device may be part of the electronic device itself.

The moveable component may be a button which may be moved to deliver haptic feedback to a user pressing/touching the button. The button may move from side-to-side/laterally in the cavity, or may move up and down within the cavity (and may partially protrude from/extend out of the cavity). Alternatively, the moveable component may be provided below a seal or casing of the electronic device in which the haptic feedback device is incorporated. In this case, haptic feedback is delivered through the seal/casing (by the moveable component moving and imparting a force onto the seal/casing), and there may not be a distinguishable/visible button for the user to press or touch. The sealing mechanisms described herein may be suitable for moveable components which move side-to-side and/or move up and down in the cavity.

Figure 1A is a perspective view of a haptic feedback device 100 comprising a labyrinth sealing mechanism. Figure 1B is a perspective view of a cross section through the haptic feedback device of Figure 1A, Figure 1C is a perspective view

of a cross section through a portion of the haptic feedback device of Figure 1A, and Figure 1D is a perspective view of a further cross section through the haptic device of Figure 1A.

5 The haptic feedback device 100 comprises a moveable component 102 and a housing 104. The housing 104 comprises a cavity or aperture, and the moveable component 102 is provided within the cavity/aperture. The housing 104 may be a housing or casing of an electronic device into which the haptic feedback device is incorporated. In the illustrated embodiment, the moveable component 102 is
10 arranged to move laterally, i.e. side-to-side, within the cavity of the housing 104. The moveable component 102 may move in a direction substantially parallel to axis A. The moveable component 102 may be a button and may comprise a surface which is pressable/touchable by a user. The haptic feedback device comprises a base 106 which extends across, and may be coupled to, the moveable
15 component 102. The base 106 may extend into, and may be coupled to, the housing 104 as shown in Figures 1A and 1B. The base 106 may form part of the labyrinth sealing mechanism. The haptic feedback device 100 may comprise, or be connected to, control circuitry which controls the operation of the haptic feedback device 100. In embodiments, the haptic feedback device 100 may
20 comprise, or be connected to, a flexible printed circuit 108, which may extend through the base 106 to make contact with the actuator. This can be seen more clearly in Figure 1C, which shows that the flexible printed circuit 108 extends through a slit, slot or hole in the base 106 in order to make contact with the actuator.

25 As shown in Figures 1B and 1C, the moveable component 102 is shaped such that it comprises a portion which is in the cavity/aperture of the housing, and another portion which extends out of the cavity/aperture of the housing and runs along an underside of the housing 104. Thus, the moveable component 102
30 is shaped and arranged within the housing 102 such that it forms a labyrinthine seal. A lower surface of the moveable component 102, i.e. the surface(s) of the moveable component 102 which are within the housing 104 and which the user is unable to touch/press during device operation, has a mesa structure. The mesa structure of the moveable component 102 means that some parts of the moveable
35 component 102 contact the base 106, while other parts contact the flexible printed

circuit 108, and other parts may be shaped to provide space for components of the haptic feedback device 100.

As the moveable component 102 is arranged to move laterally, i.e. side-to-side, within the cavity of the housing 104 (e.g. in a direction substantially parallel to axis A), there is a small gap 110 between the moveable component 102 and the housing 104 to enable the moveable component 102 to move. The gap 110 is also provided between the moveable component 102 and the cavity of the housing 104. This means that if the haptic feedback device came into contact with a liquid (e.g. if the device 100 were submerged in water), the liquid may be able to enter the haptic feedback device through gap 110. Once in the device 100, the liquid may interfere with the operation of the haptic feedback device 100 by e.g. coming into contact with control circuitry. Furthermore, once the liquid is in the device 100, the liquid may be able to flow into the electronic apparatus in which the device 100 is incorporated, where it may cause damage. The labyrinth seal provided by the mesa structure of the moveable component 102 means that a number of small/narrow channels are formed between the moveable component 102 and the base 106 and flexible printed circuit (FPC) 108. The liquid will need to penetrate the gap 110 between the edge of the button 102 and the housing 104, and run through the narrow channels formed between the moveable component 102, inner surfaces of housing 104, the base 106 and the FPC 108. However, if the channels are narrow enough, the liquid needs to overcome surface tension in order to flow along the channels. Accordingly, the series of channels of the sealing mechanism limit liquid ingress into the device 100.

In embodiments, the flexible printed circuit 108 may comprise a sensor to detect user contact on the moveable component 102 (e.g. a button press or touch). Alternatively, the sensor may be provided as a separate component within device 100, and is coupled to the control circuitry (e.g. FPC 108). The sensor may be any suitable sensor for detecting contact, such as a strain gauge, force sensor, contact sensor, etc. When a press of the moveable component 102 is sensed by the sensor, the sensor communicates this to the control circuitry, which triggers the control circuitry to control the moveable component 102 to deliver haptic feedback.

The haptic feedback device 100 may comprise a sensor (not shown) for detecting contact e.g. a press of the moveable component 102. In embodiments where the sensor is a force or contact sensor, the moveable component 102 may comprise a protrusion (not visible) which is arranged to exert a force on the sensor when the moveable component 102 is pressed/touched by a user's finger. The sensor is coupled to the control circuitry 108 so that when the sensor senses a press, the control circuitry 108 is caused to change power to the SMA actuator wires(s) 114.

The haptic feedback device 100 may comprise any suitable sensor or mechanism for detecting depression of the moveable component 102 by a user (i.e. detecting that a user has pressed or touched the moveable component 102). The press/touch on the moveable component 102 may be sensed, and the sensor may be configured to communicate with control circuitry 108 when the sensed data changes (e.g. when a force on the sensor changes), or when the force on the sensor has been applied for a minimum duration. The sensor may be a contact sensor, such as the type described in United Kingdom Patent Publication No. GB2551657, which is hereby incorporated by reference in its entirety. The sensor may be a capacitive sensor.

In embodiments, the actuator of device 100 comprises at least one shape memory alloy (SMA) actuator wire 114. The control circuitry may increase the power supplied to the at least one SMA actuator wire 114 in order to generate haptic feedback. When the SMA actuator wire(s) 114 contracts, the moveable component 102 is caused to move within the cavity (e.g. in a direction parallel to axis A).

In embodiments, the actuator of device 100 may comprise at least one resilient biasing element that is arranged to oppose the movement of the moveable component 102 caused by contraction of the at least one SMA actuator wire. The resilient biasing element may be a spring. The particular, non-limiting arrangement shown in Figures 1B and 1D comprises two springs 112a, 112b that are arranged to oppose the SMA actuator wire 114. As the SMA actuator wire 114 cools, the wire becomes more elastic and the springs 112a, 112b are able to return

the moveable component 102 to its original position. In embodiments, the resilient biasing element may be provided by at least one SMA actuator wire.

In embodiments, the SMA actuator wire may be arranged in a 'U-shape' so that the length of the wire is essentially doubled relative to an arrangement comprising a single straight length of SMA actuator wire. Accordingly, as the length of SMA actuator wire is greater, the force generated by the SMA actuator wire is larger. A larger force may allow the stroke of the actuator to be increased. However, the U-shaped arrangement is a non-limiting example. The actuator of device 100 may comprise, for example, multiple lengths of SMA actuator wire which are arranged to increase the stroke of the actuator.

In embodiments, the SMA actuator wire(s) may have a diameter between 10 μ m and 500 μ m, preferably between 20 μ m and 100 μ m, and even more preferably between 30 μ m and 50 μ m. The diameter of the SMA actuator wire(s) may be chosen to ensure the actuator is able to move the moveable component 102 with enough force to produce a satisfying haptic effect, while also being able to cool and heat quickly enough to enable a haptic effect to be delivered as soon as it is required (e.g. as soon as a button has been pressed).

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The moveable component 102 may be formed from a low friction material.

The haptic feedback device 100 may be made more watertight by coating the inner surfaces with a hydrophobic material. The hydrophobic coating may take the form of a thin film of lubricant so as to reduce friction between the moveable component 102 and other components of the device 100. Thus, the moveable component 102 may be formed from a hydrophobic material, such as PTFE (polytetrafluoroethylene). PTFE also has a low coefficient of friction. In embodiments, one or more components of the haptic feedback device 100 may be coated with a hydrophobic material (such as PTFE). Advantageously, a moveable component 102 which is formed from a hydrophobic material may prevent liquid from entering the gap 110 or the channels of the labyrinth sealing mechanism. Alternatively, the mesa structure of the moveable component 102 (i.e. the portion of the moveable component 102 which forms the labyrinthine seal) may be formed from a compressible foam.

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Figure 2A shows a cross-sectional view along an axis of a haptic device 200 comprising a gasket sealing mechanism, and Figure 2B shows a cross-sectional view along another axis of the haptic device of Figure 2A. As explained above with reference to Figures 1A to 1D, a moveable component which moves laterally within a cavity requires a gap 110 to be provided between the moveable component 102 and the housing 104 so that there is space for the moveable component to move. However, the gap 110 provides a way for liquid and/or dust to enter the haptic feedback device. The labyrinth sealing mechanism described above provides a mechanism for limiting the flow of liquid through the device 100 once the liquid has already seeped through the gap 110. Therefore, it would be useful to minimise the chance that liquid is able to enter the device through gap 110. Figures 2A and 2B show one mechanism for achieving this.

The haptic feedback device 200 comprises a moveable component 202 and a housing 204. The housing 204 comprises a cavity or aperture, and the moveable component 202 is provided within the cavity/aperture. The haptic feedback device 200 comprises a base 206 which extends across, and may be coupled to, the moveable component 202. The base 206 may extend into, and may be coupled to, the housing 204. The base 206 may form part of a labyrinth sealing mechanism. The haptic feedback device 200 may comprise or be coupled to control circuitry 208. A lower surface of the moveable component 202 may comprise a mesa structure as per the arrangement of Figures 1A to 1D and for the sake of simplicity, this is not described again here. The haptic feedback device 200 comprises at least one shape memory alloy (SMA) actuator wire 214. The SMA actuator wire 214 may be coupled to the control circuitry 208 via a clamp or crimp 220. The haptic feedback device 200 may comprise at least one resilient biasing element 212, which may be a spring, an SMA actuator wire, a flexure, or similar. The haptic feedback device 200 may comprise a sensor 218 for detecting contact e.g. a press of the moveable component 202. The moveable component 202 may comprise a protrusion 222 which is arranged to exert a force on sensor 218 when the moveable component 202 is pressed/touched by a user's finger. The sensor 218 is coupled to the control circuitry 208 so that when sensor 218 senses a press, the control circuitry 208 is caused to increase power to the SMA actuator wires(s) 214.

As the moveable component 202 is arranged to move laterally within the cavity of the housing 204, there is a small gap 210 between the moveable component 202 and the housing 204 to enable the moveable component 202 to move. To prevent any liquid which enters the gap 210 from flowing further into device 200, the device 200 comprises a gasket sealing mechanism 216. The gasket 216 is provided between the moveable component 202 and an underside of housing 204 and functions as a barrier that stops liquid from flowing from gap 210 into the rest of device 200. The gasket 216 may be formed of any suitable material to prevent or limit liquid from flowing from gap 210 further into device 200, which does not significantly limit the movement of moveable component 202. The gasket 216 may be formed of a compressible material, for example, which acts as a barrier against liquid flow while allowing the moveable component 202 to move and deliver a haptic effect. The gasket may, for example, be formed of a closed cell compressible foam. The gasket 216 may be arranged such that it is compressed when the moveable component 202 is not moving (i.e. is in a default rest position). When the actuator is moving moveable component 202, the gasket 216 remains in contact with the underside/lower surface of the housing 204, such that the sealing mechanism functions both when the moveable component 202 is in motion and when stationary.

Figure 3A shows a plan view of a haptic feedback device 300 comprising a gasket sealing mechanism, and Figure 3B shows a cross section along an axis of the device of Figure 3A. As explained above with reference to Figures 1A to 1D, a moveable component which moves laterally within a cavity requires a gap 110 to be provided between the moveable component 102 and the housing 104 so that there is space for the moveable component to move. However, the gap 110 provides a way for liquid and/or dust to enter the haptic feedback device. The labyrinth sealing mechanism described above provides a mechanism for limiting the flow of liquid through the device 100 once the liquid has already seeped through the gap 110. Therefore, it would be useful to minimise the chance that liquid is able to enter the device through gap 110. Figures 3A and 3B show another mechanism for achieving this.

The haptic feedback device 300 comprises a moveable component 302 and a housing 304. The housing 304 comprises a cavity or aperture, and the moveable component 302 is provided within the cavity/aperture. The haptic feedback device 300 comprises a base 306 which extends across, and may be coupled to, the moveable component 302. The base 306 may extend into, and may be coupled to, the housing 304. The base 306 may form part of a labyrinth sealing mechanism. The haptic feedback device 300 may comprise or be coupled to control circuitry 308. A lower surface of the moveable component 302 may comprise a mesa structure as per the arrangement of Figures 1A to 1D and for the sake of simplicity, this is not described again here. The haptic feedback device 300 comprises at least one shape memory alloy (SMA) actuator wire 314. The haptic feedback device 300 may comprise at least one resilient biasing element 312, which may be a spring, an SMA actuator wire, a flexure, or similar. The haptic feedback device 300 may comprise a sensor 318 for detecting contact e.g. a press of the moveable component 302. The sensor 318 is coupled to the control circuitry 308 so that when sensor 318 senses a press, the control circuitry 308 is caused to increase power to the SMA actuator wires(s) 314.

As the moveable component 302 is arranged to move laterally within the cavity of the housing 304, there is a small gap 310 between the moveable component 302 and the housing 304 to enable the moveable component 302 to move. To prevent any liquid from entering gap 310, the device 300 comprises a gasket sealing mechanism 316. The gasket 316 is provided around the moveable component 302 and at least partly fills gap 310. Thus, gasket 316 limits or prevents liquid from entering gap 310 and flowing into the rest of device 300. The gasket 316 may be formed of any suitable material to prevent or limit liquid from flowing into device 300, which does not significantly limit the movement of moveable component 302. The gasket 316 may be formed of a compressible material, for example, which acts as a barrier against liquid flow while allowing the moveable component 302 to move and deliver a haptic effect. The gasket may be formed of an impermeable foam material. The gasket may, for example, be formed of a closed cell compressible foam. The gasket sealing mechanism 316 may function both when the moveable component 302 is in motion and when stationary.

It will be understood that the gasket sealing mechanisms 216, 316 may be used in any haptic feedback device in which the moveable component moves laterally within the housing/cavity such that there is a gap between the moveable component and the housing/cavity. In embodiments, one or both of the gasket sealing mechanisms 216, 316 may be combined with the labyrinth sealing mechanism described earlier.

Turning to Figure 13A, this shows a cross-sectional view along an axis of a haptic device comprising a flexible sealing element, and Figure 13B shows a cross-sectional view along another axis of the haptic device of Figure 13A. As explained above with reference to Figures 1A to 1D, a moveable component which moves laterally within a cavity requires a gap 110 to be provided between the moveable component 102 and the housing 104 so that there is space for the moveable component to move. However, the gap 110 provides a way for liquid and/or dust to enter the haptic feedback device. Therefore, it would be useful to minimise the chance that liquid is able to enter the device through gap 110. Figures 13A and 13B show another mechanism for achieving this.

The haptic feedback device 1300 comprises a moveable component 1302 and a housing 1304. The housing 1304 comprises a cavity or aperture, and the moveable component 1302 is provided within the cavity/aperture. The haptic feedback device 1300 comprises a base 1306 which extends across, and may be coupled to, the moveable component 1302. The base 1306 may extend into, and may be coupled to, the housing 1304. The base 1306 may form part of a labyrinth sealing mechanism. The haptic feedback device 1300 may comprise or be coupled to control circuitry 1308. A lower surface of the moveable component 1302 may comprise a mesa structure as per the arrangement of Figures 1A to 1D and for the sake of simplicity, this is not described again here. The haptic feedback device 1300 comprises at least one shape memory alloy (SMA) actuator wire 1314. The SMA actuator wire 1314 may be coupled to the control circuitry 1308 via a clamp or crimp 1320. The haptic feedback device 1300 may comprise at least one resilient biasing element 1312, which may be a spring, an SMA actuator wire, a flexure, or similar. The haptic feedback device 1300 may comprise a sensor 1318 for detecting contact e.g. a press of the moveable component 1302. The moveable component 1302 may comprise a protrusion 1322 which is arranged to exert a

force on sensor 1318 when the moveable component 1302 is pressed/touched by a user's finger. The sensor 1318 is coupled to the control circuitry 1308 so that when sensor 1318 senses a press, the control circuitry 1308 is caused to increase power to the SMA actuator wires(s) 1314.

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As the moveable component 1302 is arranged to move laterally within the cavity of the housing 1304, there is a small gap 1310 between the moveable component 1302 and the housing 1304 to enable the moveable component 1302 to move. To prevent any liquid which enters the gap 1310 from flowing further
10 into device 1300, the device 1300 comprises at least one flexible element coupled to the moveable component 1302 and to a surface of the cavity of the housing 1304. The at least one flexible element 1316 functions as a barrier that stops liquid from flowing from gap 1310 into the rest of device 1300. The flexible
15 element(s) 1316 may be formed of any suitable material to prevent or limit liquid from flowing from gap 1310 further into device 1300, which does not significantly limit the movement of moveable component 1302. The flexible element(s) 1316 may be formed of any one of: rubber, an elastic material, an elastomer, a polymer, and a silicone material. The flexible element(s) therefore acts as a barrier against
20 liquid flow while allowing the moveable component 1302 to move and deliver a haptic effect. The flexible element(s) is able to stretch when the moveable component 1302 is in motion, such that the sealing mechanism functions both when the moveable component 1302 is in motion and when stationary.

Thus, the present techniques provide a haptic feedback device comprising:
25 a housing comprising a cavity; a moveable component provided within the cavity and moveable relative to the cavity; an actuator for moving the moveable component to provide haptic feedback; and a sealing mechanism for limiting liquid and/or dust ingress into the device. The actuator may comprise at least one length of shape memory alloy (SMA) actuator wire arranged to, on contraction, move the
30 moveable component within the cavity. The moveable component may be movable along a movement axis within the cavity, the movement axis being parallel to, or at an angle to, the at least one length of SMA actuator wire. When the movement axis is at 0° or 180° to the at least one length of SMA actuator wire, the moveable component moves side-to-side within the cavity – see e.g.
35 Figures 1A to 3A and 13A-B. When the movement axis is at substantially 90° to

the at least one length of SMA actuator wire, the moveable component moves up and down within the cavity – see e.g. Figures 4 to 12 and 14 to 15. The movement axis may be at an angle of between 0° to 90° to the at least one length of SMA actuator wire, the moveable component may move along a curved edge or surface.

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The sealing mechanism may be non-structural and may not constrain the motion of the moveable component. Alternatively, the sealing mechanism may be structural and may constrain the motion of the moveable component within the cavity.

10

The sealing mechanism may seal the device when the moveable component is stationary and in motion. Alternatively, the sealing mechanism may seal the device when the moveable component is stationary only.

15

The sealing mechanism may comprise an external sealing film provided over the cavity and at least part of the housing. The external sealing film may be formed of any one of: a flexible material, an elastic material, an elastomer, a polymer, a silicone material, a thin metallic material, a composite material, a thin aluminium film, a thin titanium film, an alloy, and a thin stainless steel film.

20

The sealing mechanism may comprise an internal sealing film provided within the cavity, wherein at least part of the moveable component is provided beneath, above or protrudes through the internal sealing film.

25

The internal sealing film may be formed of any one of: a flexible material, an elastic material, an elastomer, a polymer, a silicone material, a thin metallic material, a composite material, a thin aluminium film, a thin titanium film, an alloy, and a thin stainless steel film.

30

The sealing mechanism may comprise a gasket seal provided between the moveable component and the cavity, as shown in Figures 2A and 3A for example. The gasket seal may be formed of a liquid-impermeable material and/or a compressible material.

The sealing mechanism may comprise a mesa structure on the button (as shown in Figures 1B, 2A and 3A for example), where the mesa structure engages with one or more surfaces of the cavity of the housing.

5 The sealing mechanism may comprise at least one flexible element coupled to the moveable component and to a surface of the cavity, as shown in Figures 13A and 13B for example. The at least one flexible element may be formed of any one of: rubber, an elastic material, an elastomer, a polymer, a foam material, a closed cell foam material, and a silicone material.

10 In embodiments, at least one of the following may be formed from a hydrophobic material: the moveable component, the housing, the cavity, the actuator, and the sealing mechanism. Additionally or alternatively, at least one of the following may be coated with a hydrophobic material: the moveable
15 component, the housing, the cavity, the actuator, and the sealing mechanism. The hydrophobic material may be polytetrafluoroethylene.

Haptic feedback devices which comprise moveable components that move 'vertically' or up and down within the housing/cavity, and mechanisms for sealing
20 such devices, are now described with reference to Figures 4 to 12. The operation of these devices are described in detail in United Kingdom Patent Application No. GB1813008.8, which is incorporated by reference herein in its entirety and so only the sealing mechanisms will be described in detail here.

25 Figure 4 shows a cross-sectional view of a haptic feedback device 400 comprising an external sealing mechanism which is structural and functions at all times (i.e. both when the moveable component is in motion and is not in motion). The haptic feedback device 400 comprises a moveable component 402 which is provided in a cavity of housing 404. The device 400 comprises a further moveable
30 component 410. Movement of the further moveable component 410 causes the moveable component 402 to move. Specifically, the device 400 comprises an actuator which comprises at least one length of SMA actuator wire arranged to, on contraction, indirectly move the moveable component 402 within the cavity. More specifically, the moveable component 402 is moveable along a first axis
35 within the cavity, the further moveable component 410 is moveable in a plane

defined by the first axis and a second axis, the second axis being perpendicular to the first axis, and arranged to drive movement of the moveable component 402 along the first axis, and the at least one length of SMA actuator wire is coupled to the further moveable component 410 and arranged to, on contraction, move the
5 further moveable component 410 in the plane.

The device 400 comprises a protective seal 408 (also referred to as a protective membrane, film or cover). The protective seal 408 may be a waterproofing and/or dust proofing seal to prevent water and/or dust ingress into
10 the cavity. Generally speaking, a small gap may be provided between the moveable component 402 and the cavity, to avoid contact between a surface of the moveable component 402 with a surface of the cavity, which may increase friction and affect the performance of the device 400. However, the gap may then enable liquid and/or dirt to enter the cavity of the device 400, where it could affect
15 the performance. For example, dirt could inhibit the movement of moveable component 402 and/or the further moveable component 410, while liquid could interfere with any electronic components/circuitry. Thus, the protective seal 408 may advantageously enable a waterproof/dustproof haptic feedback device to be provided.

The protective seal 408 may be provided across the entire area of the external surface of the housing 404 and the moveable component 402, or may be provided across the moveable component 402 and at least part of the area of this external surface. In either case, the protective seal 408 may be formed of a
25 flexible material, an elastic material, or a material which exhibits some flexibility/elasticity when it is provided as a thin layer, which enables the protective seal 408 to flex as the moveable component 402 moves. (If the protective seal 408 were not made of a flexible/elastic material, the protective seal may inhibit or limit the motion of the moveable component 402, which may affect the haptic
30 sensation delivered by the device 400). The protective seal 408 may be formed of an elastomer, hard plastic, a composite material, a thin metallic layer e.g. a thin aluminium or a thin stainless steel layer, for example. It will be understood that is a non-exhaustive, non-limiting example list of materials. The protective seal 408 may be attached to the housing 404 by any suitable technique, such as
35 adhesive, welding, or otherwise.

Optionally, when a haptic feedback device comprises a protective seal, the housing of the device may be modified to accommodate the protective seal. As shown in Figure 4, the housing 404 comprises a cut-out or ledge 406 in the external surface of the housing 404, provided around the moveable component 402. The cut-out or ledge 406 provides clearance or space between the moveable component 402 and the housing 404. The protective seal 408 may be able to bend/flex into the ledge 406 when the button moves in the cavity, such that a portion of the protective seal 408 which is able to move when the moveable component 402 moves is increased. This may advantageously reduce the extent to which the protective seal 408 resists the motion of the moveable component 402.

Figure 5 shows a cross-sectional view of an alternative haptic feedback device 500 comprising an external sealing mechanism which is structural and functions at all times (i.e. both when the moveable component is in motion and is not in motion). This may be considered to include a more extreme version of the cut-out shown in Figure 4. The haptic button assembly 500 is similar to the arrangements shown in Figure 4 and therefore, for the sake of conciseness, like features are not described. Compared to device 400, haptic feedback device 500 comprises a reduced size (i.e. reduced height) moveable component 502. The moveable component 502 comprises a protrusion 510 which forms a contact point or contact surface of moveable component 502. Thus, the area or size of the contact surface of moveable component 502 is reduced relative to Figure 4. By reducing the height of the moveable component 502 and providing the protrusion 510 as the contact surface, a large gap 506 is provided between the moveable component 502 and protective seal 508. Accordingly, the extent to which the protective seal 508 resists the motion of the button is further reduced. As explained above, the protective seal 508 may be formed of an elastomer, hard plastic, a composite material, a thin metallic layer e.g. a thin aluminium or a thin stainless steel layer, for example. It will be understood that is a non-exhaustive, non-limiting example list of materials.

Figure 6 shows a cross-sectional view of a haptic feedback device 600 comprising an internal sealing mechanism. The haptic feedback device is similar

to the arrangement shown in Figure 4 and therefore, for the sake of conciseness, like features are not described. Moveable component 602 of the haptic feedback device 600 may comprise a lip 606 that protrudes from a side or along at least a part of the moveable component 602 (providing a 'local' endstop). The lip 606 may be provided all the way around the moveable component 602 if the lip also acts as a sealing mechanism. Housing 604 may comprise a corresponding ledge or groove 608, and the lip 606 of the moveable component 602 may engage with the ledge 608 of the housing 604. The ledge 608 may, for example, restrict the movement of the moveable component 602 into the cavity of the housing 604. Furthermore, the lip 606 may perform a sealing function when the button is pressed. For example, if the lip 606 of the moveable component 602 has the form of an O-ring, the lip 606 may provide sealing of the device 600 against water and dust ingress when the button is in its equilibrium position.

Figures 7A and 7B respectively show a plan view and a cross-sectional view of a sealing mechanism 700 for sealing a haptic feedback device, and Figure 7C shows a cross-sectional view of a modified sealing mechanism 700'.

The sealing mechanism shown in Figures 7A to 7C is structural and functions at all times (i.e. both when the moveable component is in motion and is not in motion). The sealing mechanisms 700, 700' may provide an efficient mechanism for water- and dust- proofing a haptic feedback device. The sealing mechanism 700 comprises a flexible skin or membrane 702 and an external moveable component 704. The flexible skin 702 may cover the cavity in the housing which houses moveable component 706, further moveable component 708 and at least one SMA actuator wire 710, such that the flexible skin 702 effectively covers the cavity. The flexible skin 702 may be considered an impermeable barrier between the external environment and the cavity of the housing of a haptic feedback device (i.e. the internal environment). Thus, the term 'external moveable component' is used to mean that external moveable component 704 is provided at least partly outside of the cavity, i.e. at least partly on the external side of the barrier formed by the flexible skin 702. The external button 704 may cooperate with the (internal) moveable component of the haptic feedback devices described above with reference to Figures 4 to 6.

Figure 7B shows an example internal moveable component 706, which is provided on the internal side of the barrier formed by the flexible skin 702. The external moveable component 704 may comprise a stem 712 that is arranged to cooperate with the internal moveable component 706. In the mechanism 700 shown in Figure 7B, the stem 712 contacts the flexible skin 702. When the external moveable component 704 is pressed by a user, the stem 712 exerts a force on the flexible skin 702, which causes the flexible skin 702 to flex/bend. The force applied to the external moveable component 704 is transferred via the stem 712 to the internal button 706, and a press of the internal moveable component 706 is detected.

Figure 7C shows a sealing mechanism 700' having a flexible skin 702' which comprises a cut-out (not visible) to reduce the overall stiffness of the mechanism in the direction of motion. Thus, the stem 712 of external button 704 at least partly extends through the cut-out in the flexible skin 702'. Thus, the stem 712 may be able to directly contact the internal moveable component 706.

The flexible skin 702, 702' may be made from any suitable material having an appropriate stiffness in the direction of motion. The flexible skin 702, 702' is preferably an impermeable material, i.e. impermeable to liquids and dirt. The flexible skin 702, 702' may be formed from a thin film polymer, for example. The flexible skin 702, 702' may be formed of a material which is impermeable to liquid, such that the sealing mechanism protects the haptic feedback device against fluid ingress. The flexible skin may be, for example, a thin silicone film. The sealing mechanism 700, 700' may comprise an adhesive or an adhesive element to fixedly attach the flexible skin 702, 702' to the housing of the device. The flexible skin (also referred to as a thin membrane) may deflect sufficiently to enable the moveable component 706 to move within the haptic feedback device. The thin membrane 702, 702' may provide a return force to return the moveable component 706 to its default, rest state when the further moveable element 708 is not being actuated to deliver a haptic sensation.

Advantageously, the sealing mechanisms 700, 700' secure the haptic feedback device against ingress of liquid and/or dirt or dust. The flexible skin may enable a water and dust proof haptic feedback device to be provided along a

curved edge of a device. The sealing mechanisms 700, 700' decouple the sealing mechanism from the moveable component/external moveable component – this may be advantageous as the external moveable component may then be customisable without affecting the sealing mechanism or mechanics of the haptic feedback device. For example, the design and texture of the external moveable component may be selected/customised without impacting the sealing mechanism.

Figures 8A to 8C show cross-sectional views of three mechanisms for sealing a haptic feedback device.

Figure 8A shows a portion of a haptic feedback device 800 comprising a sealing mechanism which is non-structural and functions only when the moveable component is not in use, because when the moveable component moves upwards, the seal is broken. Here, moveable component 802 of the haptic feedback device performs two functions – it provides a contact surface which a user presses and it forms part of the sealing mechanism. The haptic feedback device 800 comprises moveable component 802, further moveable component 806 and one or more ball bearings 808, which are provided in a cavity of the housing 804 of the device. The moveable component 802 comprises a lip 812 that extends all the way around the moveable component. The housing 804 comprises a corresponding ledge or groove 810, and the lip 812 of the moveable component may engage with the ledge 810 of the housing 804. The ledge 810 may, for example, restrict the movement of the moveable component 802 into the cavity of the housing 804, and thereby providing a sealing effect. The moveable component 802 may be formed of a thick flexible material, such that the moveable component 802 flexes when the moveable component is pressed and when the further moveable component 806 is actuated. The moveable component 802 may be moulded from a flexible material. The moveable component 802 may be formed of a material which is impermeable to liquid, such that the sealing mechanism protects the haptic button assembly against fluid ingress. The moveable component 802 may be bonded to the housing 804 – the lip 812 may be fixedly attached to the ledge 810 of the housing 804, thereby providing a seal. The sealing mechanism may comprise an adhesive or an adhesive element to fixedly attach the moveable component 802 to the housing 804. The moveable component 802 may deflect

sufficiently to enable the moveable component to move within the haptic feedback device. The moveable component 802 may provide a return force to return the moveable component to its default, rest state when the further moveable component 806 is not being actuated to deliver a haptic sensation.

5

Figure 8B shows a portion of a haptic feedback device 820 comprising a sealing mechanism which is non-structural and functions only when the moveable component is not in use, because when the moveable component moves upwards, the seal is broken. Here, moveable component 822 of the haptic feedback device
10 performs two functions – it provides a contact surface which a user presses, and it forms part of the sealing mechanism. The haptic feedback device 820 comprises moveable component 822, further moveable component 826 and one or more ball bearings 828, which are provided in a cavity of the housing 824 of the assembly.

15 The moveable component 822 comprises a lip 832 that extends all the way around the moveable component. The housing 824 comprises a corresponding ledge or groove 830, and the lip 832 of the moveable component may engage with the ledge 830 of the housing 824. The ledge 830 may, for example, restrict the movement of the moveable component 822 into the cavity of the housing 824,
20 and thereby providing a sealing effect. The moveable component 822 may be formed of a thin layer of material, such that the moveable component 822 flexes when the moveable component is pressed and when the further moveable component 826 is actuated. The moveable component 822 may be moulded from a flexible material, or may be formed from a thin metallic film or layer. The
25 moveable component 822 may be formed of a material which is impermeable to liquid, such that the sealing mechanism protects the haptic feedback device against fluid ingress. The moveable component 822 may be bonded to the housing 824 – the lip 832 may be fixedly attached to the ledge 830 of the housing 824, thereby providing a seal. The sealing mechanism may comprise an adhesive or
30 an adhesive element to fixedly attach the moveable component 822 to the housing 824. The moveable component 822 may deflect sufficiently to enable the moveable component to move within the haptic feedback device. The moveable component 822 may provide a return force to return the moveable component to its default, rest state when the further moveable component 826 is not being
35 actuated to deliver a haptic sensation.

Figure 8C shows a portion of a haptic feedback device 840 comprising a sealing mechanism which is structural and functions at all times (i.e. both when the moveable component is in motion and is not in motion). Here, moveable component 842 of the haptic feedback device performs two functions – it provides a contact surface which a user presses and it forms part of the sealing mechanism. The haptic feedback device 840 comprises moveable component 1242, further moveable component 846 and one or more ball bearings 848, which are provided in a cavity of the housing 844 of the device. The moveable component 842 comprises a lip 852 that extends all the way around the moveable component. The housing 844 comprises a corresponding ledge or groove 850, and the lip 852 of the moveable component may engage with the ledge 850 of the housing 844, optionally via an O-ring 858. The O-ring 848 is provided on ledge 850 of the housing and between the ledge and the lip 852 of the moveable component. In embodiments, the O-ring 858 may be replaced by any suitable internal seal, that is able to prevent ingress of dirt and liquid into the housing of the device. For example, internal seal 858 could be a flexible Y-shaped seal, flexible C-shaped seal, flexible hollow O-ring, etc. The ledge 850 may, for example, restrict the movement of the moveable component 842 into the cavity of the housing 844, and thereby providing a sealing effect. The moveable component 842 (or at least the contactable/pressable portion of the moveable component) may be formed of a thin layer of material, such that the moveable component 842 flexes when the moveable component is pressed and when the further moveable component 846 is actuated. The moveable component 842 may be moulded from a flexible material, or may be formed from a thin metallic film or layer. The moveable component 842 may be formed of a material which is impermeable to liquid, such that the sealing mechanism protects the haptic feedback device against fluid ingress. The internal seal 858 provides an additional barrier against dirt or fluid ingress.

The device 840 may comprise a flexure 852 or similar flexible element provided below the moveable component 842. The flexure 852 extends across the cavity of the device below the moveable component 842, and is attached along its edge(s) to an internal surface of the housing 844. Thus, flexure 852 may function as a further barrier against dirt or fluid ingress. The flexure 852 is flexible

and is therefore able to flex when the moveable component 842 moves in and out of the cavity of the housing 844. The moveable component 842 may be bonded to the housing 844 – the lip 852 may be fixedly attached to the ledge 850 of the housing 844, thereby providing a seal. The sealing mechanism may comprise an adhesive or an adhesive element to fixedly attach the moveable component 842 to the housing 844. The moveable component 842 may deflect sufficiently to enable the moveable component to move within the haptic feedback device. The moveable component 842 may provide a return force to return the moveable component to its default, rest state when the moveable component 846 is not being actuated to deliver a haptic sensation.

Figures 9A and 9B show cross-sectional views of two further mechanisms for sealing a haptic feedback device.

Figure 9A shows a portion of a haptic feedback device 900 comprising a sealing mechanism which is non-structural and functions at all times (i.e. both when the moveable component is in motion and is not in motion). The sealing mechanism comprises an O-ring type of seal 910. The O-ring 910 is provided between moveable component 902 and housing 904 of the haptic feedback device 900. The cavity comprises moveable component 902, further moveable component 906 and one or more ball bearings 908. The O-ring 910 constrains the edges of moveable component 902 within the housing 904 of the device. The O-ring 910 may permit some movement or flexing of the moveable component 902 in and out of the housing 904, but prevents or minimises lateral (sideways) movement of the moveable component 902 in the housing. The O-ring 910 forms a tight seal between the moveable component 902 and the housing 904 and thereby protects the haptic feedback device against fluid and dirt ingress. This is similar to the gasket sealing technique described above with reference to Figures 3A and 3B.

Figure 9B shows a portion of a haptic feedback device 950 comprising a sealing mechanism which is structural and functions at all times (i.e. both when the moveable component is in motion and is not in motion). The sealing mechanism comprises an internal seal 960. The internal seal 960 is provided between moveable component 952 and housing 954 of the haptic feedback device

950. The cavity comprises moveable component 952, further moveable component 956 and one or more ball bearings 958. The internal seal 960 is provided across a portion of both the moveable component 952 and the cavity of the housing 954. Specifically, the internal seal 960 is provided where edges of the moveable component 952 and cavity meet. The internal seal 960 is provided below the moveable component 952 and within the cavity such that it cannot be seen from the outside of the device 950. The internal seal 960 may be ring shaped, for example. The internal seal 960 may be attached to both the cavity and the moveable component 952 such that when moveable component 952 moves within the cavity, the seal 960 prevents or minimises ingress of dirt and fluid into the cavity. The internal seal 960 may be formed of a flexible material to enable the moveable component 952 to move within the cavity to deliver a haptic sensation.

Figure 10 shows a cross-sectional view of a further mechanism for sealing a haptic feedback device, where the sealing mechanism is structural and functions at all times (i.e. both when the moveable component is in motion and is not in motion). The arrangement is similar to that shown in Figure 9C. Here, the O-ring type internal seal 910 shown in Figure 9C may be replaced with a Y-shaped flexible internal seal, C-shaped seal or hollow O-ring 1010. The haptic feedback device 1000 comprises moveable component 1002, further moveable component 1006 and one or more ball bearings 1008, which are provided in a cavity of the housing 1004 of the device. The moveable component 1002 comprises a notch 1014 along one or more surfaces of the moveable component which are within the cavity of the housing 1004. The notch 1014 may, for example, be a circumferential notch provided around a surface of the moveable component 1002. The housing 1004 comprises a groove or notch 1012 in one or more surfaces of the cavity of the housing. The groove 1012 may be, for example, a circumferential groove provided around a surface of the cavity. The Y-shaped flexible internal seal 1010 comprises a portion which extends into the notch 1014 of the moveable component 1002, and a portion which extends into the groove 1012 of the cavity wall. In the arrangement depicted in Figure 10, the stem portion of the Y-shaped seal is provided in the notch 1014 and the fork or V portion of the Y-shaped seal is provided in the groove 1012. (It will be understood that, alternatively, the stem portion may be provided in groove 1012 and the fork portion in the notch 1014).

The stem portion of the Y-shaped seal 1010 may be fixedly attached in notch 1014, and each end of the fork portion may be fixedly attached in groove 1012. The Y-shaped seal 1010 is formed of a flexible material such that when the moveable component 1002 moves up and down in the cavity, the seal stretches and continues to prevent ingress of fluid and dirt into the cavity.

Figure 11 shows a cross-sectional view of a haptic feedback device and a sealing mechanism which is structural and functions at all times (i.e. both when the moveable component is in motion and is not in motion). The haptic feedback device 1100 comprises a moveable component 1102 and a housing 1104. In this case, the moveable component 1102 is part of the housing 1104. The housing 1104 may comprise at least a portion which is flexible and pressable and therefore provides the button 1102 of the device 1100. The device comprises a further moveable component 1106 and one or more ball bearings 1108. Advantageously, by forming the moveable component 1102 as part of the housing 1104, there is no gap between the moveable component and the housing and therefore, a separate sealing mechanism is not required. This may also provide a cheaper and simpler haptic feedback device to manufacture. The housing 1104 may be formed of a flexible material such that when the further moveable component 1106 is actuated, the moveable component/portion 1102 flexes and provides a haptic sensation. Alternatively, the housing 1104 may be formed of a material which is not generally flexible unless it is provided as a thin layer. Thus, the moveable component/portion 1102 may be thinner than the rest of the housing 1104 such that the moveable component/portion is flexible. For example, at least the moveable component 1102 may be formed from a thin layer of metal, e.g. a 50µm thick layer of aluminium.

Figure 12 shows a cross-sectional view of a haptic feedback device and a sealing mechanism. The haptic feedback device 1200 comprises a moveable component 1202 and a housing 1204. In this case, the moveable component 1202 is part of the housing 1204. The housing 1204 may comprise at least a portion which is flexible and pressable and therefore provides the moveable component 1202 of the device 1200. Advantageously, by forming the moveable component 1202 as part of the housing 1204, there is no gap between the

moveable component and the housing and therefore, a sealing mechanism is not required. This may also provide a cheaper and simpler device to manufacture.

The device 1200 comprises a further moveable component 1206, which
5 takes the form of a lever arm. The further moveable component 1206 may be coupled to a first SMA actuator wire 1208 to move the lever arm in a first direction, and may be coupled to a second SMA actuator wire 1210 to move the lever arm in a second direction. Alternatively, one of the actuator wires 1208, 1210 may be replaced by a return spring or similar resilient element. Further alternatively, the
10 flexible portion of the housing 1204 may itself be stiff enough to provide a return force – in this case, a return spring or second SMA actuator wire may not be required. Movement of the further moveable component 1206 may cause the moveable component/portion 1202 of the housing 1204 to flex. Thus, the housing 1204 may be formed of a flexible material such that when the further moveable
15 component 1206 is actuated, the moveable component/portion 1202 flexes and provides a haptic sensation. Alternatively, the housing 1204 may be formed of a material which is not generally flexible unless it is provided as a thin layer. Thus, the moveable component 1202 may be thinner than the rest of the housing 1204 such that the moveable component/portion is flexible. For example, at least the
20 moveable component 1202 may be formed from a thin layer of metal, e.g. a 50µm thick layer of aluminium.

Figure 14 shows a cross-sectional view of a haptic feedback device 1400 comprising a continuous casing and a sealing mechanism which is structural and
25 functions at all times (i.e. both when the moveable component is in motion and is not in motion). The term “continuous casing” is used herein to mean that a user cannot see a haptic button/haptic feedback device, or that there is no visible gap in the casing around the haptic feedback device. In other words, the haptic feedback device 1400 may be considered to be a gapless (or minimal gap, or no
30 visible gap) device. Similarly, the devices shown in Figures 11 and 12 may be considered to be gapless or continuous casing devices.

The haptic feedback device 1400 comprises a moveable component 1406 and a housing 1402. The haptic feedback device 1400 may be incorporated into
35 an apparatus (e.g. a consumer electronic device) in a way that the haptic feedback

device 1400 is provided below a surface or casing 1412 of the apparatus. This design means that a user cannot see a haptic button or the haptic feedback device 1400, as the surface or casing 1412 of the apparatus is substantially smooth, which may be aesthetically pleasing. As there is no visible button, the design may also remove the need for the casing 1412 of the apparatus to be milled to create a hole through which a button can protrude. Instead, the casing may only need to be partially milled internally to create a pocket or space in which the haptic feedback device can be placed without protruding through the casing such that it is visible to a user. The casing 1412 may be formed of any suitable material which is amenable to milling, such as stainless steel, aluminium, titanium, etc. It will be understood that this is a non-exhaustive list of example materials. Alternatively, if the casing 1412 is formed of a polymeric material, the casing 1412 may be moulded into the required shape, such that a milling operation is not required.

In embodiments where there is no visible button, other techniques may be used to guide a user to making contact with the casing 1412 in a place where haptic feedback can be delivered to the user. For example, location features (not shown) may be provided on the casing 1412 in close proximity to the haptic feedback device. The location features may be e.g. a change in the material, texture or curvature of the casing 1412 in the vicinity of the haptic feedback device. Additionally or alternatively, the casing 1412 may be formed of an opaque or transparent material, while the button could be coloured such that the button can be seen or identified through the casing 1412.

The casing 1412 may therefore comprise at least a portion which is flexible and pressable and enables haptic feedback to be delivered to a user contacting that portion of the casing 1412. The device comprises a moveable component 1406 and a further moveable component 1404, and may comprise one or more ball bearings 1408. The casing 1412 may comprise two or more mechanical edge constraints. The mechanical edge constraints determine the extent to which the casing 1412 resists deflection. In other words, when the moveable component 1406 moves, the casing 1412 may limit the motion of the moveable component 1406 and therefore resist deflection, depending on the number of mechanical edge constraints.

Figure 15 shows schematic views of casings 1500, 1502 and 1504 comprising mechanical edge constraints and having zero, one and two edges that are mechanically constrained to be 'free', respectively. (In other words, casings 1500, 1502 and 1504 have, respectively, zero, one and two free edges). The mechanical edge constraints 1506 are provided around or in close proximity to the moveable component 1508 and the portion 1510 of the casing which deflects/flexes when the moveable component 1508 moves. (It will be understood that the moveable component 1508 does not protrude through the casing in this 'continuous casing' embodiment, but is provided below the casing. The moveable component 1508 is merely included in the illustrations to indicate the position of the moveable component 1508 relative to the mechanical edge constraints.) Casing 1500, which has four fixed edges 1506 (i.e. no free edges), is the stiffest and provides the most resistance against deflection by the moveable component 1514. Casing 1502, which has one free edge (achieved by a cut or slit along the edge) and three fixed edges is less stiff, and casing 1504, which has two free edges and two fixed edges is least stiff. Casing 1504 is shown as having the short edges as fixed edges, and the long edges as the free edges. However, it will be understood that the short edges could be free edges and the long edges could be fixed edges.

Depending on the thickness of the casing itself, it may be necessary to mechanically support the casing in the region of the moveable component 1508 from the inside, either only when the moveable component 1508 is not in motion (i.e. not being used to deliver haptic feedback) or also during motion. This is because the casing may need to be quite thin in order for the haptic effect delivered by the moveable component 1508 to be felt through the casing, but if the casing is thin (at least in the vicinity of the moveable component), it could become damaged over time. For example, the casing could be 20µm thick (e.g. if the casing, at least in the vicinity of the moveable component is provided by a metal foil), and so could be damaged over time e.g. from repeated delivery of haptic feedback, or from repeated contact by a user, or just from ordinary wear and tear. Thus, a support mechanism between the casing and the moveable component 1508 may be provided to minimise the risk of damage or increase the lifetime of the thin casing, while also permitting haptic feedback to be delivered.

Thus, turning back to Figure 14, in order for the casing 1412 to be able to flex enough for haptic feedback to be delivered via the casing (i.e. to be less resistant to deflection by the moveable component 1406), the casing 1412 may comprise two cuts/slits/free edges. Preferably, the cuts are provided along opposite sides of the flexible portion of the casing 1412. Thus, when the moveable component 1406 is caused to move 'vertically' or up and down in the cavity (as shown by the arrow), the casing 1412 is able to flex. If there were no cuts, the casing 1412 may be too rigid and may exert a force on the moveable component 1406 that prevents the moveable component from moving, thereby preventing or damping the haptic effect. The casing 1412 may also function as a flexure that provides a return force to return the moveable component 1406 to its default, rest state when the moveable component is not being actuated to deliver a haptic sensation.

Advantageously, by providing the haptic feedback device below the casing 1412, sealing is provided when the haptic feedback device is not in motion. However, as the casing 1412 comprises cuts, when the casing 1412 and moveable component 1406 are in motion, liquid and/or dust may be able to enter the haptic feedback device through the gaps in the casing. Accordingly, the haptic feedback device 1400 comprises a protective seal 1410 (also referred to as a protective membrane, film or cover). The protective seal 1410 may be any waterproofing and/or dust proofing seal to prevent water and/or dust ingress into the haptic feedback device or the apparatus into which the haptic device is incorporated. Any of the sealing mechanisms described herein may provide the protective seal for this gapless/continuous casing device. The protective seal 1410 may be provided between the casing 1412 and the moveable component 1406, and may extend all the way across the cavity of the housing 1402 as shown. The protective seal 1410 may be coupled to the housing and/or the casing 1412 using any suitable means, such as an adhesive. Alternatively, the protective seal 1410 may have an O-ring like or gasket like structure, such that it is provided between the housing 1402 and the moveable component 1406. In other words, the protective seal 1410 may comprise a cut-out through which the moveable component 1406 is able to extend/move, similar to the embodiment shown in Figure 7C. Alternatively, the protective seal may be coupled between the housing 1402 and

the casing 1412, but may be provided between the moveable component 1406 and the further moveable component 1404.

Thus, in embodiments, the housing and the sealing mechanism may be integrally formed. The sealing mechanism may comprise one slit in the vicinity of the moveable component for increasing the flexibility of the sealing mechanism. Alternatively, the sealing mechanism may comprise two spaced apart parallel slits in the vicinity of the moveable component for increasing the flexibility of the sealing mechanism. If the sealing mechanism comprises one or more slits, the sealing mechanism may be used in conjunction with any of the other sealing mechanisms described herein to improve the sealing. The sealing mechanism may further comprise an internal sealing film provided within the cavity, wherein at least part of the moveable component is provided beneath, above or protrudes through the internal sealing film. Additionally or alternatively, the sealing mechanism may further comprise a gasket seal provided between the moveable component and the cavity.

Figures 16A to 16E show cross-sectional schematic views of further haptic devices.

20

In Figure 16A, the haptic device 1600 comprises housing 1602, and the housing 1602 comprises a cavity or recess. The haptic device 1600 comprises a moveable component 1606, which is provided within the cavity of the housing 1602. The moveable component 1606 may comprise a contact surface, which may be level with/flush with an external surface of the housing 1602, or may protrude from or be recessed within the housing 1602. It will be understood that the housing 1602 surrounds and encases the moveable component 1606 such that only the contact surface of the moveable component 1606 may be visible/contactable by a user. The moveable component 1606 is moveable within the cavity.

30

The haptic device 1600 comprises a sealing mechanism, which functions to seal the cavity. The sealing mechanism may comprise a thin membrane 1608 which is provided between the moveable component 1606 and the actuation mechanism. The actuation mechanism may comprise a further moveable

35

component 1604, such as that described with reference to Figure 4. The further moveable component 1604 may be able to transmit a force or a displacement through the thin membrane 1608 to move the moveable component 1606. The sealing mechanism may comprise an O-ring seal 1610 (or a hollow O-ring seal) which encloses the thin membrane 1608. The O-ring seal 1610 and thin membrane 1608 may be integrally formed, or may be separate components which are fixedly attached to each other. The O-ring seal 1610 may be formed from a compliant material. The sealing mechanism seals the cavity against liquid and/or dust ingress, both when the haptic device 1600 is being used to deliver haptic feedback and when it is not being used to deliver haptic feedback. The sealing mechanism may be under compression within the cavity. The moveable component 1606 may comprise pillars or supports 1606a, 1606b, which contact the thin membrane 1608 and support the moveable component 1606 on the sealing mechanism. When the moveable component 1606 is touched/pressed, the force exerted by the user on the moveable component is transferred through the supports 1606a,b to a force sensing mechanism (not shown).

Figure 16B shows an alternative arrangement of the haptic device of Figure 16A. Haptic device 1620 is similar to haptic device 1600 except that the moveable component 1600 no longer comprises pillars but instead comprises a protrusion 1606c. The protrusion 1606c contact the thin membrane 1608 and support the moveable component 1606 on the sealing mechanism. The further moveable component 1604 comprises a recess which corresponds to the protrusion 1606c, such that the protrusion 1606c of the moveable component 1606 may engage with the recess of the further moveable component 1604. When the moveable component 1606 is touched/pressed, the force exerted by the user is transferred through the protrusion 1606c to a force sensing mechanism (not shown). The force causes the thin membrane 1608 to flex, and the recess of the further moveable component 1604 provides the thin membrane 1608 with space into which it can flex.

Figure 16C shows an alternative arrangement of the haptic device of Figure 16B. Haptic device 1640 is similar to haptic device 1620 except that the thin membrane 1608 does not extend across the whole of the underside or base of the moveable component 1606. Instead, the thin membrane or seal 1608 seals

against a side/the sides of the moveable component 1606. A separate element 1612 is provided between the moveable component 1606 and the further moveable component 1604, and this element 1612 extends under the thin membrane 1608. Element 1612 may be a spring or flexible, resilient element.

5

Figure 16D shows an alternative arrangement of the haptic device of Figure 16C. Haptic device 1660 is similar to haptic device 1640 except that the seal 1608 seals against a rigid protrusion 1614 of the spring element 1612, instead of sealing against the moveable component 1606 directly. This may be advantageous because it may be simpler to couple the seal 1608 to the rigid protrusion 1614 than to the side of the moveable component 1606.

Figure 16E shows an alternative arrangement of the haptic device of Figure 16D. Haptic device 1680 is similar to haptic device 1660 except that the further moveable component 1604 comprises a rigid protrusion 1616, and the seal seals against the rigid protrusion 1616 instead of against the moveable component 1606 directly. This may be advantageous because it may be simpler to couple the seal 1608 to the rigid protrusion 1616 of the further moveable component 1604.

Thus, generally speaking the sealing mechanism may comprise a sealing film which is provided within the cavity and the sealing film may either be provided below the moveable component (e.g. between the moveable component and the further moveable component), or against a side(s) of the moveable component, or against a rigid structure (e.g. a protrusion of the further moveable component or another element). Thus, in some cases, the sealing mechanism may be or may comprise a gasket seal provided between the moveable component and the cavity. In certain cases, the gasket seal may abut against a rigid structure that is provided between the moveable component and the gasket seal. The rigid structure may be part of the further moveable component or may be part of a separate component/element.

30

It will be understood that any of the sealing mechanisms described herein may be adapted for use with any haptic feedback device in which a moveable component moves 'vertically' or 'horizontally'/laterally. One or more of the sealing

mechanisms described herein may be combined within a single haptic feedback device.

Thus, the present techniques provide a haptic feedback device comprising:
5 a housing comprising a cavity; a moveable component provided within the cavity and moveable relative to the cavity; an actuator for moving the moveable component to provide haptic feedback; and a sealing mechanism for limiting liquid and/or dust ingress into the device. The actuator may comprise at least one length of shape memory alloy (SMA) actuator wire arranged to, on contraction, move the
10 moveable component within the cavity.

The haptic feedback device may further comprise a further moveable component provided within the cavity in contact with the moveable component.

15 In embodiments, such as those shown in Figures 4, 5 and 6, the moveable component may be moveable along a first axis within the cavity; the further moveable component may be moveable in a plane defined by the first axis and a second axis, the second axis being perpendicular to the first axis, and arranged to drive movement of the moveable component along the first axis; and the at least
20 one length of SMA actuator wire may be coupled to the further moveable component and arranged to, on contraction, move the further moveable component in the plane.

In alternative embodiments, such as that shown in Figure 12, the moveable
25 component may be moveable along a first axis within the cavity; the further moveable component may be rotatable about a second axis that is parallel to the first axis, and arranged to drive movement of the moveable component along the first axis; and the at least one SMA actuator wire may be coupled to the further moveable component and arranged to, on contraction, rotate the further moveable
30 component about the second axis.

The sealing mechanism may be non-structural and may not constrain the motion of the moveable component. Alternatively, the sealing mechanism may be structural and may constrain the motion of the moveable component within the
35 cavity.

The sealing mechanism may seal the device when the moveable component is stationary and in motion. Alternatively, the sealing mechanism may seal the device when the moveable component is stationary only.

5

The sealing mechanism may comprise an external sealing film provided over the cavity and at least part of the housing, as shown in Figures 4 and 5, for example. The external sealing film may be formed of any one of: a flexible material, an elastic material, an elastomer, a polymer, a silicone material, a thin
10 metallic material, a composite material, a thin aluminium film, a thin titanium film, an alloy, and a thin stainless steel film.

The sealing mechanism may comprise an internal sealing film provided within the cavity, wherein at least part of the moveable component is provided
15 beneath, above or protrudes through the internal sealing film. See for example Figures 7A-C, 8C and 14. The sealing mechanism may comprise an internal sealing film provided within the cavity between the moveable component and the further moveable component. The internal sealing film may be formed of any one
20 of: a flexible material, an elastic material, an elastomer, a polymer, a silicone material, a thin metallic material, a composite material, a thin aluminium film, a thin titanium film, an alloy, and a thin stainless steel film.

The sealing mechanism may comprise a gasket seal provided between the moveable component and the cavity, as shown in Figures 9A and 9B for example.
25 The gasket seal may abut against a rigid structure located between the gasket seal and the moveable component. The gasket seal may be formed of a liquid-impermeable material and/or a compressible material.

The sealing mechanism may comprise a mesa structure, where the mesa
30 structure engages with one or more surfaces of the cavity of the housing.

The sealing mechanism may comprise at least one flexible element coupled to the moveable component and to a surface of the cavity, as shown in Figures 8 and 10 for example. The at least one flexible element may be formed of any one

of: rubber, an elastic material, an elastomer, a polymer, a foam material, a closed cell foam material, and a silicone material.

In embodiments, at least one of the following may be formed from a hydrophobic material: the moveable component, the housing, the cavity, the actuator, and the sealing mechanism. Additionally or alternatively, at least one of the following may be coated with a hydrophobic material: the moveable component, the housing, the cavity, the actuator, and the sealing mechanism. The hydrophobic material may be polytetrafluoroethylene.

Further embodiments of the present techniques are set out in the following numbered clauses:

1. A waterproof tactile feedback device comprising: a button with a mesa structure at the centre of its lower surface; a housing or surround, level with the top surface of the button; a lower casing; resilient means; at least one SMA wire; and a Printed Circuit containing detection means for depressing the button, wherein a labyrinth seal is formed between the top surface of the button and the underside of the housing and between the lower surface of the button and a surface of the lower casing.

2. The device of clause 1 wherein the button is made from a low friction material.

3. The device of clause 1 or clause 2 wherein the button is made from PTFE.

4. The device of any of the preceding clauses wherein the surface of the button that forms the labyrinthine seal is coated in a hydrophobic material.

5. The device of clauses 1 to 4 wherein the labyrinthine seal includes a gasket placed between the top surface of the button and the underside of the housing.

6. The device of clause 5 wherein the gasket is made from an impermeable compressible foam.

7. The device of any of the preceding clauses wherein an impermeable compressible foam is placed between the edge of the button and the housing surrounding the button.

5 Those skilled in the art will appreciate that while the foregoing has described what is considered to be the best mode and where appropriate other modes of performing present techniques, the present techniques should not be limited to the specific configurations and methods disclosed in this description of the preferred embodiment. Those skilled in the art will recognise that present
10 techniques have a broad range of applications, and that the embodiments may take a wide range of modifications without departing from any inventive concept as defined in the appended claims.

CLAIMS

1. A haptic feedback device comprising:
a housing comprising a cavity;
5 a moveable component provided within the cavity and moveable relative to the cavity;
an actuator for moving the moveable component to provide haptic feedback; and
a sealing mechanism for limiting liquid and/or dust ingress into the device.
10
2. The haptic feedback device as claimed in claim 1 wherein the actuator comprises at least one length of shape memory alloy (SMA) actuator wire arranged to, on contraction, move the moveable component within the cavity.
- 15 3. The haptic feedback device as claimed in claim 2 wherein the moveable component is movable along a movement axis within the cavity, the movement axis being parallel to the at least one length of SMA actuator wire.
4. The haptic feedback device as claimed in claim 2 further comprising:
20 a further moveable component provided within the cavity in contact with the moveable component.
5. The haptic feedback device as claimed in claim 4 wherein:
the moveable component is moveable along a first axis within the cavity;
25 the further moveable component is moveable in a plane defined by the first axis and a second axis, the second axis being perpendicular to the first axis, and arranged to drive movement of the moveable component along the first axis; and
the at least one length of SMA actuator wire is coupled to the further moveable component and arranged to, on contraction, move the further moveable
30 component in the plane.
6. The haptic feedback device as claimed in claim 4 wherein:
the moveable component is moveable along a first axis within the cavity;

the further moveable component is rotatable about a second axis that is parallel to the first axis, and arranged to drive movement of the moveable component along the first axis; and

the at least one SMA actuator wire is coupled to the further moveable component and arranged to, on contraction, rotate the further moveable component about the second axis.

7. The haptic feedback device as claimed in claim 2 wherein the moveable component is moveable along a movement axis within the cavity, the movement axis being at an angle to the at least one length of SMA actuator wire.

8. The haptic feedback device as claimed in any one of claims 1 to 7 wherein the sealing mechanism is non-structural and does not constrain the motion of the moveable component.

9. The haptic feedback device as claimed in any one of claims 1 to 7 wherein the sealing mechanism is structural and constrains the motion of the moveable component within the cavity.

10. The haptic feedback device as claimed in any one of claims 1 to 9 wherein the sealing mechanism seals the device when the moveable component is stationary and in motion.

11. The haptic feedback device as claimed in any one of claims 1 to 9 wherein the sealing mechanism seals the device when the moveable component is stationary only.

12. The haptic feedback device as claimed in any one of claims 1 to 10 wherein the sealing mechanism comprises an external sealing film provided over the cavity and at least part of the housing.

13. The haptic feedback device as claimed in claim 12 wherein the external sealing film is formed of any one of: a flexible material, an elastic material, an elastomer, a polymer, a silicone material, a thin metallic material, a composite

material, a thin aluminium film, a thin titanium film, an alloy, and a thin stainless steel film.

14. The haptic feedback device as claimed in any one of claims 1 to 13 wherein the sealing mechanism comprises an internal sealing film provided within the cavity, wherein at least part of the moveable component is provided beneath, above or protrudes through the internal sealing film.

15. The haptic feedback device as claimed in any one of claims 4 to 13 wherein the sealing mechanism comprises an internal sealing film provided within the cavity between the moveable component and the further moveable component.

16. The haptic feedback device as claimed in claim 14 or 15 wherein the internal sealing film is formed of any one of: a flexible material, an elastic material, an elastomer, a polymer, a silicone material, a thin metallic material, a composite material, a thin aluminium film, a thin titanium film, an alloy, and a thin stainless steel film.

17. The haptic feedback device as claimed in any preceding claim wherein the sealing mechanism comprises a gasket seal provided between the moveable component and the cavity.

18. The haptic feedback device as claimed in claim 17 wherein the gasket seal abuts against a rigid structure located between the gasket seal and the moveable component.

19. The haptic feedback device as claimed in claim 17 or 18 wherein the gasket seal is formed of a liquid-impermeable material.

20. The haptic feedback device as claimed in claim 17, 18 or 19 wherein the gasket seal is formed of a compressible material.

21. The haptic feedback device as claimed in any preceding claim, wherein the sealing mechanism comprises a mesa structure on the button, where the mesa structure engages with one or more surfaces of the cavity of the housing.

22. The haptic feedback device as claimed in any preceding claim wherein the sealing mechanism comprises at least one flexible element coupled to the moveable component and to a surface of the cavity.

5

23. The haptic feedback device as claimed in claim 22 wherein the at least one flexible element is formed of any one of: rubber, an elastic material, an elastomer, a polymer, a foam material, a closed cell foam material, and a silicone material.

10 24. The haptic feedback device as claimed in any one of claims 4 to 6 wherein the moveable component and the housing are integrally formed.

25. The haptic feedback device as claimed in any one of claims 14 to 236 wherein the moveable component and the sealing mechanism are integrally
15 formed.

26. The haptic feedback device as claimed in any one of claims 4 to 6 wherein the housing and the sealing mechanism are integrally formed.

20 27. The haptic feedback device as claimed in claim 26 wherein the sealing mechanism comprises one slit in the vicinity of the moveable component for increasing the flexibility of the sealing mechanism.

28. The haptic feedback device as claimed in claim 26 wherein the sealing
25 mechanism comprises two spaced apart parallel slits in the vicinity of the moveable component for increasing the flexibility of the sealing mechanism.

29. The haptic feedback device as claimed in claims 26, 27 or 28 wherein the sealing mechanism further comprises an internal sealing film provided within the
30 cavity, wherein at least part of the moveable component is provided beneath, above or protrudes through the internal sealing film.

30. The haptic feedback device as claimed in any one of claims 26 to 29 wherein the sealing mechanism further comprises a gasket seal provided between the
35 moveable component and the cavity.

31. The haptic feedback device as claimed in any preceding claim wherein at least one of the following are formed from a hydrophobic material: the moveable component, the housing, the cavity, the actuator, and the sealing mechanism.

5

32. The haptic feedback device as claimed in any preceding claim wherein at least one of the following are coated with a hydrophobic material: the moveable component, the housing, the cavity, the actuator, and the sealing mechanism.

10 33. The haptic feedback device as claimed in claim 31 or 32 wherein the hydrophobic material is polytetrafluoroethylene.

34. An apparatus comprising:

15 a haptic feedback device according to any of claims 1 to 33 for delivering a haptic sensation to a user of the apparatus.

35. The apparatus as claimed in claim 34 where the apparatus is any one of: a smartphone, a camera, a foldable smartphone, a foldable image capture device, a foldable smartphone camera, a foldable consumer electronics device, a camera with folded optics, an image capture device, an array camera, a 3D sensing device or system, a consumer electronic device, a domestic appliance, a mobile computing device, a mobile electronic device, a laptop, a tablet computing device, an e-reader, a computing accessory, a computing peripheral device, an audio device, a security system, a gaming system, a gaming controller, a robot or robotics device, an augmented reality system, an augmented reality device, a virtual reality system, a virtual reality device, a wearable device, and a vehicle.

25

36. The apparatus as claimed in claim 34 or 35 wherein the sealing mechanism comprises a portion of a surface of the apparatus.

30

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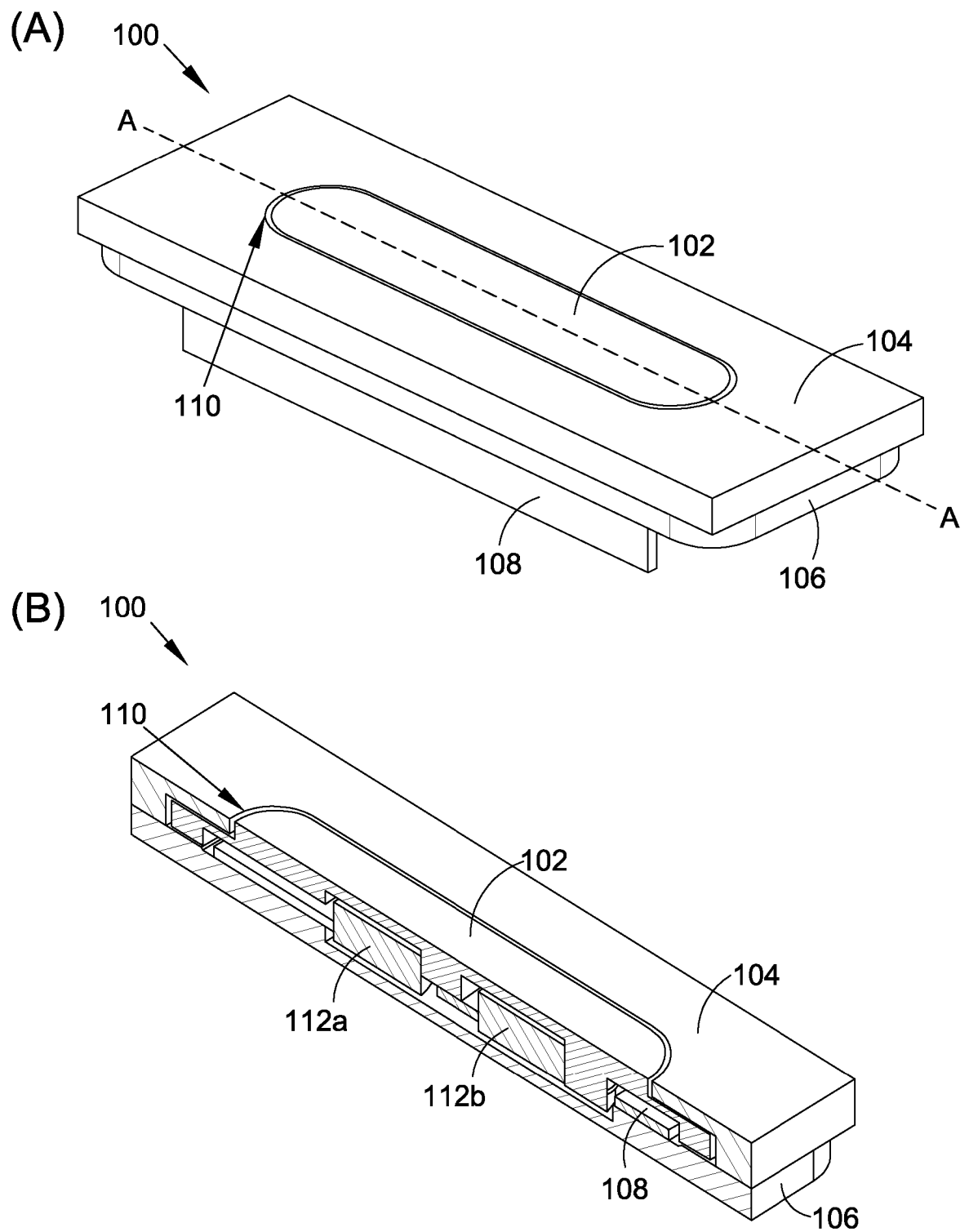


FIGURE 1

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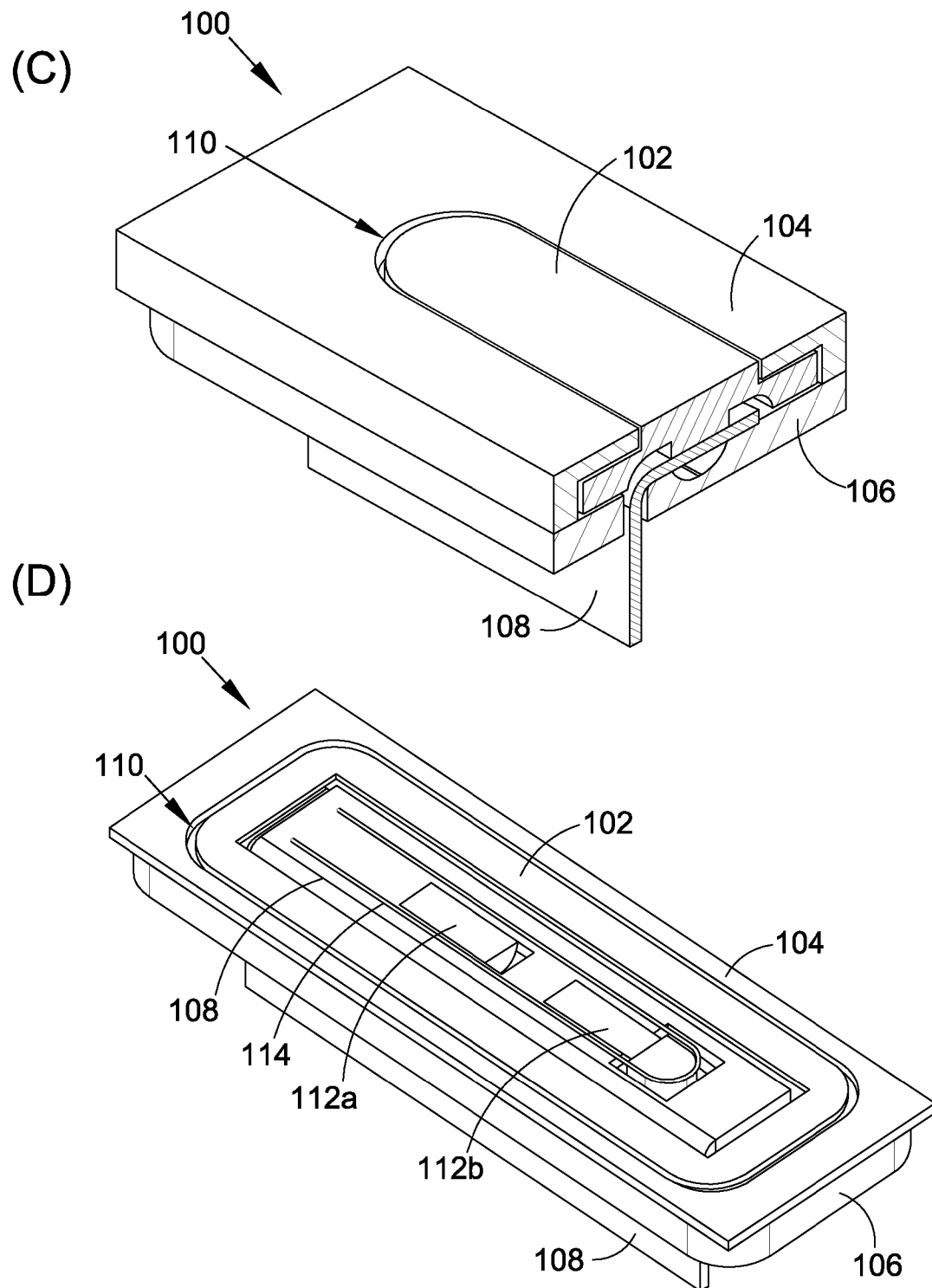


FIGURE 1

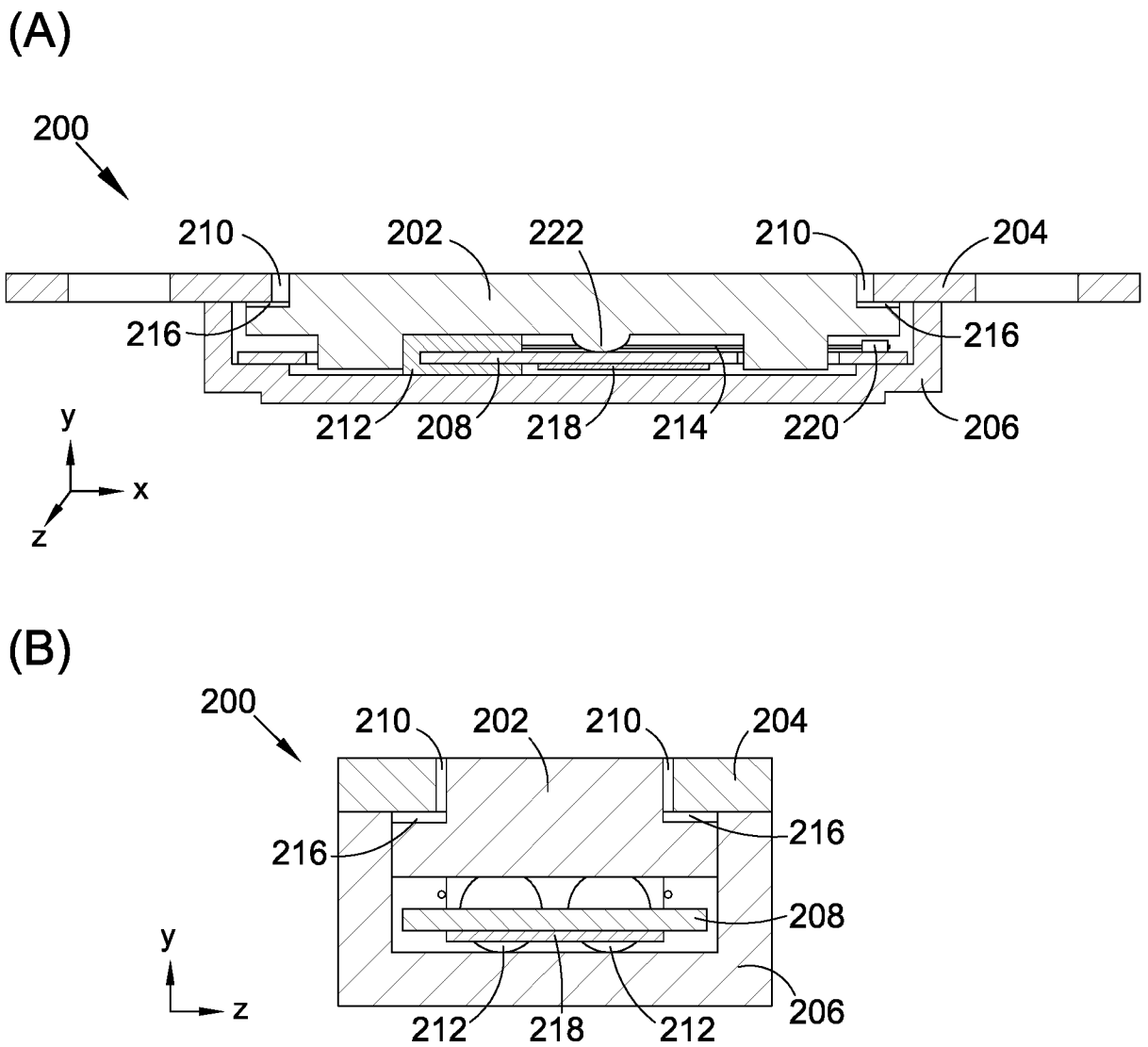
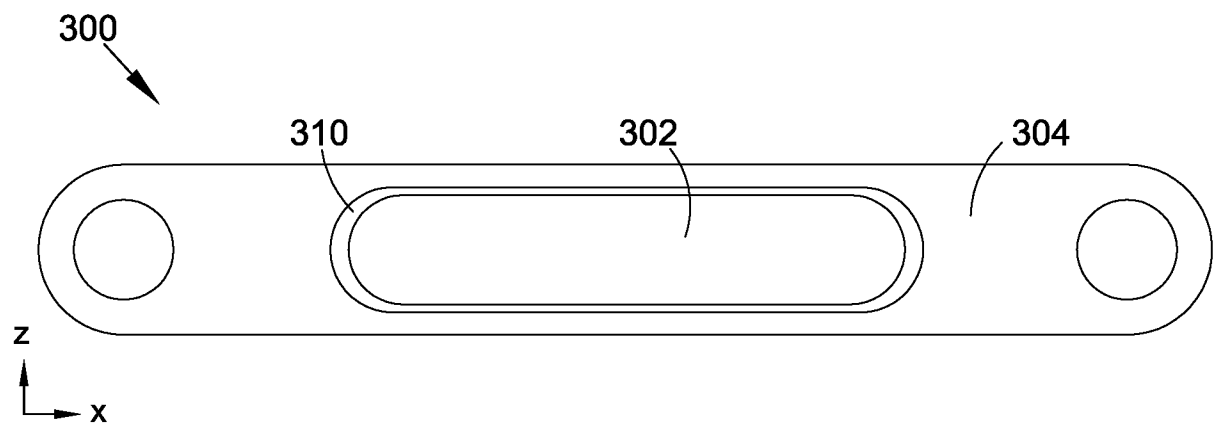


FIGURE 2

(A)



(B)

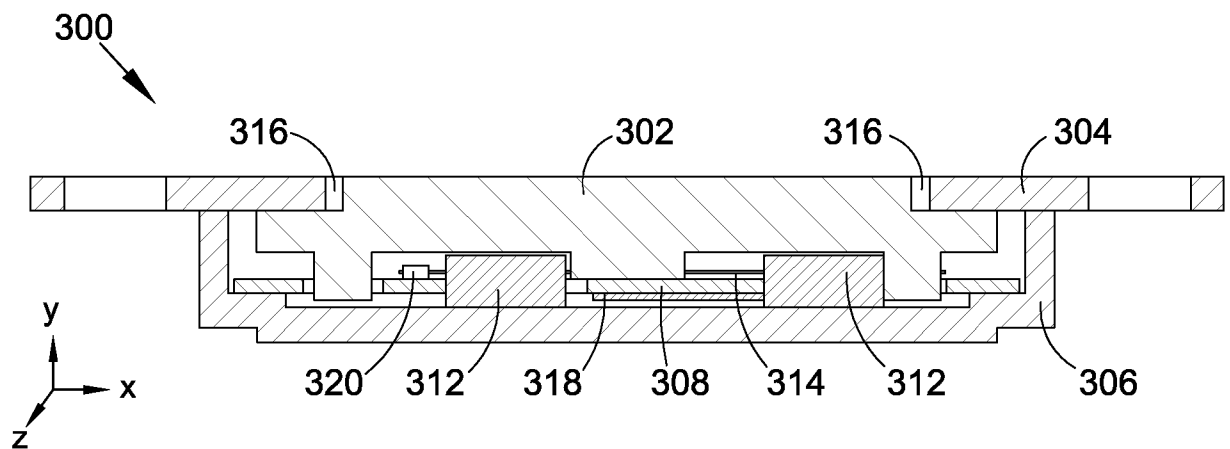


FIGURE 3

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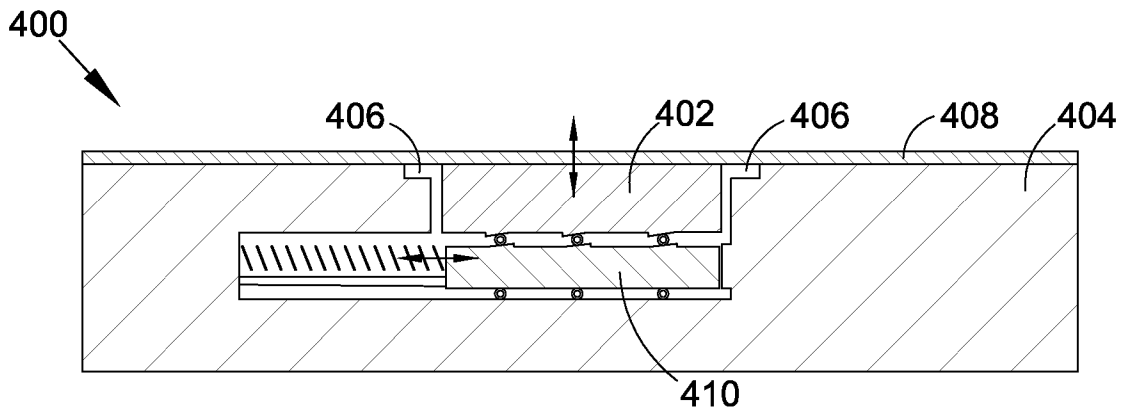


FIGURE 4

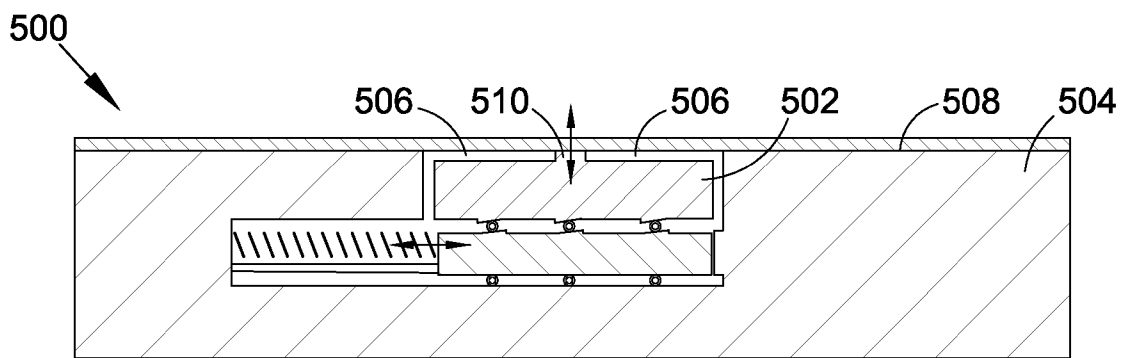


FIGURE 5

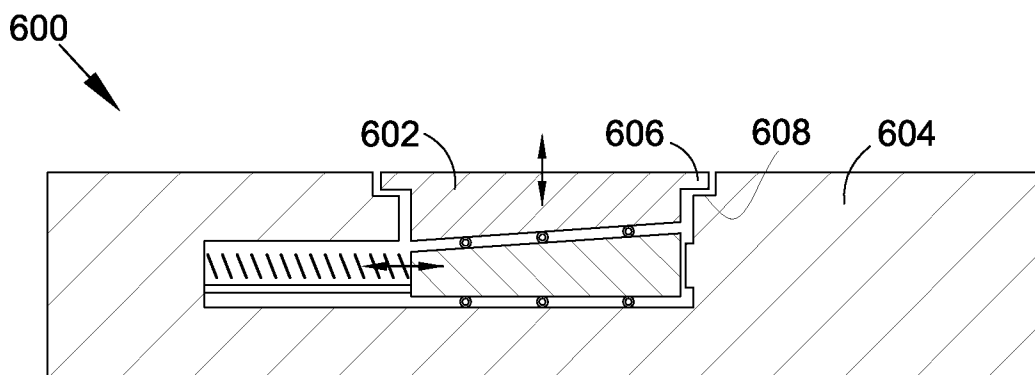


FIGURE 6

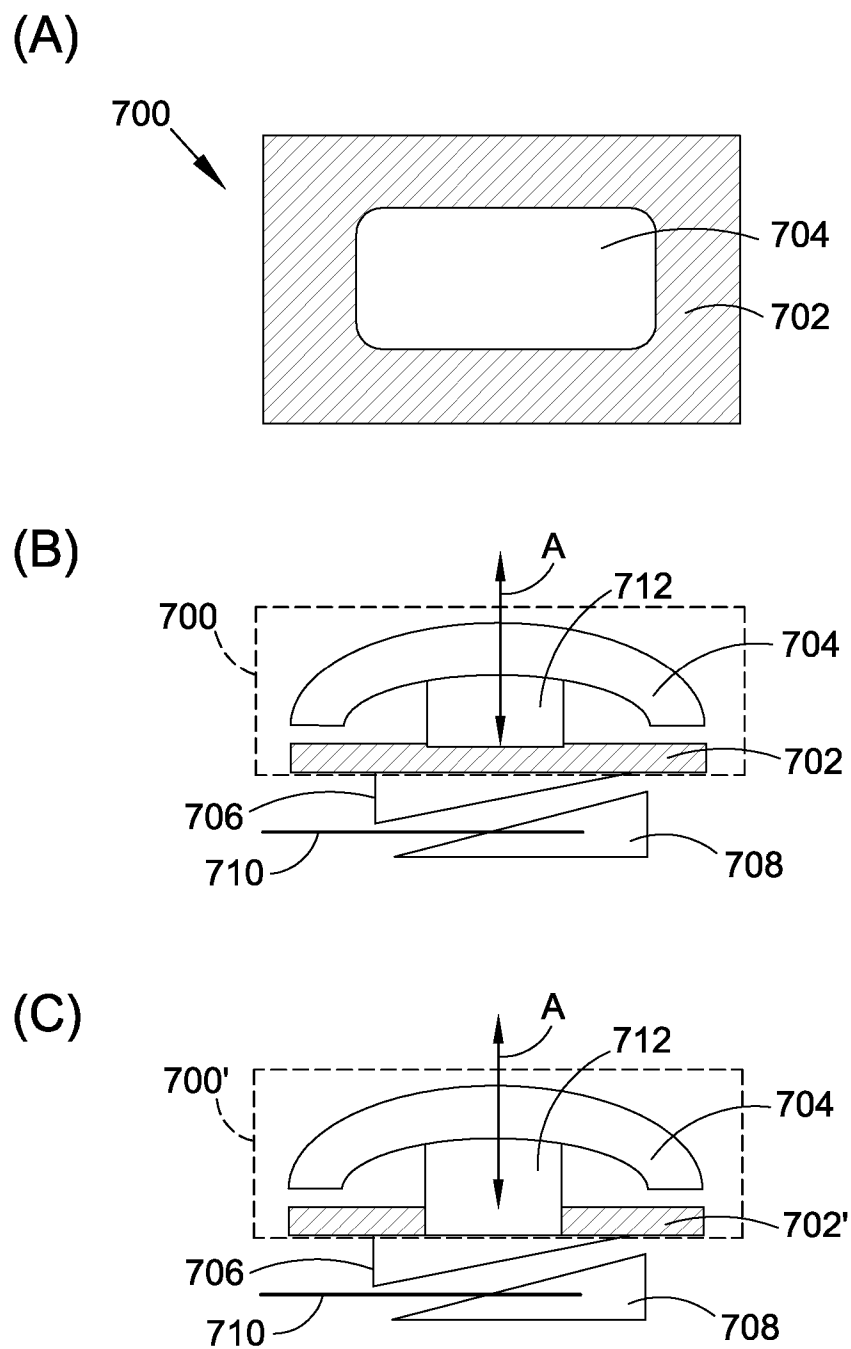


FIGURE 7

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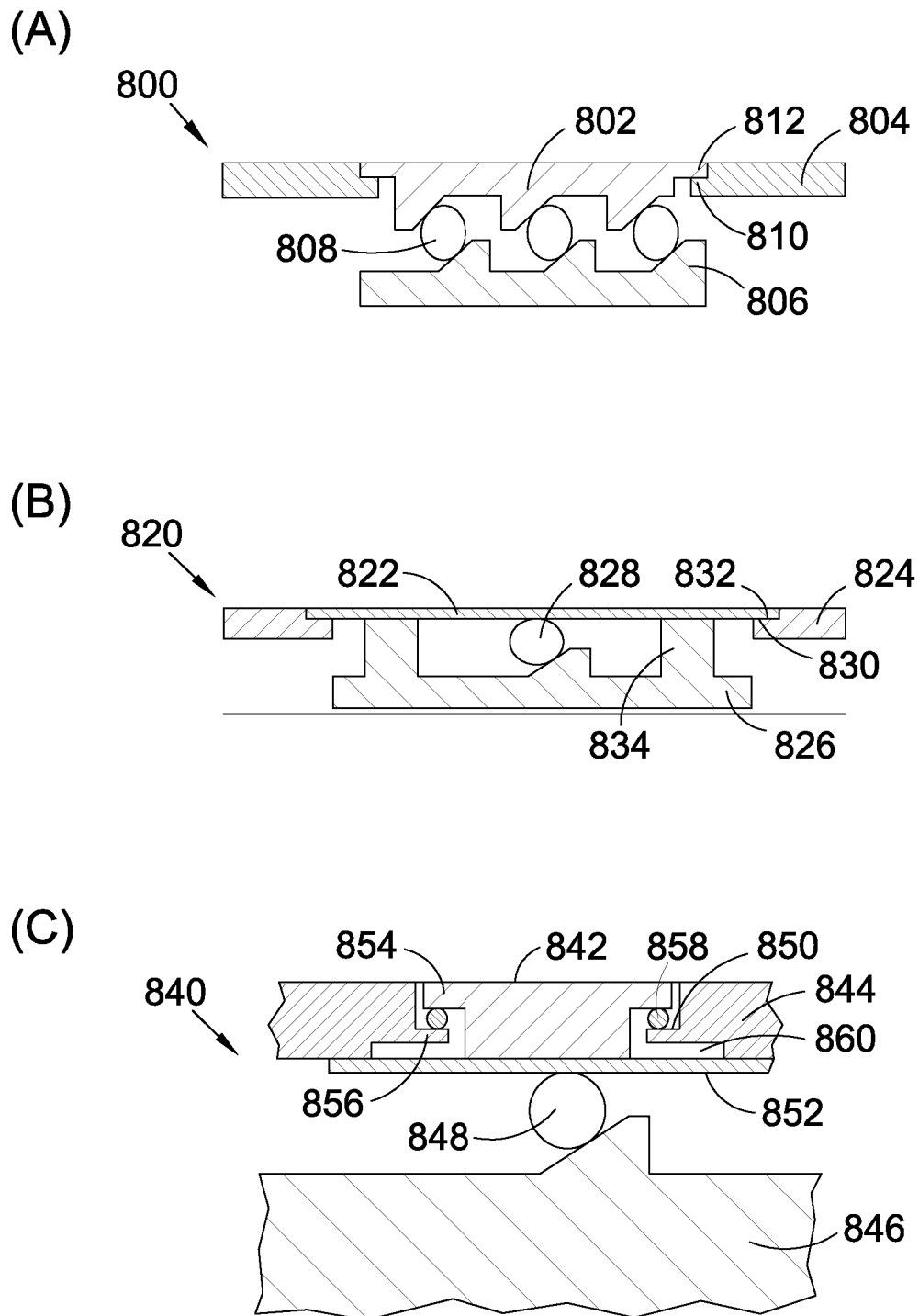


FIGURE 8

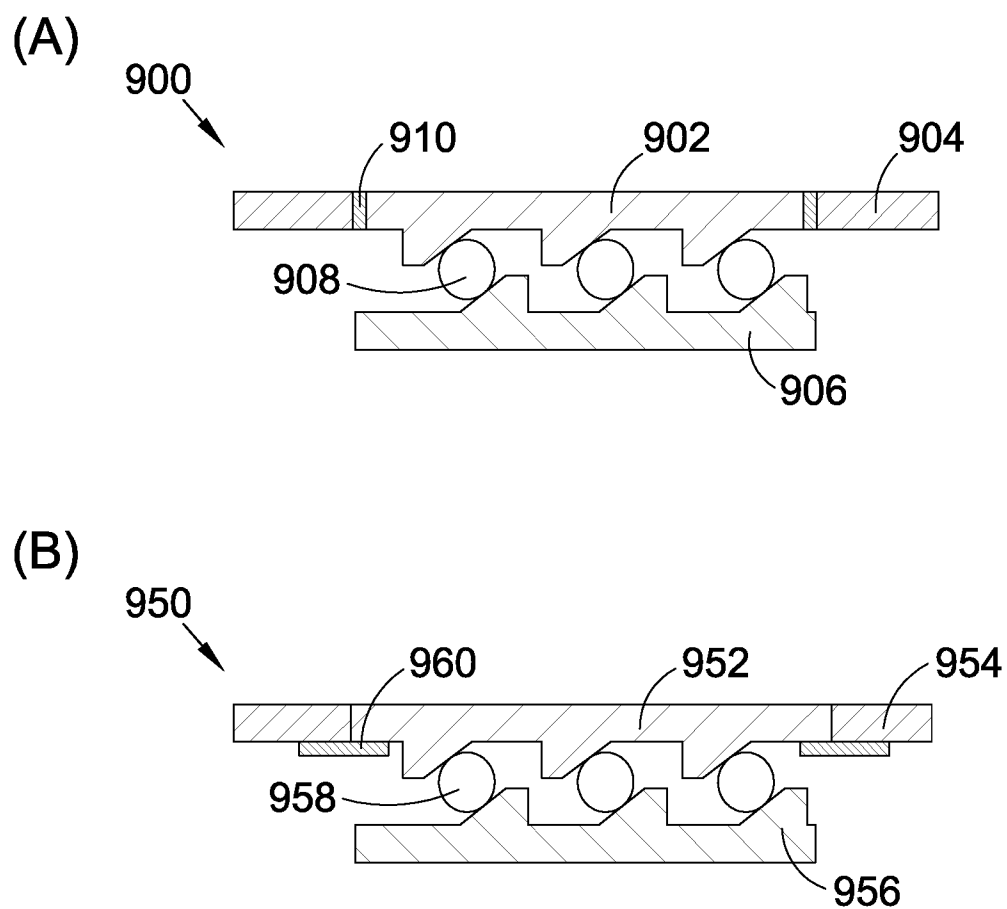


FIGURE 9

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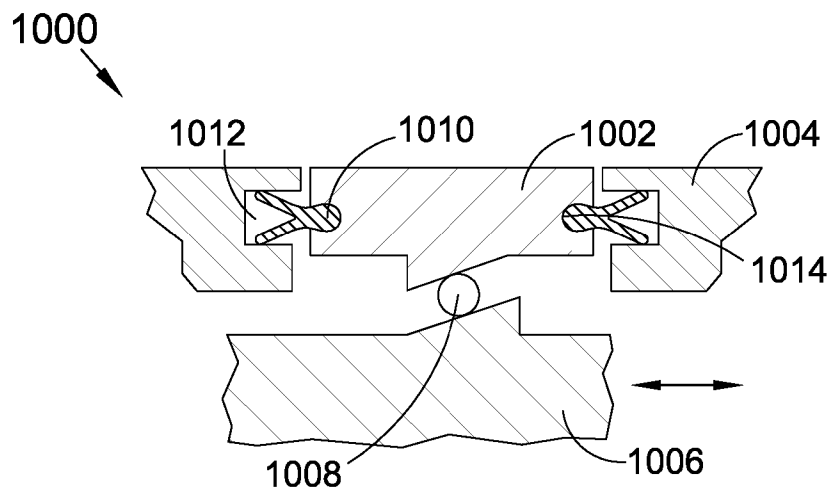


FIGURE 10

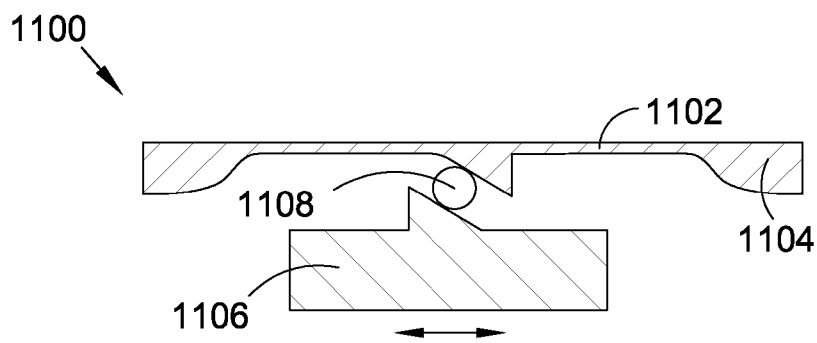


FIGURE 11

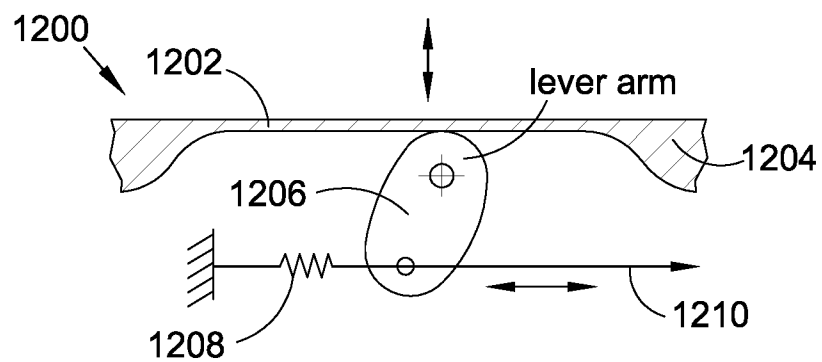
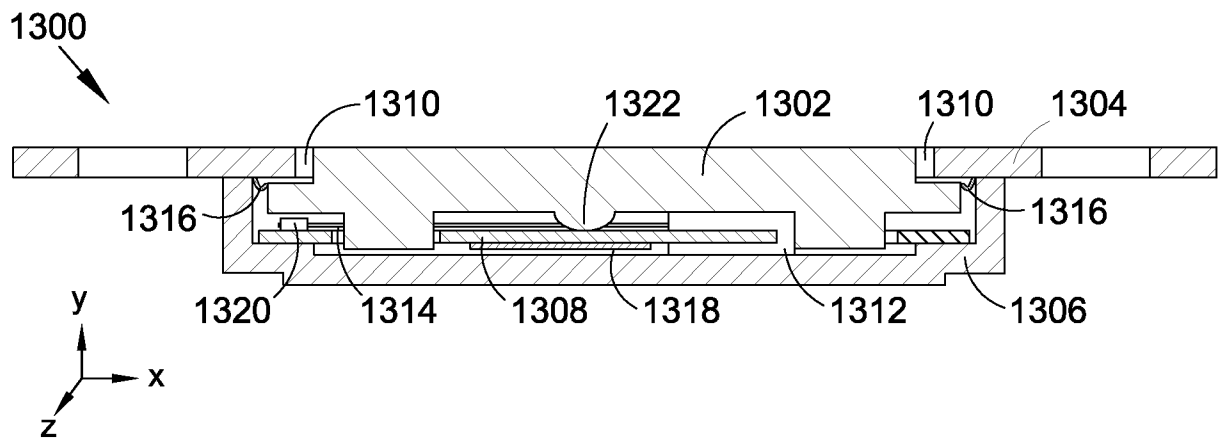


FIGURE 12

(A)



(B)

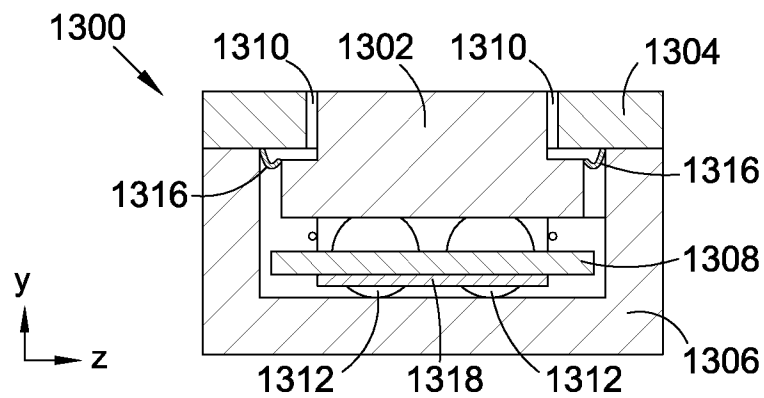


FIGURE 13

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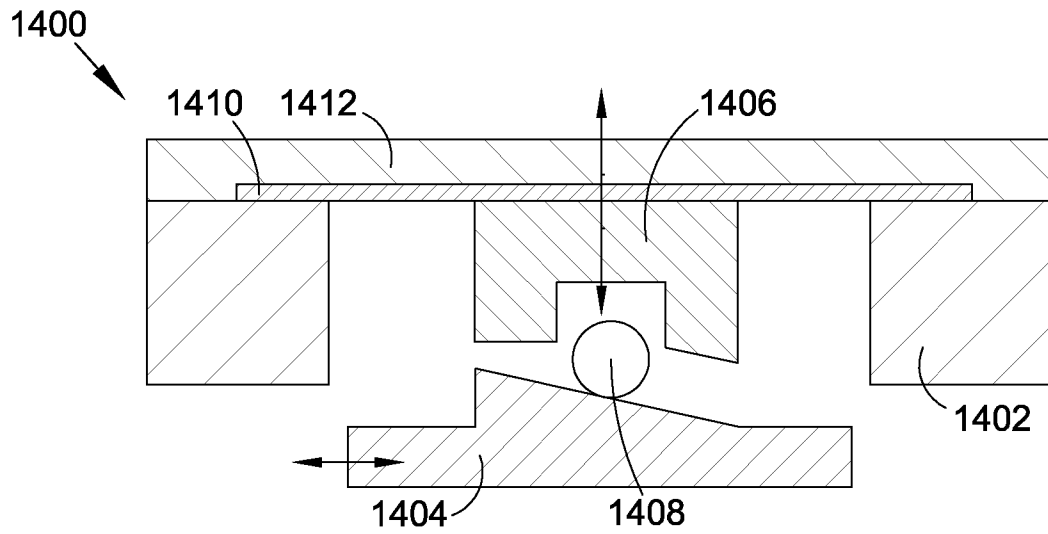


FIGURE 14

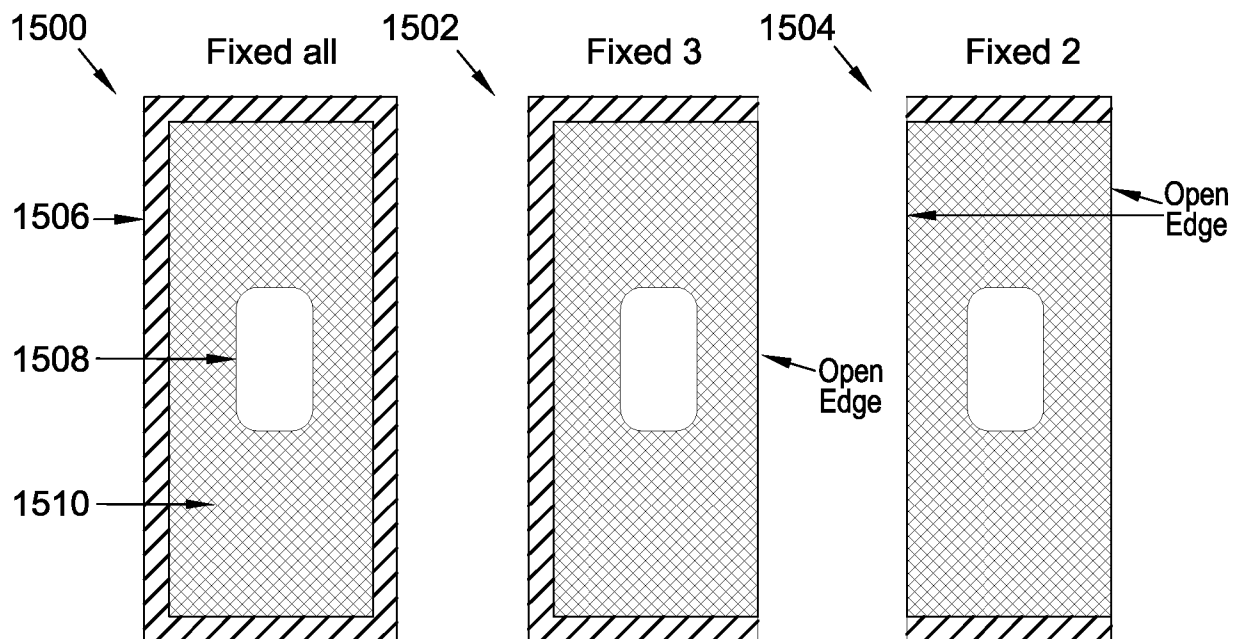


FIGURE 15

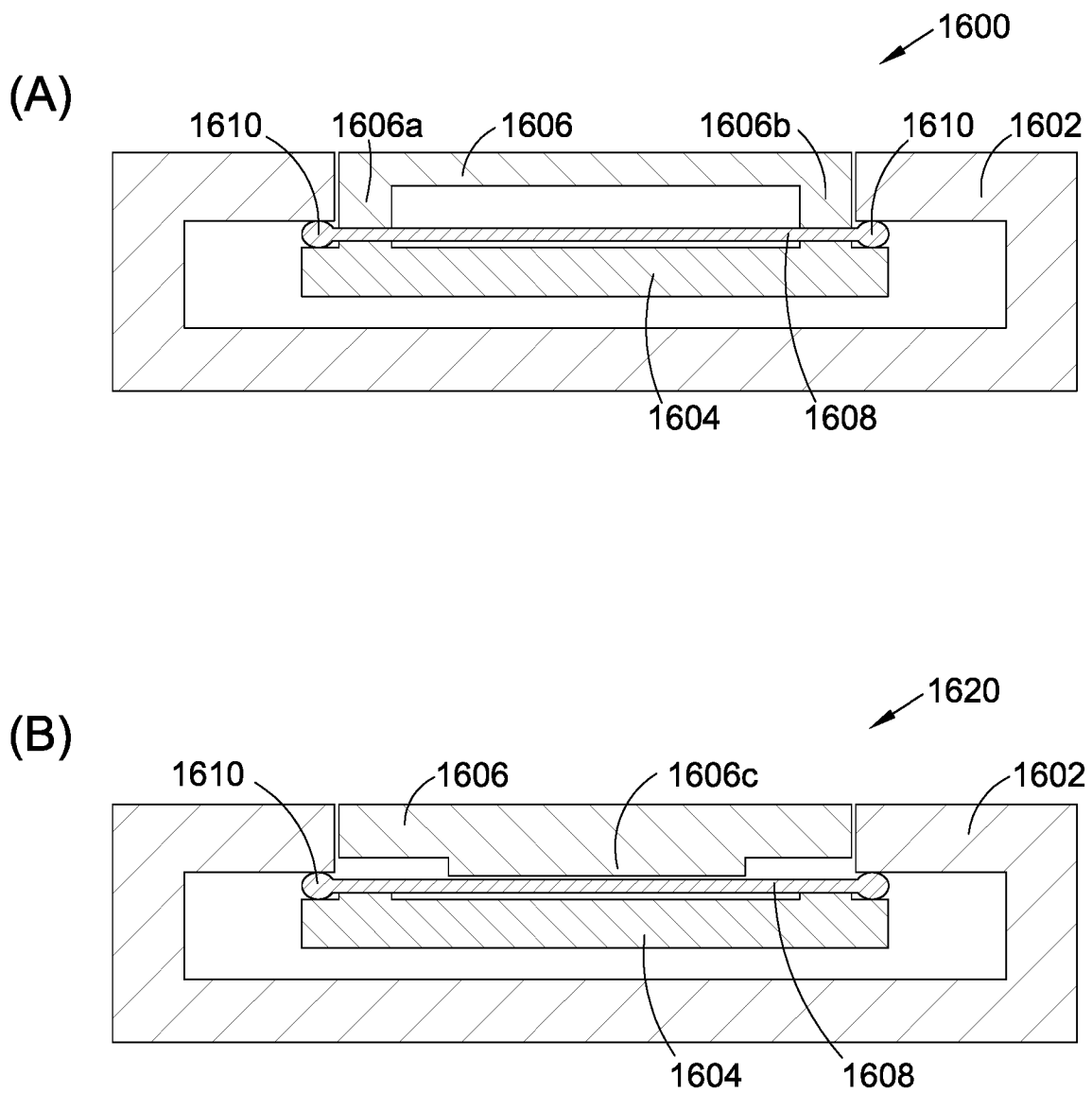
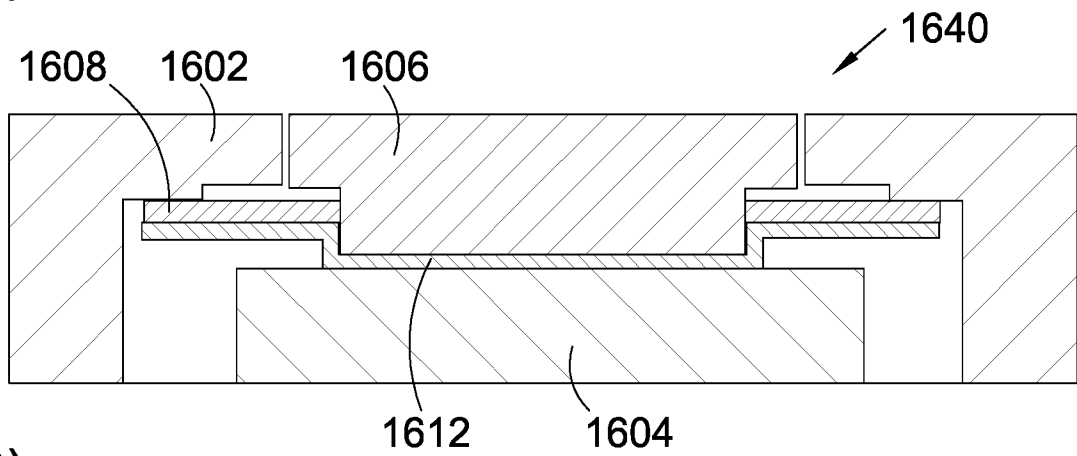
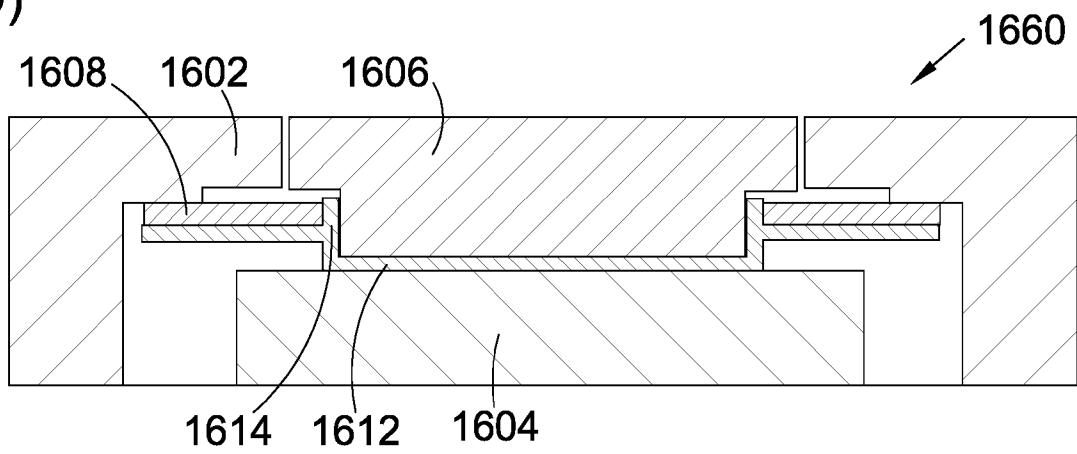


FIGURE 16

(C)



(D)



(E)

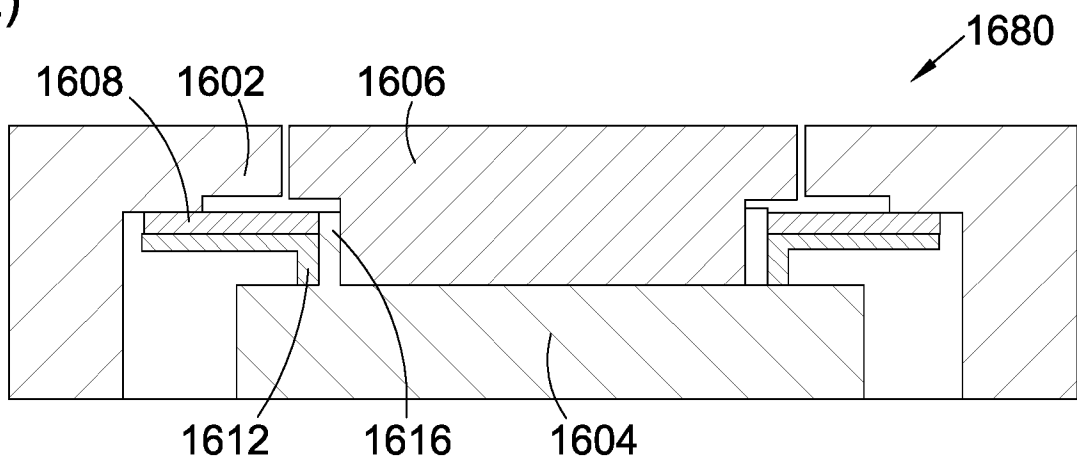


FIGURE 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2018/052923

A. CLASSIFICATION OF SUBJECT MATTER

INV. G06F3/01 G06F3/02 G06F3/041
ADD.

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)

G06F

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

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

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/093741 A1 (BAYER MATERIALSCIENCE AG [DE]) 19 June 2014 (2014-06-19) paragraphs [0007] - [0014], [0032] - [0035], [0055] - [0059]; figures 3A, 3B -----	1-36
A	WO 2013/175197 A1 (CAMBRIDGE MECHATRONICS LTD [GB]) 28 November 2013 (2013-11-28) page 5, line 26 - page 6, line 4; figure 3 -----	1-36
A	US 2014/009434 A1 (HIROYUKI KOJIMA [JP]) 9 January 2014 (2014-01-09) paragraphs [0007], [0029], [0030]; figures 3A, 3B, 7 -----	1-36
A	US 2016/058375 A1 (ROTHKOPF FLETCHER R [US]) 3 March 2016 (2016-03-03) paragraph [0142]; figure 7 -----	1-36



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

7 December 2018

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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