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Mikroelektromekaaninen laite liikkeenrajoittimilla

Mikroelektromekanisk anordining med rörelsebegränsare

Microelectromechanical device with motion limiters

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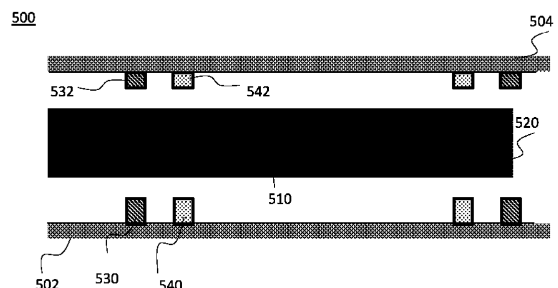
A microelectromechanical device that comprises a first structural layer (502), a second structural layer (504), and a movable mass (520) suspended to a primary rotary motion between the first structural layer (502) and the second structural layer (504). A cantilever motion limiter structure (400) is etched into the movable mass, and a first stopper element (530) is arranged on the first structural layer (502), opposite to the cantilever motion limiter structure (400). Improved mechanical robustness is achieved with optimal use of element space.

Mikroelektromekaaninen laite, joka käsittää ensimmäisen rakennekerroksen (502), toisen rakennekerroksen (504), ja liikkuvan massan (520), joka on ripustettu primäärikiertoliikkeeseen ensimmäiseen rakennekerroksen (502) ja toisen rakennekerroksen (504) välissä. Ulokemainen liikkeenrajoitinrakenne (400) on etsattu liikkuvaan massaan, ja ensimmäinen pysäytinelementti (530) on järjestetty ensimmäisen rakennekerroksen (502) päälle, ulokemaista liikkeenrajoitinrakennetta (400) vastapäätä. Saavutetaan parannettu mekaaninen kestävyys optimaalisella elementtitilan käytöllä.



Microelectromechanical device with motion limiters

Field of the invention

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The present invention relates to microelectromechanical devices and especially to a microelectromechanical device, as defined in the preamble of the independent claim.

Background of the invention

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Micro-Electro-Mechanical Systems, or MEMS can be defined as miniaturized mechanical and electro-mechanical systems where at least some elements have a mechanical functionality. MEMS devices can be applied to quickly and accurately detect very small changes in physical
15 properties.

Motion limiters are commonly used in MEMS devices to control the maximum distance that a movable structure inside a device can displace. Another purpose for motion limiters is to dissipate energy in a
20 controlled way in case a movable structure collides with an anchored structure inside a device due to a sudden high acceleration event. Such an event may occur, for example, when a device is accidentally dropped to the floor on a manufacturing line. Design limits are also at risk during element testing.

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In collision, the primary purpose of a motion limiter is to protect the device from breakages by preventing fragile points of structures, e.g., sharp corners or narrow beams touching other surfaces. However, the motion limiter itself may also break if it is not robust enough. The
30 robustness of a motion limiter can be enhanced, for example, by

20145184 PRH 24-01-2017

increasing the contact area between the contacting surfaces. However, this increases the risk of stiction between the contacting surfaces. Another conventional approach is to add flexibility to the impact such that the kinetic energy of the moving mass is transformed into potential
5 energy within the motion limiter structure.

Efficient motion limiting is especially complicated in structures where a movable mass is designed to undergo out-of-plane linear or rotary motion above or between further structural layers. It is difficult to
10 create truly robust structure without significantly increasing the size or complexity of the configuration.

Brief description of the invention

15 The object of the present invention is to provide a compact robust motion limiter configuration for microelectromechanical devices that include a movable mass designed to move out-of-plane of its structural layer. The objects of the present invention are achieved with a microelectromechanical device according to the characterizing portions
20 of the independent claims.

The claims define a microelectromechanical device that comprises a first structural layer, and a movable mass suspended to a primary out-of plane motion relative the first structural layer. A cantilever motion
25 limiter structure is etched into the movable mass, and a first stopper element is arranged on the first structural layer, opposite to the cantilever motion limiter structure.

Advantageous embodiments of the invention are disclosed in the
30 dependent claims. The solution provides improved mechanical robustness with optimal use of element space.

20145184 PRH 24-01-2017

Further advantages of the invention are discussed in more detail with the following embodiments.

Brief description of the figures

5

In the following the invention will be described in greater detail, in connection with preferred embodiments, with reference to the attached drawings, in which

Figure 1 shows a microelectromechanical structure applying out-of-plane
10 motion;

Figures 1A and 1B illustrate an exemplary structure of a microelectromechanical device;

Figure 2 illustrates an exemplary motion limiter structure applicable in a microelectromechanical device;

15 Figure 3 illustrates another exemplary motion limiter structure;

Figure 4 illustrates a further exemplary motion limiter structure;

Figures 5A illustrates a side view of an exemplary microelectromechanical device that includes motion limiters;

Figures 5B illustrates a top view of an exemplary
20 microelectromechanical device that includes motion limiters;

Figure 6 illustrates an example of positioning of a motion limiter structure and first stopper elements;

Figure 7 illustrates an example of positioning of second stopper elements;

25 Figure 8 illustrates an exemplary two-stage motion limiting configuration.

20145184 PRH 24-01-2017

Detailed description of some embodiments

30 The following embodiments are exemplary. Although the specification may refer to “an”, “one”, or “some” embodiment(s), this does not

necessarily mean that each such reference is to the same embodiment(s), or that the feature only applies to a single embodiment. Single features of different embodiments may be combined to provide further embodiments.

5

In the following, features of the invention will be described with a simple example of a device architecture in which various embodiments of the invention may be implemented. Only elements relevant for illustrating the embodiments are described in detail. Various implementations of
10 microelectromechanical devices that are generally known to a person skilled in the art may not be specifically described herein.

Figures 1A and 1B illustrate an exemplary structure of a microelectromechanical device according to the present invention. The
15 microelectromechanical device refers here to a layered structure formed of planar, solid or patterned layers. Terms in-plane and out-of plane thus refer here to directions that are aligned with a plane of a structural layer or non-aligned with a plane of a structural layer, respectively.

20 A microelectromechanical device 100 includes at least one structural layer and a movable mass suspended from it. Figure 1B shows a configuration that includes a first structural layer 102, a second structural layer 104, and a third structural layer 106. The first structural layer 102 may be, for example, a substrate or a handle wafer. The
25 second structural layer 104 may be, for example, a covering cap wafer of a microelectromechanical device die. It is noted that structural divisions (e.g. a handle wafer, a cap wafer etc.) used here are conceptual only. For a person skilled in the art it is clear that the structural layers may be patterned separately or in combination from,
30 for example, a layered silicon-on-insulator substrate.

20145184 PRH 24-01-2017

The third structural layer 106 may be applied as a movable mass 120. The movable mass 120 may be suspended on the first structural layer 102 such that the movable mass 120 can undergo out-of-plane motion in relation of at least the first structural layer 102. In the configuration of Figures 1A and 1B the out-of-plane motion is rotary motion about an in-plane rotation axis 110 between the first structural layer 102 and the second structural layer 104. The invention is not, however, limited to rotary motion only. Features of the invention may be applied also to out-of-plane linear motion in respect of an underlying or covering layer.

Figures 1A and 1B illustrate the element in neutral position when no biasing charges or external accelerating forces are applied to it. At operation the movable mass 120 may, for example in response to external z-direction acceleration, move in a see-saw or teeter-totter type of rotary motion about the in-plane rotary axis 110. The movable mass 120 may extend planarly to opposite directions from the rotary axis. During said rotary motion, the movable mass 120 may turn about the rotary axis such that one end of the movable mass moves away from the suspending structural layer and the other end of the movable mass moves towards the suspending structural layer. Movement of the movable mass may be induced and/or detected with electrodes 108 arranged to the underlying or covering layers. Figures 1A and 1B illustrate the embodiment with an exemplary configuration of one movable mass. The invention is, however, correspondingly applicable to configurations with one or more movable masses and to configurations where the movement includes oscillatory rotary motion, or linear out-of-plane motion.

Advantageously at least one of the motion limiters of a microelectromechanical device is a flexible motion limiter that facilitates some form of an elastic displacement in response to mechanical force

20145184 PRH 24-01-2017

exerted to it at contact. Figure 2 illustrates an exemplary motion limiter structure 200 applicable in a microelectromechanical device of Figures 1A and 1B. The microelectromechanical device of Figure 2 includes at least one motion limiter structure etched into the movable
5 mass 120 by locally removing volume material of the movable mass. Element parts of the motion limiter structure are thus at least partly separated from the movable mass but in neutral position share the same spatial volume with it. By appropriate choice of the etched lines, it is possible to provide within the movable mass a cantilever motion
10 limiter structure that maintains a mechanical connection to the movable mass, as shown in Figure 2.

The cantilever motion limiter structure of Figure 2 includes a simple elongate element 202. Elongate in this context means that the on-
15 plane length of an element is at least twice the maximum on-plane width of the element. One end of the elongate element is fixed and the other end is free. The fixed end may be anchored to a support or coupled to the support via an intermediate structure, as will be discussed later on, Openings 206 that are etched into the movable
20 mass extend in the plane of the movable mass, but not planarly cross through the movable mass, and form inner side walls to the movable mass. The elongate element 202 of Figure 2 extends between two inner side walls of the movable mass, and one end 204 of the elongate element 202 is mechanically coupled to the movable mass 120. In the
25 microelectromechanical device, the elongate element moves with the movable mass, and the lateral end of the elongate element is positioned to become into contact with another element when the motion of the movable mass needs to be controlled. The lateral end of the elongate beam may thus be considered to form an impact element
30 208. When contact to the impact element takes place, the elongate element carries the force to the support in the movable mass, where it

20145184 PRH 24-01-2017

is forced against by a moment and shear stress. At impact, the impact element is adapted to undergo a resilient rotary motion about an in-plane rotary axis that coincides with the point where the elongate element couples to the movable mass.

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Figure 3 illustrates an alternative motion limiter structure 300. The motion limiter structure of Figure 3 includes again an elongate element 302 that extends between two inner side walls of the movable mass. One end 304 of the elongate element 302 is mechanically coupled to
10 the movable mass. The lateral end of the elongate element 302 includes an impact element 308. It is understood that while the thickness of the movable mass layer is constant, the spring constant or stiffness of the elongate element is by far dependent on the on-plane length width of the elongate element. Figure 3 illustrates that the
15 spring rate and thus the flexibility of the elongate element may be adjusted by adjusting the on-plane dimensions of the elongate element. In addition, during lifetime of a microelectromechanical device, dimensions or mutual positioning between structural layers may change because of, for example, temperature variations. As shown in
20 Figure 3, in order to allow tolerance to the positioning, the largest width of the impact element may be adjusted to be larger (for example, three or more times) the width of the remaining part of the elongate element.

25 Figure 4 illustrates a further alternative motion limiter structure 400. The motion limiter structure of Figure 4 includes again an elongate element 402 that extends between two inner side walls of the movable mass. One end of the elongate element 402 is mechanically coupled to the movable mass. The elongate element 402 includes an impact
30 element 408, a torsion element 410 and a coupling beam 412. The impact element 408 represents here again a section of the motion

20145184 PRH 24-01-2017

limiter structure that is adapted to provide a point of contact at a time the motion of the movable mass needs to be limited. In the configuration of Figure 4, the impact element 408 is a formed section with different in-plane width than the coupling beam 412. The impact
5 element is a section of the motion limiter structure 400 that is to be positioned opposite to a designed point of contact in the first structural layer. Figure 4 illustrates a rectangular impact element, but the impact element may have any shape. The impact element 408 may locate in any point of the movable mass, but advantageously one of the side
10 surfaces of the motion limiter structure coincides with the side surface of the movable mass.

At impact, the impact element 408 is adapted to undergo a resilient rotary motion about an in-plane rotary axis. The motion is delivered by
15 the coupling beam 412 to an in-plane torsion element 410 that twists according to it. When twisted, the torsion element 410 stores the mechanical energy of the motion and exerts an increasing force in the opposite direction; proportional to the amount it is twisted. The torsion element 410 couples to the movable mass, and thus provides an in-
20 plane torsional spring for the rotary motion of the impact element.

An axis 414 passing through two coupling points 416, 418 in the movable mass defines a first direction, a direction of the in-plane rotary axis of the impact element. In a simple and therefore advantageous
25 embodiment, the torsion element may be implemented as a torsion bar, a linear elongate element that extends in the first direction between the two coupling points 416, 418 in the movable mass, as shown in Figure 4. Other corresponding spring forms, like a meander type spring, may be applied in the torsion element. The torsion element
30 is subject to twisting about the in-plane rotary axis by torque applied at its ends and the point of connection to the coupling beam between its

20145184 PRH 24-01-2017

ends. Advantageously the first direction is aligned to a side or end surface of the movable mass. In case of the movable mass is adapted for rotary motion, the first direction is advantageously aligned to be parallel or perpendicular to the axis of rotation of the movable mass.

5

The coupling beam 412 refers here to an element that acts as a lever arm for a mechanical force that results from out-of-plane impact of the impact element. The coupling beam may 412 be a linear bar, but other structural forms axially coupling the impact element 408 and the
10 torsion element 410 may be applied within the scope. The point of contact 404 to the torsion element 410 is advantageously between the coupling points 416, 418, more specifically in the middle of the torsion element 410.

15 The disclosed configuration provides a balanced and efficient torsional force to limit the out-of-plane motion. With the torsion spring, flexibility in the out-of-plane direction can be optimized by spring stiffness of the torsion element 410 and lever arm length of the coupling beam 412. On the other hand, in the other directions, the structure is very rigid
20 and therefore stable. Furthermore, it has been detected that in MEMS device dimensions, a torsion spring allows a compact spring design even with very reasonable springs widths.

The microelectromechanical device includes also at least one first
25 stopper element on the first structural layer, opposite to the impact element of the motion limiter structure. Figure 5A shows a side view and Figure 5B a top view of an exemplary microelectromechanical device that includes any of the motion limiter structures of Figure 2 to 4. As in Figure 1B, Figure 5A shows a microelectromechanical device
30 that includes a first structural layer 502, a second structural layer 504 and a movable mass 520 adapted for primary rotation about an in-

20145184 PRH 24-01-2017

plane rotary axis 510. In the example, the first structural layer 502 is a substrate, the second structural layer 504 is a cap wafer, and the movable mass 520 is an element in a structure wafer between them.

5 Basically the first stopper element could be provided by a region of the first structural layer 502 underneath the motion limiter structure or a region of the second structural layer over the motion limiter structure. However, advantageously, the first stopper element includes at least one protrusion 530 that is locally raised from its structural layer and 10 thus extends farther towards the movable mass 520 than the surface of the structural layer. At minimum the first stopper element may include one protrusion on one structural surface, but in this example, the movable mass moves between two structural layers, and the first stopper element includes two protrusions, one protrusion 530 on the 15 first structural layer 502 and another protrusion 532 on the second structural layer 504. Figure 5B illustrates positions of protrusions 532, 542 on the second structural layer.

Opposite positioning of the impact element of the motion limiter 20 structure and the first stopper element may be interpreted that projection of the impact element and projection of the first stopper element on the first structural layer at least partly coincide. Figure 6 illustrates an example of positioning of the motion limiter structure 400 of Figure 4 and the first stopper elements 530, 532 on the structural 25 layers of Figures 5A and 5B. Figure 6 shows a projection of a motion limiter structure 600, a bottom part 530 of a first stopper element, and a top part 532 of a first stopper element in a top view. As may be seen, the parts 530, 532 of the first stopper element may coincide with each other, and they do coincide with the impact element of the motion 30 limiter structure 400. Advantageously, the elements are axially symmetric and the symmetry axes of the elements are aligned with the

20145184 PRH 24-01-2017

coupling beam of the motion limiter structure 400. Advantageously at least one part of the first stopper element extends beyond the projection of the movable mass on the first structural layer. This makes the arrangement less sensitive to small alignment errors.

5

Because of the resiliency provided by the torsion element, an element pair that includes a motion limiter structure and at last one stopper element may be considered as a flexible limiter. A microelectromechanical device may include one or more of such flexible
10 limiters in different parts of its structure. The flexibility of the flexible limiter may be easily tuned with stiffness of the elongate element. For example, in the motion limiter structure of Figure 4, the tuning may be done with the torsion spring of the torsion element and the level arm length provided by the coupling beam. The tuning may be adapted to
15 provide a flexural strength to overcome possible adherence between the motion limiter structure and the first stopper element at contact.

Returning back to Figures 5A and 5B, the microelectromechanical device may include also one or more stiff limiter. The role of the stiff
20 limiter is to provide a stronger motion limiting stage that becomes activated later than a motion limiting stage provided by the flexible limiters. In a simple configuration, the stiff limiter may require one second stopper element. The second stopper element may include at least one protrusion 540 that is locally raised from its structural layer
25 and thus extends farther towards the movable mass than the surface of the structural layer. At minimum, the second stopper element may include one protrusion on one structural surface, but in this example, also the second stopper element includes two protrusions, one protrusion 540 on the first structural layer 502 and another protrusion
30 542 on the second structural layer 504. In order to achieve a correct order of contact, a gap between a motion limiter structure and a first

20145184 PRH 24-01-2017

stopper element 530 of a flexible limiter is adapted to close before a gap between a second stopper element 540 and the movable mass 520 closes.

5 The second stopper element may extend within the projection of the movable mass, or at least part of the second stopper element may extend beyond the projection of the movable mass. Figure 7 illustrates an example of positioning of the second stopper element on the structural layers of Figure 5A. Figure 7 shows projection of a potential 10 impact section for the second stopper element in the movable mass 520, a bottom part 540 of a second stopper element, and a top part 542 of a second stopper element in a top view. As may be seen, the parts 540, 542 of the second stopper element coincide at least with a designed impact region of the movable mass. The stiffness of the 15 exemplary stiff element may vary according to the type of the element. The stiff limiter may be a flexible element with high flexural strength, or it may be a rigid element, as shown in Figure 7. The strength of motion limiting of the rigid element of Figure 7 is dependent on the contact area of the second stopper element, more specifically, on the 20 contact area of the part that makes the first contact with the movable mass.

A combination of one or more flexible limiters and one or more stiff limiters may be used to create a multi-stage motion limiter with 25 different strengths of motion limiting. For example, the multistage motion limiter may include first stage for which a flexible limiter is tuned to limit the motions of the movable mass in overload situations of normal operation or during testing, and a second stage for which a stiff (rigid) limiter is tuned to limit the motions of the movable mass 30 during mechanical shocks. Further stage combinations may be applied within the scope. The flexural strengths of the motion limiter structure

20145184 PRH 24-01-2017

of the flexible limiter may be adjusted to be high enough to provide a restoring force that pulls the movable mass off the second stopper element after contact.

5 Figure 8 illustrates an exemplary configuration for the two-stage motion limiter structures and stopper elements of Figures 5A and 5B. Figure 8 shows a top view of a structural layer including two movable masses 800, 802. The movable masses may be suspended for anti-phase primary rotary motion about an axis 804. As shown in figure 8, 10 both ends of the movable masses 800, 802 may include a flexible limiter 810, 812, 814, 816.

The configuration may include also one or more stiff limiters 820, 822, 824, 826. In the exemplary configuration of Figure 8, in order to 15 ensure correct order of contact, the distance from the stiff limiters to the rotary axis have been adjusted to be less than the distance from the flexible limiters to the rotation axis. It is, however, noted that the order of contact between the limiters is dependent on the type of the primary motion and the dimensions of the gaps between the contact 20 points.

It is apparent to a person skilled in the art that as technology advances, the basic idea of the invention can be implemented in various ways. The invention and its embodiments are therefore not 25 restricted to the above examples, but they may vary within the scope of the claims.

20145184 PRH 24-01-2017

Claims

1. A microelectromechanical device, comprising:
 a first structural layer (502);
5 a second structural layer (504), **characterized** by
 a movable mass (520) suspended to a primary rotary motion between the first structural layer (502) and the second structural layer (504);
 a cantilever motion limiter structure (400) etched into the movable
10 mass,
 a first stopper element (530) on the first structural layer (502), opposite to the cantilever motion limiter structure (400).

2. A microelectromechanical device of claim 1, **characterized** in that
15 the cantilever motion limiter structure (200; 300) includes an elongate element (202; 302), one end of the elongate element coupled to the movable mass.

3. A microelectromechanical device of claim 2, **characterized** in that
20 the elongate element (202; 302) extends between two inner side walls of the movable mass.

4. A microelectromechanical device of claim 3, **characterized** in that lateral end of the elongate element (202; 302) forms an impact
25 element (208; 308).

5. A microelectromechanical device of claim 2, **characterized** in that the elongate element (402) is coupled to the movable mass with a torsion element (410) providing an in-plane torsion spring, each end of
30 the torsion spring coupled to the movable mass.

20145184 PRH 24-01-2017

6. A microelectromechanical device of claim 5, **characterized** in that the elongate element (402) includes

an impact element (408),

a coupling beam (412) coupling the torsion element to the
5 impact element.

7. A microelectromechanical device of claim 6, **characterized** in that, at impact, the impact element (408) is adapted to undergo a resilient rotary motion about an in-plane rotary axis (414).
10

8. A microelectromechanical device of claim 6 or 7, **characterized** in that the torsion element (410) is a torsion bar coupled to two coupling points (416, 418) in the movable mass.

15 9. A microelectromechanical device of any of the preceding claims, **characterized** in that the first stopper element (530) is a protrusion locally raised from the first structural layer (502).

10. A microelectromechanical device of any of the preceding claims,
20 **characterized** in that projection of an impact element (408) and projection of the first stopper element (530) on the first structural layer (502) at least partly coincide.

11. A microelectromechanical device of claim 6, **characterized** in that
25 the largest width of the impact element (408) is at least three times the width of the coupling beam (412).

12. A microelectromechanical device of claim 4 or claim 6 to 11, **characterized** in that one side surface of the impact element (408)
30 coincides with a side surface of the movable mass.

20145184 PRH 24-01-2017

13. A microelectromechanical device of claim 9, **characterized** in that the first stopper element (530) extends beyond the projection of the movable mass on the first structural layer (502).

5 14. A microelectromechanical device of any of claims 1 to 13, **characterized** in that an element pair including a cantilever motion limiter structure (400) and a first stopper element (530) form a flexible limiter.

10 15. A microelectromechanical device of claim 14, **characterized** by a stiff limiter (540) adapted to provide a motion limiter stage that becomes activated later than a motion limiter stage provided by the flexible limiter (400, 530).

15 16. A microelectromechanical device of claim 15, **characterized** by the stiff limiter (540) including a second stopper element protruding from the first structural layer (502), positioned such that a gap between a motion limiter structure and a first stopper element (530) of a flexible limiter closes before a gap between a second stopper element (540)
20 and the movable mass closes.

17. A microelectromechanical device of claim 15 or 16, **characterized** in that the distance from the stiff limiter (540) to the rotation axis (510) is less than the distance from the flexible limiter (530) to the
25 rotation axis (510).

18. A microelectromechanical device of claim 16 or 17, **characterized** in that at least part of the second stopper element (540) extends beyond the projection of the movable mass on the first structural layer
30 (502).

20145184 PRH 24-01-2017

19. A microelectromechanical device of any of the preceding claims, **characterized** in that the second structural layer (504) includes at least one first stopper element (532).

5 20. A microelectromechanical device of claim 19, **characterized** in that the second structural layer (502) includes at least one second stopper element (542).

21. A microelectromechanical device of claim 20, **characterized** in
10 that the second structural layer (504) includes a corresponding set of first and second stopper elements than the first structural layer (502).

22. A microelectromechanical device of any of the preceding claims, **characterized** in that the first structural layer (502) is a substrate and
15 the second structural layer (504) is a cap wafer of a MEMS die.

23. A microelectromechanical device of claim 22, **characterized** in that a gap between an impact element of a motion limiter structure and a first stopper element (530) of the first structural layer is greater than
20 a gap between an impact element of a motion limiter structure and the first stopper element (532) of the second structural layer.

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20145184 PRH 24 -01- 2017

Patenttivaatimukset

1. Mikroelektromekaaninen laite, joka käsittää:
ensimmäisen rakennekerroksen (502);
5 toisen rakennekerroksen (504), **tunnettu**
liikkuvasta massasta (520), joka on ripustettu ensisijaiseen kiertoliikkeeseen ensimmäisen rakennekerroksen (502) ja toisen rakennekerroksen (504) välissä;
ulokemaisen liikkeenrajoitinrakenteen (400), joka on etsattu
10 liikkuvan massan sisään,
ensimmäisen pysäytinelementin (530) ensimmäisen rakennekerroksen päällä (502), ulokemaista liikkeenrajoitinrakennetta vastapäätä.

15 2. Patenttivaatimuksen 1 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että ulokemainen liikkeenrajoitinrakenne (200; 300) sisältää pitkänomaisen elementin (202; 302), jonka pitkänomaisen elementin yksi pää on kytketty liikkuvaan massaan.

20 3. Patenttivaatimuksen 2 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että pitkänomainen elementti (202; 302) ulottuu liikkuvan massan kahden sivuseinän välissä.

4. Patenttivaatimuksen 3 mukainen mikroelektromekaaninen laite,
25 **tunnettu** siitä, että pitkänomaisen elementin (202; 302) lateraalinen pää muodostaa iskuelementin (208; 308).

5. Patenttivaatimuksen 2 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että pitkänomainen elementti (402) on kytketty
30 liikkuvaan massaan torsioelementillä (410), joka muodostaa

20145184 PRH 14-04-2015

tasomaisen torsiojousen, torsiojousen kummankin pään ollessa kytketty liikkuvaan massaan.

6. Patenttivaatimuksen 5 mukainen mikroelektromekaaninen laite, 5 **tunnettu** siitä, että pitkänomainen elementti (402) sisältää
iskuelementin (408),
kytkentäpalkin (412), joka kytkee torsioelementin iskuelementtiin.

10 7. Patenttivaatimuksen 6 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että iskuelementti (408) on iskun aikana sovitettu suorittamaan joustava kiertoliike tasokiertoakselin (414) ympäri.

8. Patenttivaatimuksen 6 tai 7 mukainen mikroelektromekaaninen laite, 15 **tunnettu** siitä, että torsioelementti (410) on torsiopalkki, joka on kytketty liikkuvassa massassa olevaan kahteen kytkentäpisteeseen (416, 418).

9. Jonkin edellä olevan patenttivaatimuksen mukainen 20 mikroelektromekaaninen laite, **tunnettu** siitä, että ensimmäinen pysäytinelementti (530) on ulkonema, joka kohoaa paikallisesti ensimmäisestä rakennekerroksesta (502).

10. Jonkin edellä olevan patenttivaatimuksen mukainen 25 mikroelektromekaaninen laite, **tunnettu** siitä, että iskuelementin (408) projektio ja ensimmäisen rakennekerroksen päällä olevan ensimmäisen pysäytinelementin projektio ovat ainakin osittain kohdakkain.

11. Patenttivaatimuksen 6 mukainen mikroelektromekaaninen laite, 30 **tunnettu** siitä, että iskuelementin (408) suurin leveys on vähintään kolme kertaa kytkentäpalkin (412) leveys.

20145184 PRH 14 -04- 2015

12. Jonkin patenttivaatimuksista 4 tai 6-11 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että iskuelementin (408) yksi sivupinta on yhtenevä liikkuvan massan sivupinnan kanssa.

5

13. Patenttivaatimuksen 9 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että ensimmäinen pysäytinelementti (530) ulottuu ensimmäisen rakennekerroksen (502) päällä olevan liikkuvan massan projektiota edemmäs.

10

14. Jonkin patenttivaatimuksista 1–13 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että ulokemaisen liikkeenrajoitinrakenteen (400) ja ensimmäisen pysäytinelementin (530) sisältävä elementtipari muodostavat joustavan rajoittimen.

15

15. Patenttivaatimuksen 14 mukainen mikroelektromekaaninen laite, **tunnettu** jäykästä rajoittimesta (540), joka on sovitettu aikaansaamaan liikkeenrajoitinvaihe, joka aktivoituu myöhemmin kuin joustavan rajoittimen (400, 530) aikaansaama liikkeenrajoitinvaihe.

20

16. Patenttivaatimuksen 15 mukainen mikroelektromekaaninen laite, **tunnettu** jäykästä rajoittimesta (540), joka sisältää toisen pysäytinelementin, joka ulkonee ensimmäisestä rakennekerroksesta (502), ja joka on sijoitettu siten, että joustavan rajoittimen
25 ensimmäisen liikkeenrajoitinrakenteen ja pysäytinelementin (530) välinen rako sulkeutuu ennen toisen pysäytinelementin (540) ja liikkuvan massan välisen raon sulkeutumista.

17. Patenttivaatimuksen 15 tai 16 mukainen mikroelektromekaaninen
30 laite, **tunnettu** siitä, että etäisyys jäykästä rajoittimesta (540)

20145184 PRH 14 -04- 2015

kiertoakseliin (510) on pienempi kuin etäisyys joustavasta rajoittimesta (530) kiertoakseliin.

18. Patenttivaatimuksen 16 tai 17 mukainen mikroelektromekaaninen
5 laite, **tunnettu** siitä, että ainakin osa toisesta pysäytinelementistä (540) ulottuu liikkuvan massan ensimmäisen rakennekerroksen päällä olevaa projektiota edemmäs.

19. Jonkin edellä olevan patenttivaatimuksen mukainen
10 mikroelektromekaaninen laite, **tunnettu** siitä, että toinen rakennekerros (504) sisältää vähintään yhden ensimmäisen pysäytinelementin (532).

20. Patenttivaatimuksen 19 mukainen mikroelektromekaaninen laite,
15 **tunnettu** siitä, että toinen rakennekerros (504) sisältää vähintään yhden toisen pysäytinelementin (542).

21. Patenttivaatimuksen 20 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että toinen rakennekerros (504) sisältää ensimmäistä
20 rakennekerrosta (502) vastaavan sarjan ensimmäisiä ja toisia pysäytinelementtejä.

22. Jonkin edeltävän patenttivaatimuksen mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että ensimmäinen
25 rakennekerros (502) on substraatti ja toinen rakennekerros (504) on MEMS-sirun kansilevy.

23. Patenttivaatimuksen 22 mukainen mikroelektromekaaninen laite, **tunnettu** siitä, että liikkeenrajoitinrakenteen iskuelementin ja
30 ensimmäisen rakennekerroksen ensimmäisen pysäytinelementin (530) välinen rako on suurempi kuin liikkeenrajoitinrakenteen iskuelementin

20145184 PRH 14-04-2015

ja toisen rakennekerroksen ensimmäisen pysäytinelementin (532) välinen rako.

20145184 PRH 14 -04- 2015

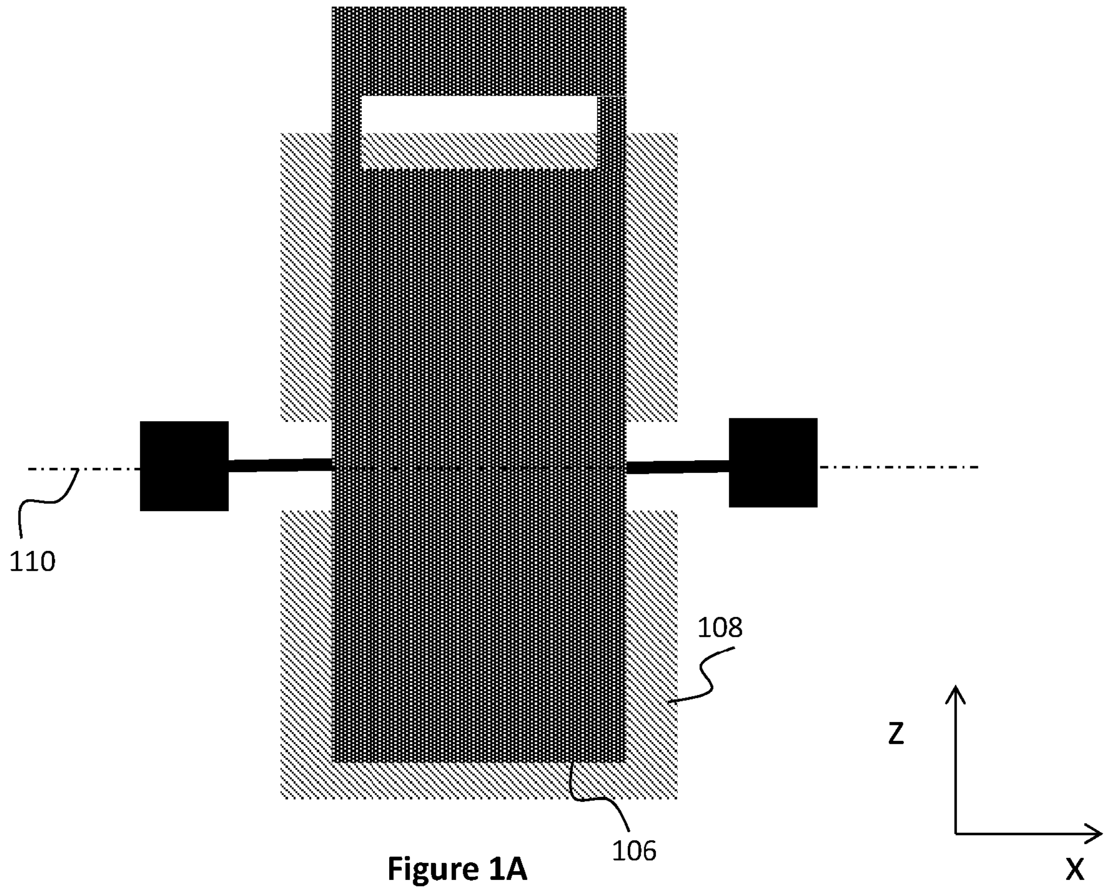

Figure 1A

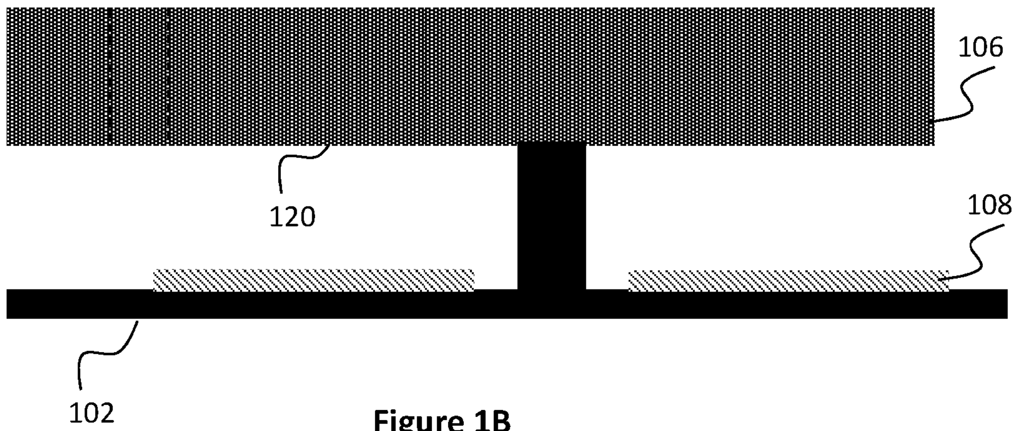

Figure 1B

20145184 PRH 14 -04- 2015

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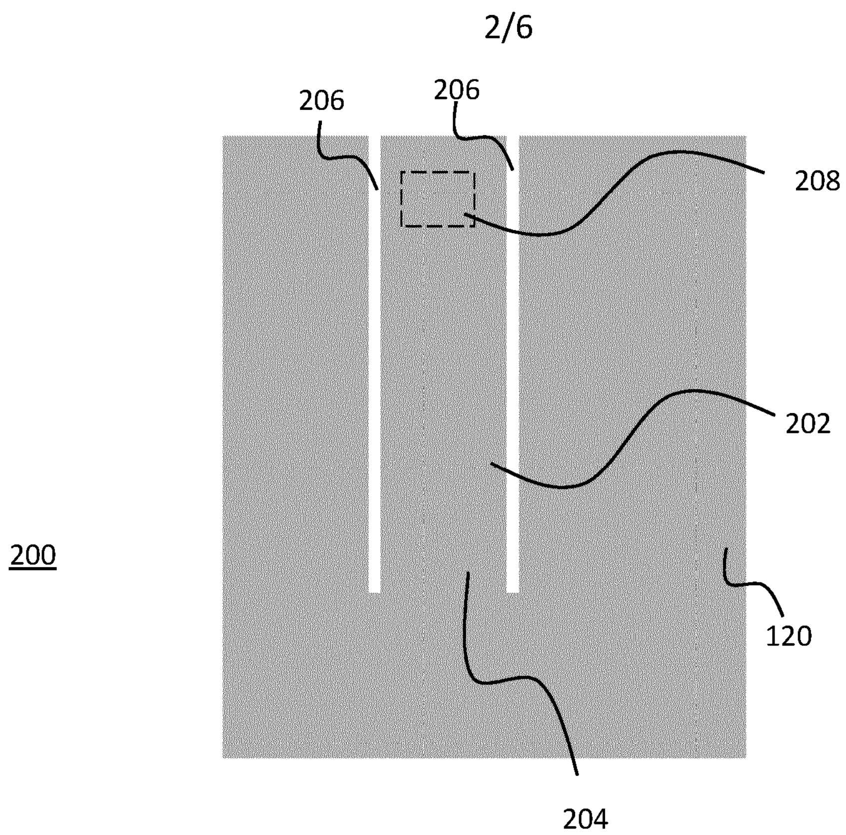

Figure 2

300

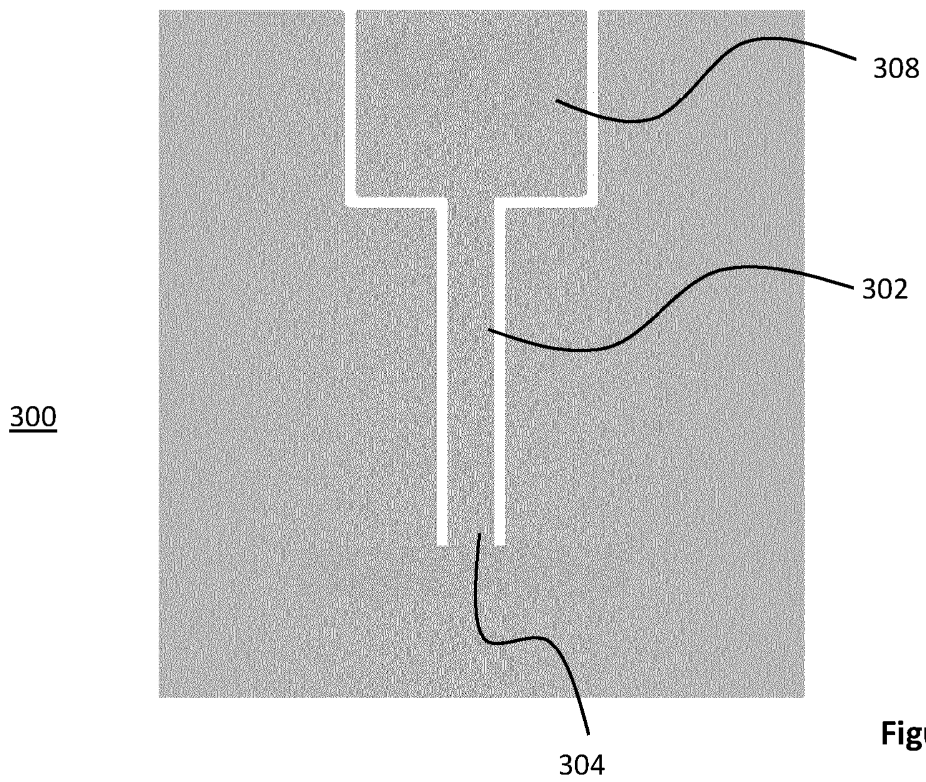

Figure 3

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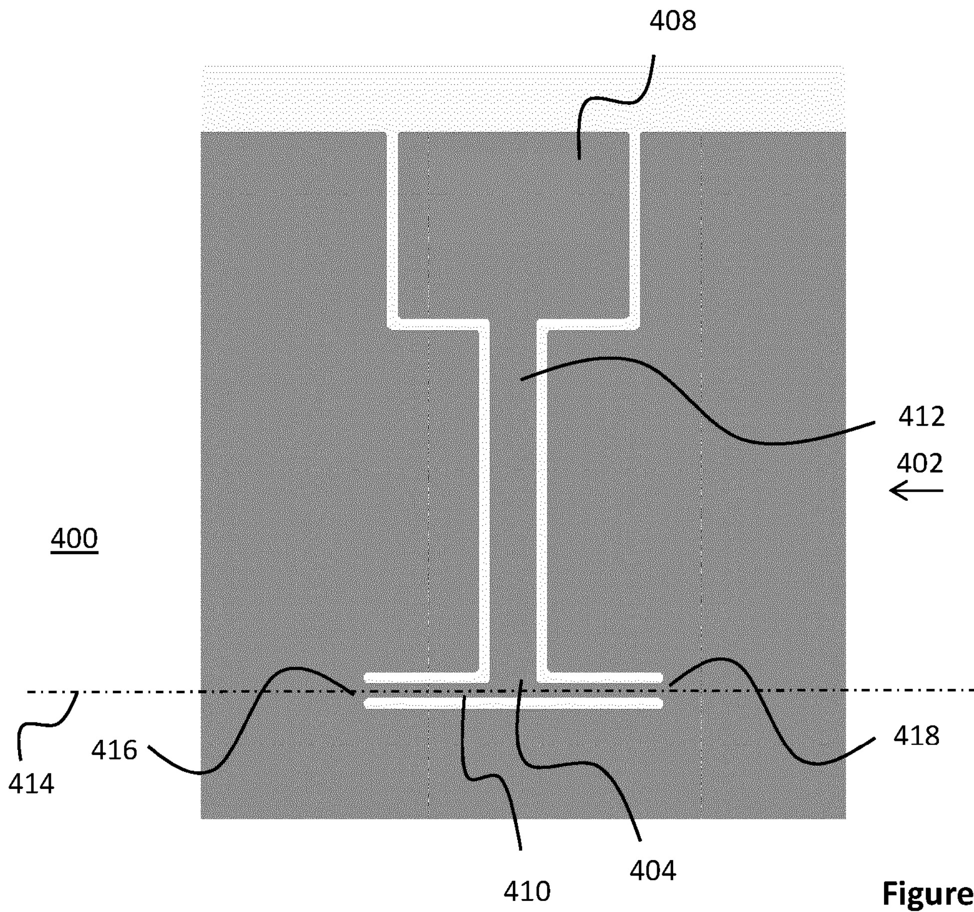

Figure 4

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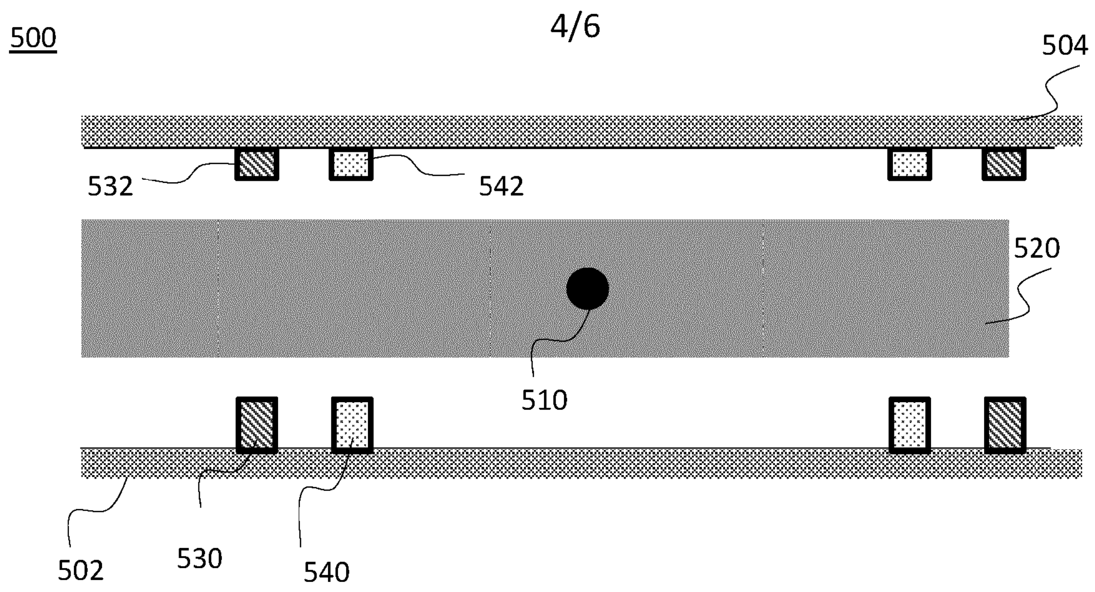

Figure 5A

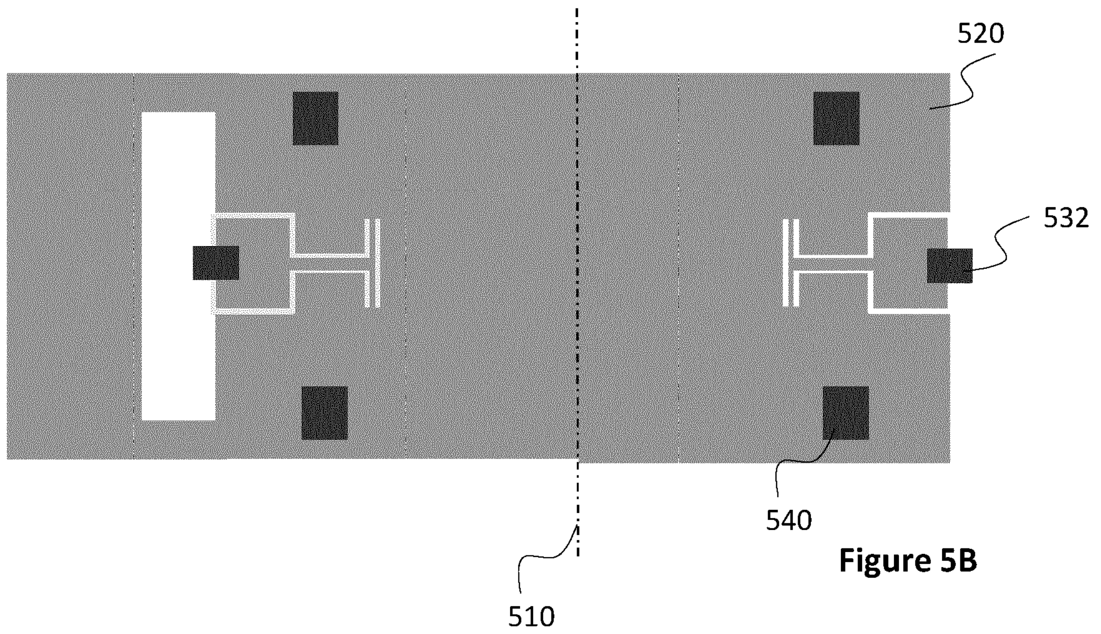

Figure 5B

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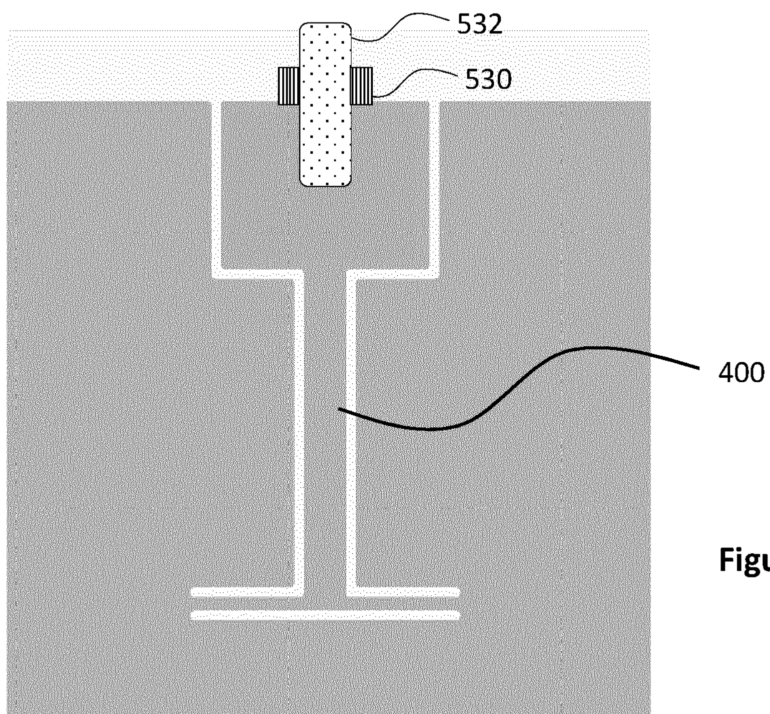

Figure 6

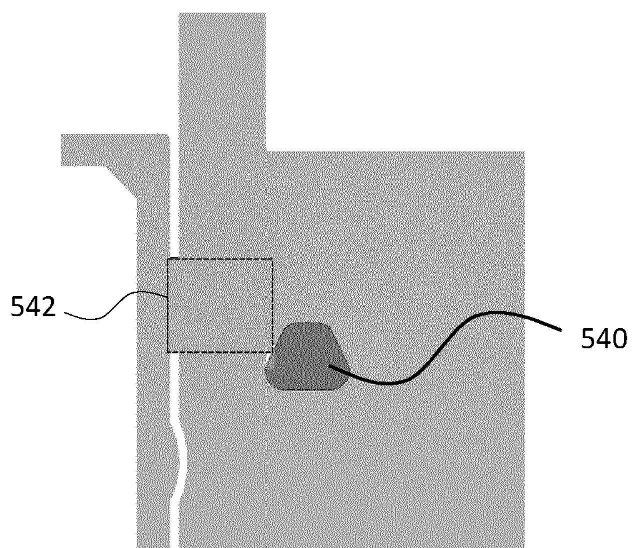

Figure 7

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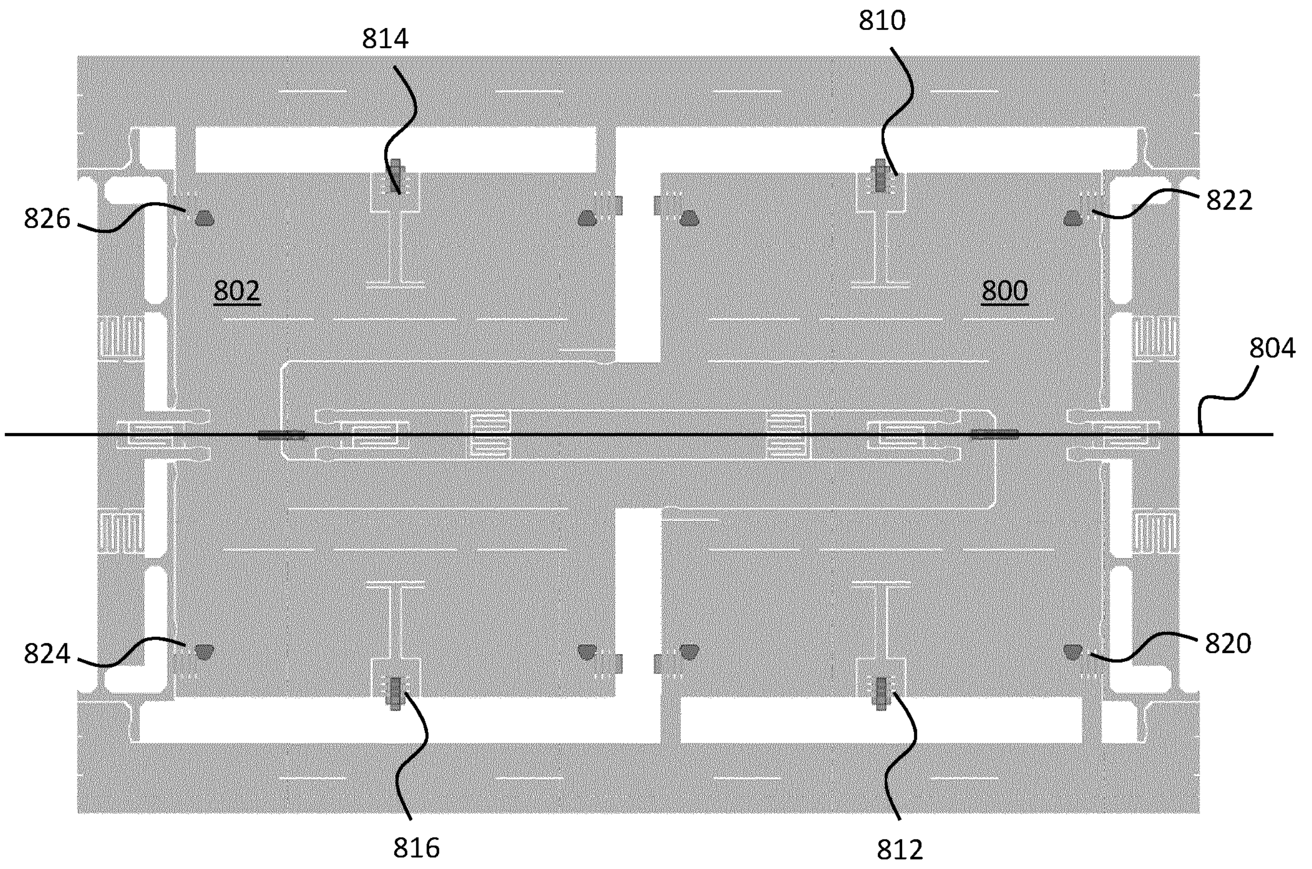

Figure 8

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