



- (51) International Patent Classification:
G01P 15/00 (2006.01)
- (21) International Application Number:
PCT/US2012/062749
- (22) International Filing Date:
31 October 2012 (31.10.2012)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
13/289,993 4 November 2011 (04.11.2011) US
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- (81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP,
KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD,
ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI,
NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU,
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TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA,
ZM, ZW.

- (84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
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EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: LOW-G-MEMS ACCELERATION SWITCH

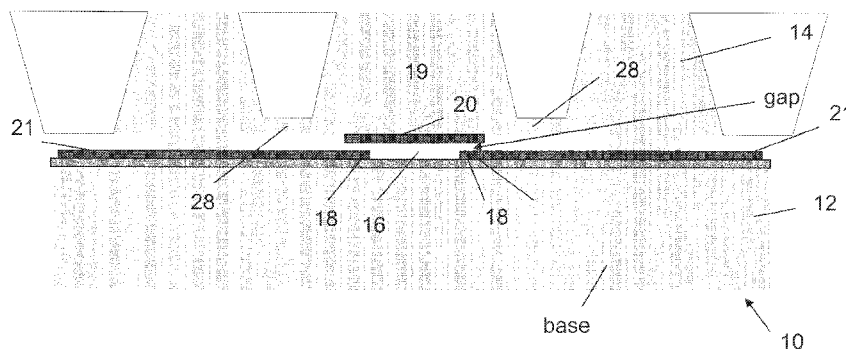


FIG. 1

(57) **Abstract:** A motion-sensitive low-G MEMS acceleration switch, which is a MEMS switch that closes at low-g acceleration (e.g., sensitive to no more than 10 Gs), is proposed. Specifically, the low-G MEMS acceleration switch has a base, a sensor wafer with one or more proofmasses, an open circuit that includes two fixed electrodes, and a contact plate. During acceleration, one or more of the proofmasses move towards the base and connects the two fixed electrodes together, resulting in a closing of the circuit that detects the acceleration. Sensitivity to low-G acceleration is achieved by proper dimensioning of the proofmasses and one or more springs used to support the proofmasses in the switch.



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LOW-G MEMS ACCELERATION SWITCH**CROSS REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims priority to United States Serial Patent Application No. 13/289,993, filed November 4, 2011, and entitled "Low-G MEMS Acceleration Switch," and is hereby incorporated herein by reference.

BACKGROUND

5 **[0002]** An inertial switch is a switch that can change its state, e.g., from open to closed, in response to acceleration and/or deceleration. For example, when the absolute value of acceleration along a particular direction exceeds a certain threshold value, the inertial switch changes its state, which change can then be used to trigger an electrical circuit controlled by the inertial switch. Inertial switches are employed in a wide variety of applications such as
10 automobile airbag deployment systems, vibration alarm systems, detonators for artillery projectiles, and motion-activated light-flashing footwear.

[0003] A conventional inertial switch is a relatively complex, mechanical device assembled using several separately manufactured components such as screws, pins, balls, springs, and other elements machined with relatively tight tolerance. As such, conventional inertial switches
15 are relatively large (e.g., several centimeters) in size and relatively expensive to manufacture and assemble. In addition, conventional inertial switches are often prone to mechanical failure.

[0004] One acceleration switch is manufactured using a layered wafer and has a movable electrode supported on a substrate layer of the wafer and a stationary electrode attached to that substrate layer. The movable electrode is adapted to move with respect to the substrate layer in
20 response to an inertial force such that, when the inertial force per unit mass reaches or exceeds a contact threshold value, the movable electrode is brought into contact with the stationary electrode, thereby changing the state of the inertial switch from open to closed. The MEMS device is a substantially planar device, designed such that, when the inertial force is parallel to the device plane, the displacement amplitude of the movable electrode from a zero-force
25 position is substantially the same for all force directions.

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[0005] There is a need for a low-G MEMS acceleration switch. There is a further need for a MEMS acceleration switch that is insensitive to transverse loads. There is a further need for a MEMS acceleration switch that does not have the current flow through the entire device and provides for lower resistance in the closed state.

- 5 **[0006]** The foregoing examples of the related art and limitations related therewith are intended to be illustrative and not exclusive. Other limitations of the related art will become apparent upon a reading of the specification and a study of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0007]** This patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided
10 by the Office upon request and payment of the necessary fee.

[0008] FIG. 1 illustrates an example of a MEMS acceleration switch of the present invention that has a base, sensor wafer and an open circuit.

[0009] FIG. 2 illustrates an example of an embodiment similar to that of FIG. 1 except it is a flip chip version.

- 15 **[0010]** FIG. 3 illustrates an example of an embodiment similar to the FIG. 1 embodiment except it is a triple stack that includes a lid and the proofmass has apertures for damping.

[0011] FIG. 4 illustrates an example of one embodiment of a process for making the MEMS acceleration switch depicted in FIG. 3.

- [0012]** FIG. 5 illustrates an example of an embodiment of a MEMS acceleration switch with
20 springs that support a central proofmass and additional proofmasses in a surrounding relationship to the central proofmass.

[0013] FIG. 6 illustrates an example of an embodiment of the spring system in the MEMS acceleration switch depicted in FIG. 5.

- [0014]** FIG. 7 illustrates an example of an embodiment of a MEMS acceleration switch with
25 double sided springs on opposite sides of the wafer in order to decrease sensitivity for transverse loads.

[0015] FIG. 8 illustrates an example of an embodiment of a low-G MEMS acceleration switch with double sided springs that are connected to corners instead of at the sides.

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DETAILED DESCRIPTION OF EMBODIMENTS

[0016] The device is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to “an” or “one” or “some” embodiment(s) in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

5 **[0017]** A motion-sensitive low-G MEMS acceleration switch, which is a MEMS switch that closes at low-g acceleration (e.g., sensitive to no more than 10 Gs), is proposed. Specifically, the low-G MEMS acceleration switch has a base, a sensor wafer with one or more proofmasses, an open circuit that includes two fixed electrodes, and a contact plate. During acceleration, one or more of the proofmasses move towards the base and connects the two fixed electrodes
10 together, resulting in a closing of the circuit that detects the acceleration. Sensitivity to low-G acceleration is achieved by proper dimensioning of the proofmasses and one or more springs used to support the proofmasses in the switch. In addition to high sensitivity in the direction of interest, the proposed switch is insensitive to transverse loads during acceleration and does not have the current flow through the entire device thereby providing for lower resistance in the
15 closed circuit state.

[0018] FIG. 1 illustrates an example of a MEMS acceleration switch that has a base, sensor wafer and an open circuit. In the example of FIG. 1, MEMS acceleration switch 10 includes a base 12 made of materials such as Si and the like, and a sensor wafer 14. Under acceleration, one or more proofmasses 19 of the sensor wafer 14 moves towards the base 12 which has an
20 open circuit, generally denoted as 16 (one or more springs 28 can be used to support the proofmasses 19 as shown in FIGs. 5-8). The open circuit 16 is positioned between the base 12 and the sensor wafer 14. The open circuit 16 includes two fixed electrodes 18 and a contact plate 20. During acceleration, the proofmass 19 with contact plate 20 moves towards the base 12 and connects the two electrodes 18, resulting in a closing of the circuit. Electrical contact to
25 the switch is achieved with wires, not shown, bonded to wire bondpads 21.

[0019] In various other embodiments, the low-G MEMS acceleration switch 10 for activation at a load less than 10G may be dimensioned for a lower G activation load that does not exceed 5 G, 3 G, 2 G and the like.

[0020] In some embodiments, the MEMS acceleration switch 10 is substantially insensitive
30 to transverse load, which is a load applied in a direction perpendicular to the intended axis of

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measurement (sensitive axis), with zero or minimum displacement along the sensitive axis when the transverse load is applied, e.g., a given transverse load results in less than 1% of displacement along the sensitive axis than if the same axial load is applied along the sensitive axis, i.e., the axis of measurement. As such, the MEMS acceleration switch 10 provides a
5 displacement along the sensitive axis that is substantially independent of the transverse load. As such, the MEMS acceleration switch 10 provides a displacement along the sensitive axis that is substantially independent of the transverse load. In addition, a transverse load as high as 10 times (or more) than the nominal range (e.g., anywhere between 1 and 10 Gs) does not result in closure of the switch.

10 **[0021]** FIG. 2 illustrates an example of an embodiment of the MEMS acceleration switch similar to that of FIG. 1 except it is a flip chip version where the base 12 is on the top and proofmass 19 is still within sensor wafer 14. In the example of FIG. 2, vias 22 for electrical contact to the switch are provided in place of wire bondpads. The benefit of the flip chip design depicted in FIG. 2 is that the switch can be flip chip mounted on a substrate or circuit
15 board rather than mounted on the substrate with an adhesive and connected to the substrate via bonded wires

[0022] FIG. 3 illustrates an example of an embodiment similar to the FIG. 2 embodiment except it is a triple stack that includes a lid 24. In the example of FIG. 3, the proofmass 19 has one or more apertures 26 for damping in the event that the MEMS acceleration switch 10 needs
20 to be a damped switch. Wire bondpads 21 are provided.

[0023] FIG. 4 illustrates an example of one embodiment of a process for making the MEMS acceleration switch depicted in FIG. 3. The device is made from a stack of three wafers - a lid, a core, and a base, which are bonded using any suitable bonding technique, such as solderglass bonding. The core wafer is fabricated from an SOI wafer. A photo mask defines the areas
25 from which the subsequent DRIE etch from the back of the wafer will remove bulk silicon. The etch stops on the buried oxide. A photo mask applied to the front of the wafer then defines and an RIE etch forms the springs and the proofmass. Finally, a metal deposition (e.g, gold), a photo mask and a metal etch define and form the contact plate. The three wafers are then bonded. The spring thickness can be defined by the device layer of an SOI wafer.

30 **[0024]** FIG. 5 illustrates an example of an embodiment of the sensor wafer 14 of the MEMS acceleration switch 10 with springs that support a central proofmass and additional proofmasses

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at the exterior of and in a surrounding relationship to the central proofmass. In the example of FIG. 5, which shows the sensor wafer only, the MEMS acceleration switch 10 has springs 28 that support a central proofmass 19a and additional proofmasses 19b in a surrounding relationship to the central proofmass 19a. Such arrangement of springs and the proofmasses allows the proofmasses to move and actually increases the displacements of the proofmasses during acceleration.

[0025] In the example of FIG. 5, springs 28 can be connected along their lengths by coupling rungs, and are configured and constructed for maximum displacement along the intended axis of measurement (the sensitive axis) for axial loads (vs. transverse loads). In some embodiments, springs 28 are in pairs and separated by a mass that can be a solid block made of a material such as silicon, silicon carbide and the like. In some embodiments, at least one pair of springs 28 is on the top (front) side of the wafer. This provides a great deal of displacement, e.g., 2 to 10 μm .

[0026] In some embodiment and as illustrated by the example depicted in FIG. 6, the springs 28 are single-sided and positioned on only one side of the sensitive wafer 14 and each spring includes a pair of relatively long (e.g., 100-500 μm), thin (e.g., 5-20 μm) and narrow (e.g., 5-20 μm) beams connected by coupling rungs. The low length-to-width aspect ratio of the overall spring restricts displacement due to lateral forces while the small thickness allows for maximum displacement due to perpendicular forces. Additionally, since a switch with single-sided springs has a smaller spring constant resulting in larger displacement from axial and transverse loads, such acceleration switch with single-sided springs is sensitive to transverse load, which may result in 10-30% of displacement along the sensitive axis if axial load is applied along the sensitive axis.

[0027] FIG. 7 illustrates an example of an embodiment of the sensor wafer 14 of a low-G MEMS acceleration switch with double sided springs on two/opposite sides of the sensor wafer. The effect is a decrease in sensitivity for transverse loads. For a non-limiting example, a given transverse load results in less than 1% of displacement along the sensitive axis if the same axial load is applied along the sensitive axis.

[0028] FIG. 8 illustrates an example of an embodiment of the sensor wafer 14 a low-G MEMS acceleration switch with double sided springs 28 that are connected to corners instead of at the sides as shown in FIGs. 5-7. Such spring arrangement provides for increased

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displacement, which comes from rearranging the springs compared to FIG 7 (although it also has double-sided springs), thereby improving manufacturability.

[0029] While the invention has been described and illustrated with reference to certain particular embodiments thereof, those skilled in the art will appreciate that various adaptations, changes, modifications, substitutions, deletions, or additions of procedures and protocols may be made without departing from the spirit and scope of the invention.

[0030] Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the appended claims.

[0031] What is claimed is:

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CLAIMS

- 1 1. A MEMS acceleration switch, comprising:
2 a base;
3 a sensor wafer with a proofmass; and
4 an open circuit that includes two fixed electrodes and a contact plate, wherein during
5 acceleration, the proofmass moves towards the base and connects the two fixed electrodes,
6 resulting in a closing of the circuit that detects the acceleration, wherein the MEMS
7 acceleration switch is sensitive to no more than 10 Gs.
- 1 2. The switch of claim 1, wherein:
2 the MEMS acceleration switch is sensitive to no more than 5 Gs.
- 1 3. The switch of claim 1, wherein:
2 the MEMS acceleration switch is sensitive to no more than 2 Gs.
- 1 4. The switch of claim 1, wherein:
2 the MEMS acceleration switch is insensitive to transverse loads with zero or minimum
3 displacement along the sensitive axis for transverse loads.
- 1 5. The switch of claim 4, wherein:
2 the MEMS acceleration switch provides a displacement along a sensitive axis is
3 substantially independent of the transverse load.
- 1 6. The switch of claim 4, wherein:
2 a transverse load as high as 10 times or more than nominal range does not result in
3 closing of the circuit.
- 1 7. The switch of claim 1, wherein:
2 the MEMS acceleration switch does not have current flow through the entire device and
3 thus provides for lower resistance in the state of closed circuit.
- 1 8. The switch of claim 1, wherein:
2 the proofmass has one or more apertures for damping in the event that the MEMS
3 acceleration switch needs to be a damped switch.

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1 9. A MEMS acceleration switch, comprising:
2 a sensor wafer having a central proofmass and one or more adjacent proofmasses at the
3 exterior of the central proofmass; and
4 a plurality of springs that supports the central proofmass and the one or more adjacent
5 proofmasses in a surrounding relationship to the central proofmass, wherein such arrangement
6 of the springs and the proofmasses increases displacements of the proofmasses during
7 acceleration.

1 10. The switch of claim 9, wherein:
2 the springs are connected along their lengths by coupling rungs.

1 11. The switch of claim 9, wherein:
2 the springs are configured and constructed for maximum displacement along the
3 intended axis of measurement for axial loads.

1 12. The switch of claim 9, wherein:
2 the springs bend a perpendicular direction but not in the transverse direction.

1 13. The switch of claim 9, wherein:
2 the springs are in pairs and separated by a mass.

1 14. The switch of claim 9, wherein:
2 the springs are single-sided positioned on only one side of the sensor wafer.

1 15. The switch of claim 14, wherein:
2 each of the single-sided springs includes a pair of beams connected by coupling rungs
3 with low length-to-width aspect ratio that restricts displacement due to lateral forces and allows
4 for maximum displacement due to perpendicular forces.

1 16. The switch of claim 9, wherein:
2 the springs are double-sided positioned on both sides of the sensor wafer in order to
3 decrease sensitivity for transverse loads.

1 17. The switch of claim 9, wherein:
2 the springs are coupled to sides of the proofmasses.

1 18. The switch of claim 9, wherein:
2 the springs are coupled to corners of the proofmasses.

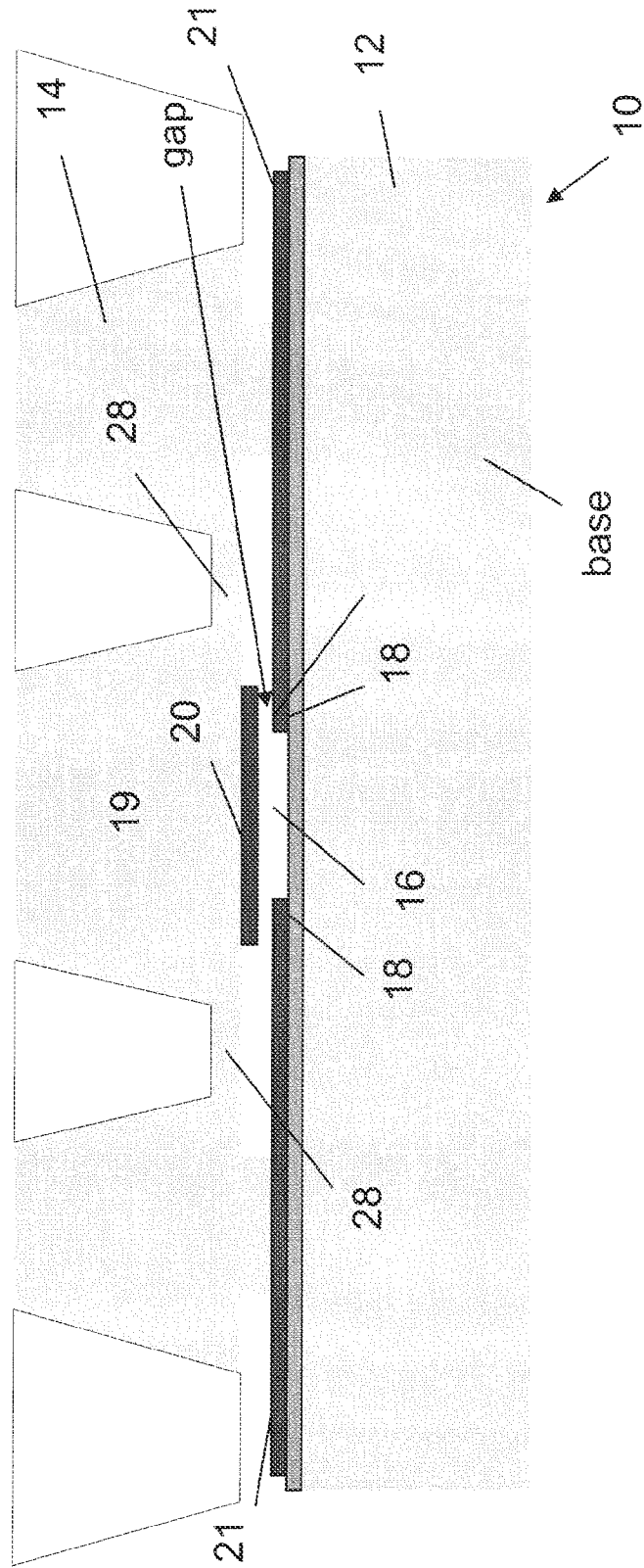


FIG. 1

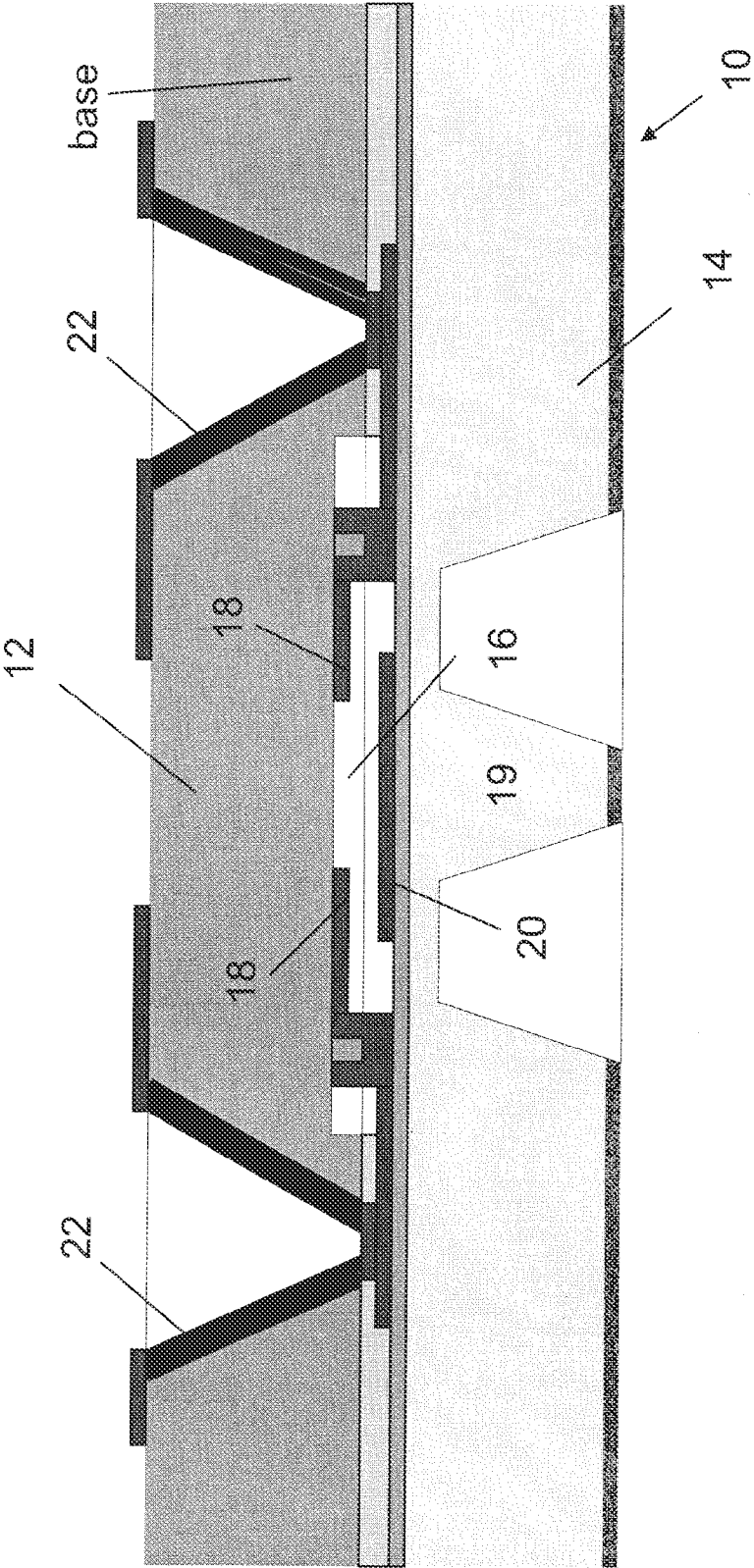


FIG. 2

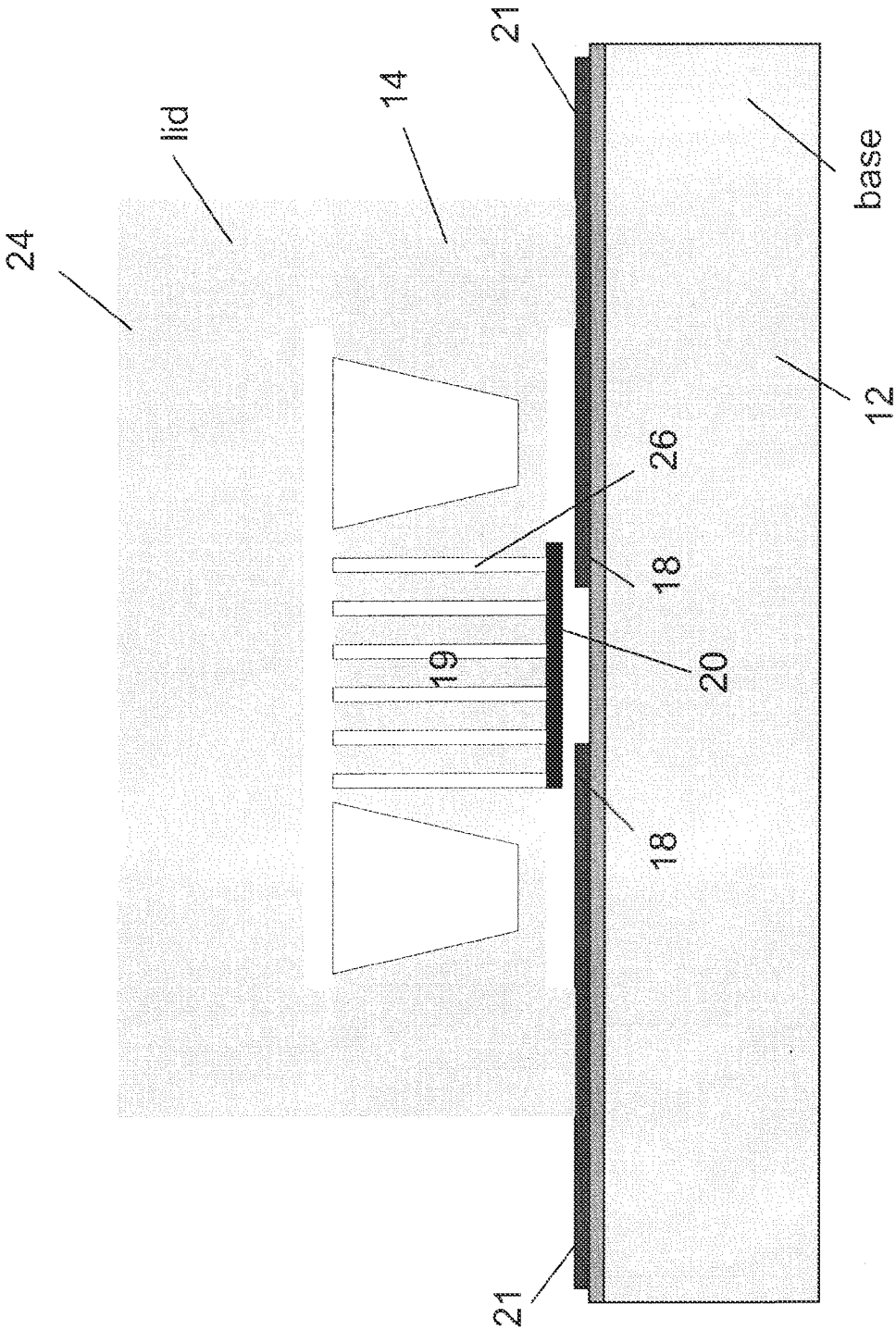


FIG. 3

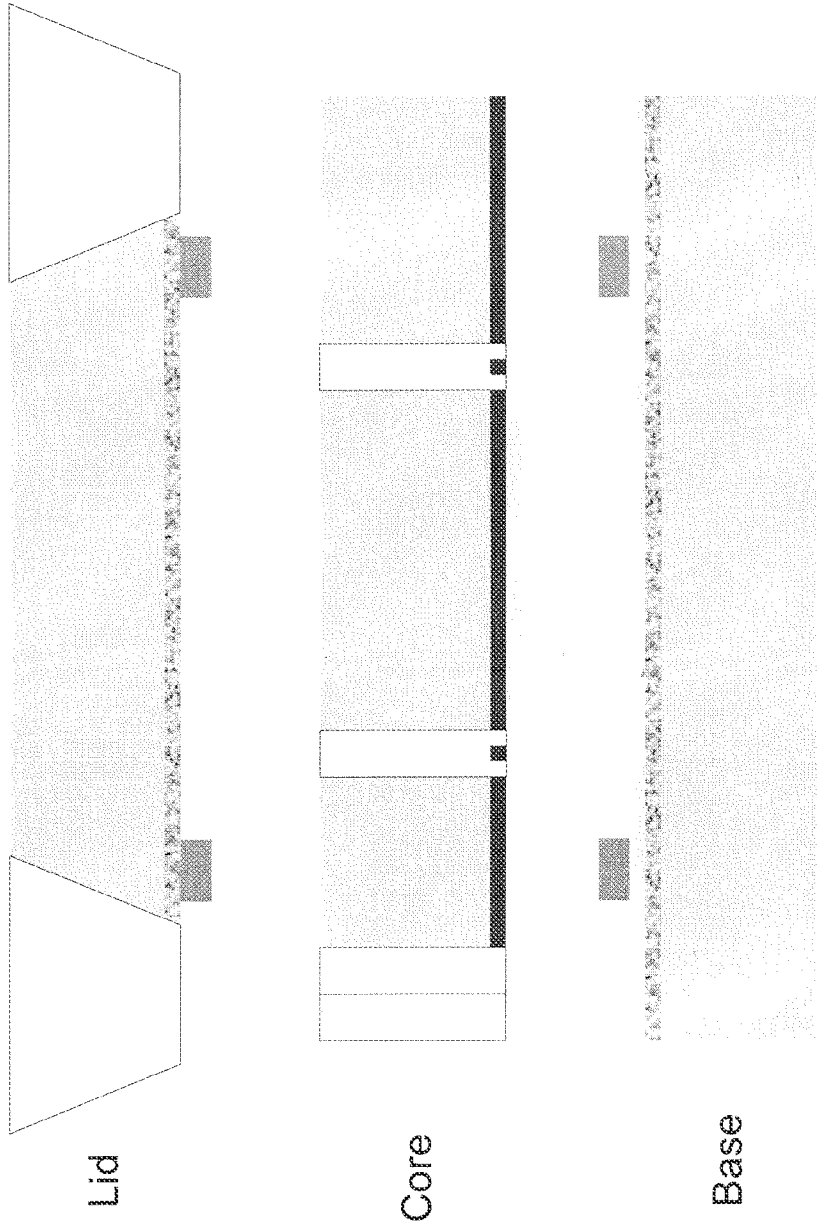
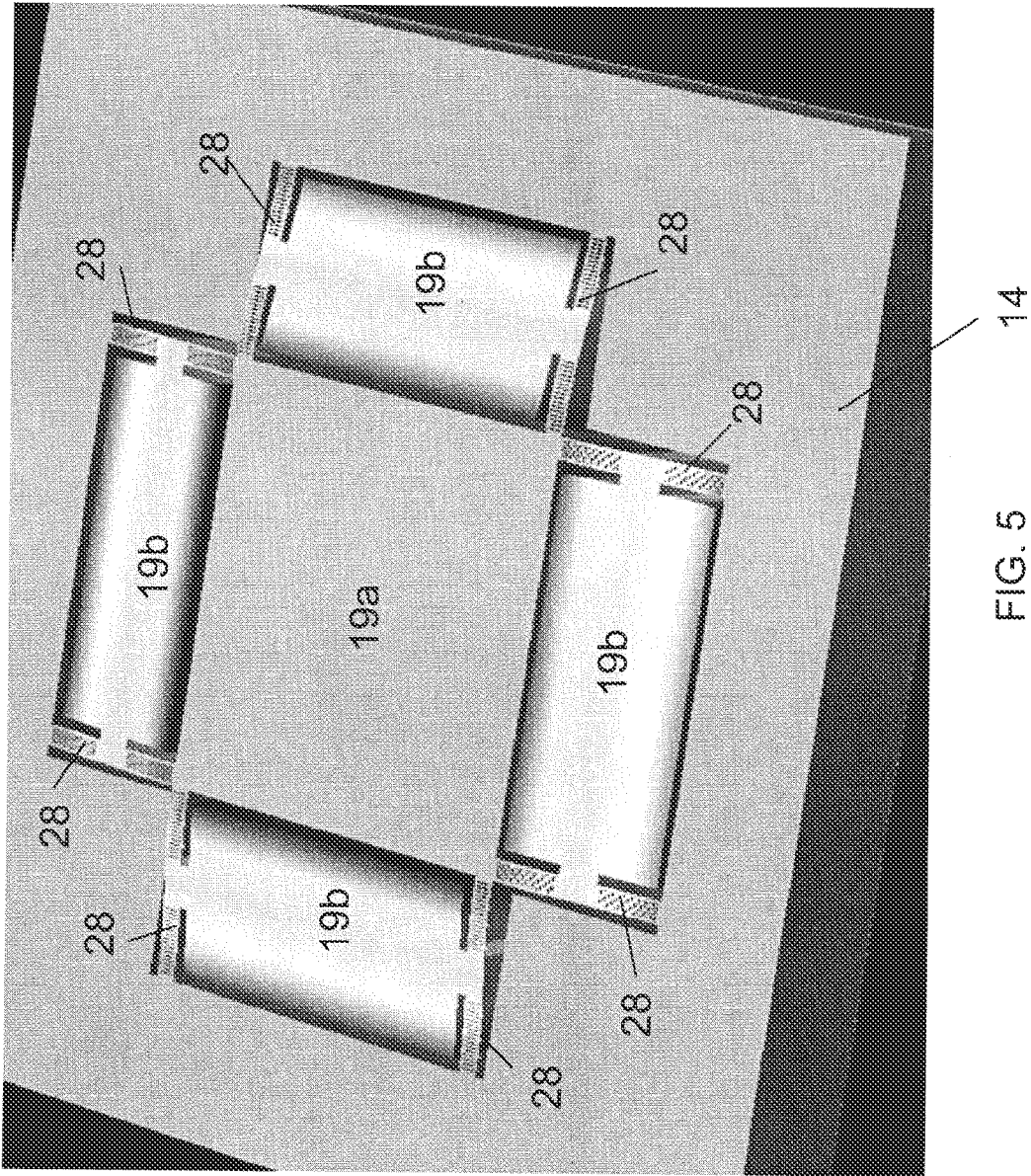


FIG. 4



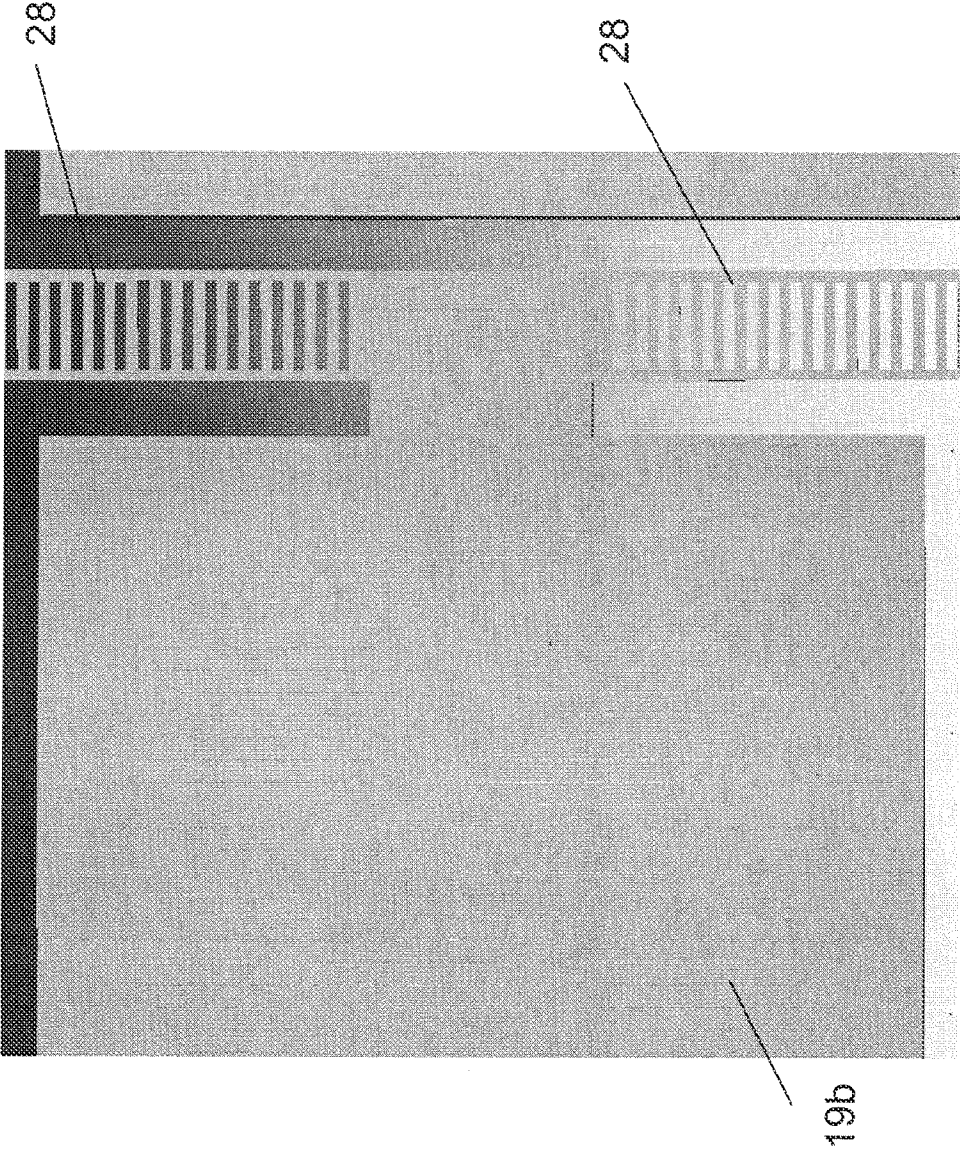


FIG. 6

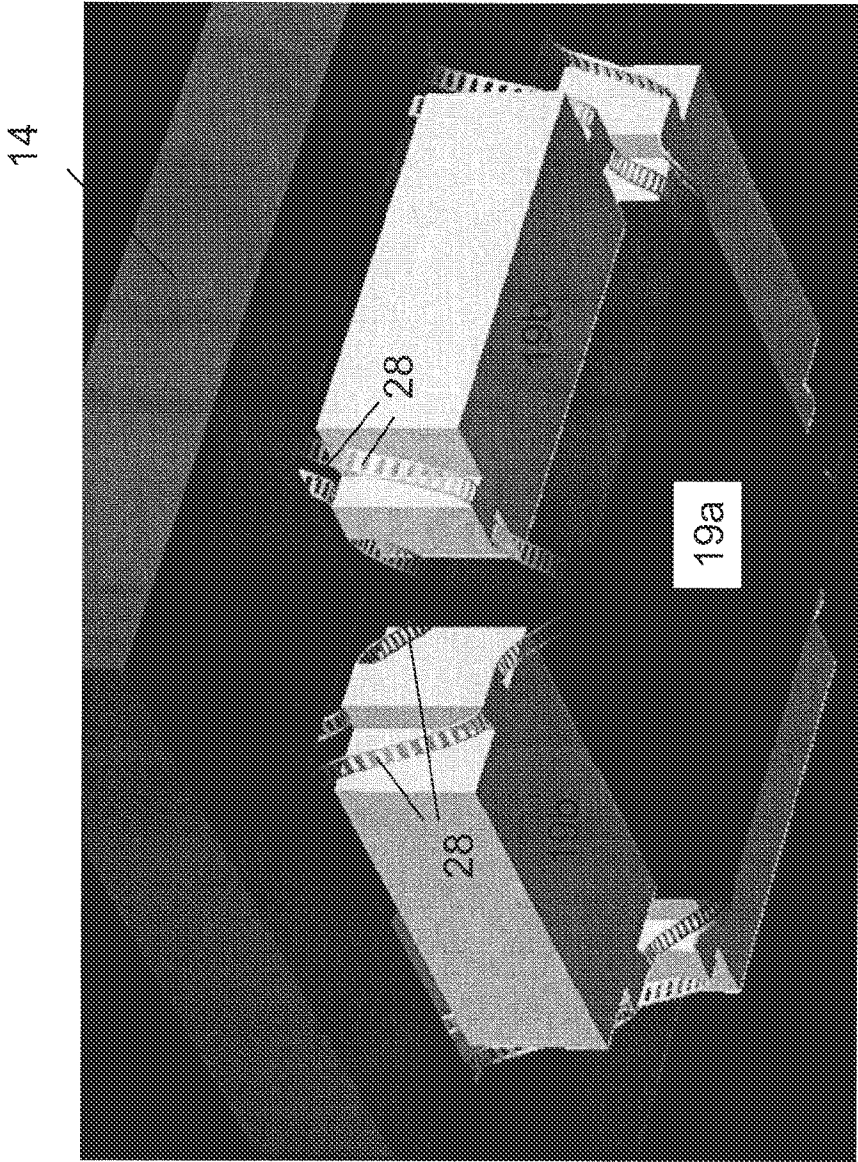


FIG. 7

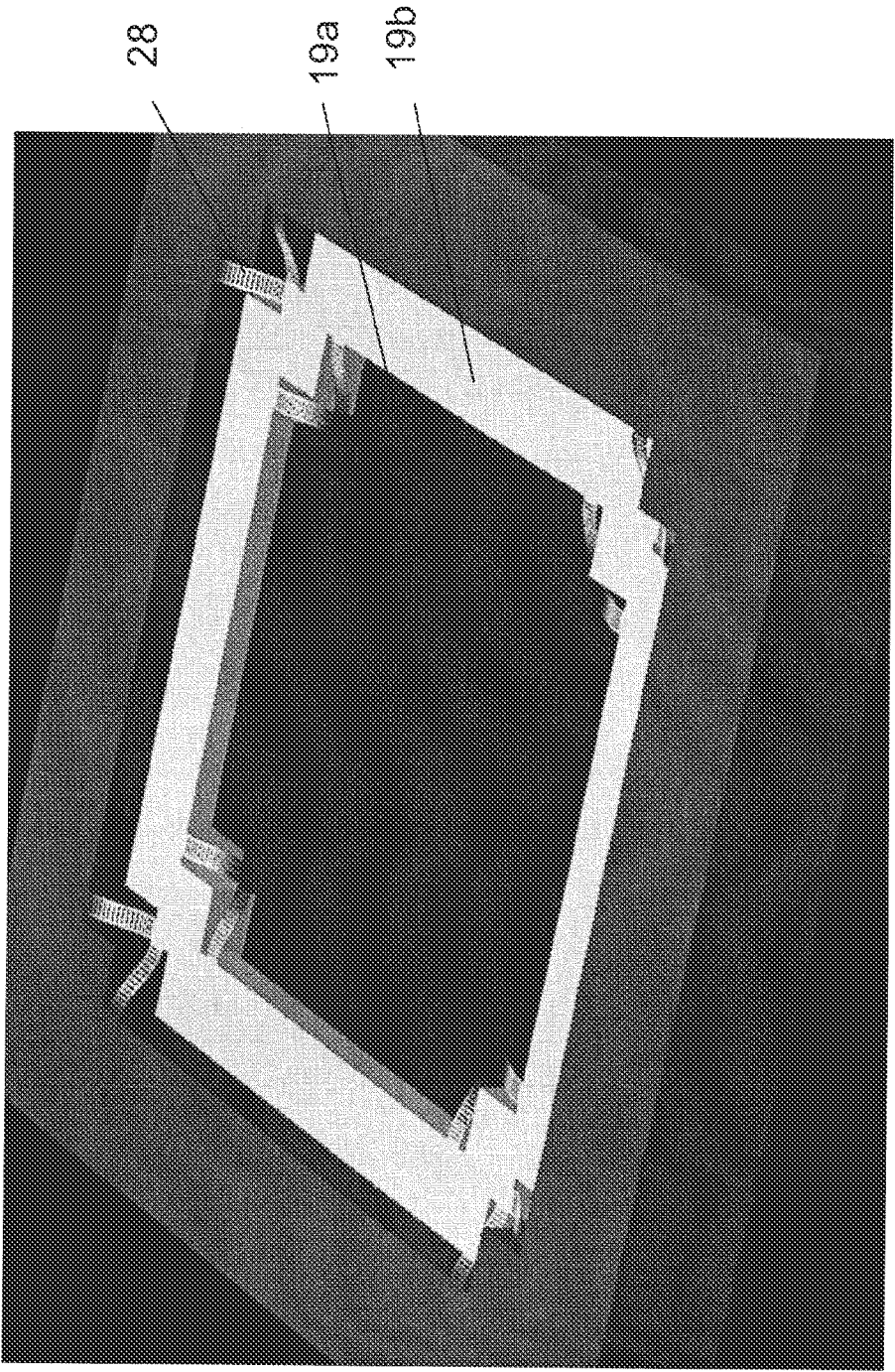


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 12/62749

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01P 15/00 (2012.01)

USPC - 73/514.01

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)

IPC(8)- G01P 15/00 (2012.01)

USPC- 73/514.01

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

IPC(8)- G01P 15/00, G01P 15/00, G01P 03/04, G01P 15/125 (2012.01)

USPC- 73/514.01, 73/510, 73/514.32, 73/514.320P

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

PatBase, Google Patent, Google Scholar.

Terms: Accelerometer Microaccelerometer MEMS acceleration switch proof mass proofmass or seismic mass springs gravity or gravitation low orbit acceleration switch rung

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2009/0139331 A1 (Axelrod, et al) 4 June 2009 (04.06.2009) para [0020], [0027], [0029], [0032], [0035], [0036], [0041]-[0045], [0057], Fig. 2-3, 4A-B, 5A, 5B, 6A-C, 7	1-9, 11-14, 16 and 17 ----- 10, 15, 18
Y	US 2005/0126287 A1 (Malametz) 16 June 2005 (16.06.2005) para. [0022], [0023], Fig. 1-3	10, 15
Y	US 2010/0244160 A1 (Kanemoto) 30 September 2010 (30.09.2010) Fig. 1	18
A	US 2007/0222011 A1 (Robert et al.) 27 September 2007 (27.09.2007) entire document	1-18
A	US 2005/0145029 A1 (Stewart) 7 July 2005 (07.07.2005) entire document	1-18
A	US 2011/0023606 A1 (Burghardt et al.) 3 February 2011 (03.02.2011) entire document	1-18

☐ Further documents are listed in the continuation of Box C.

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"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

16 December 2012 (16.12.2012)

Date of mailing of the international search report

18 JAN 2013

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