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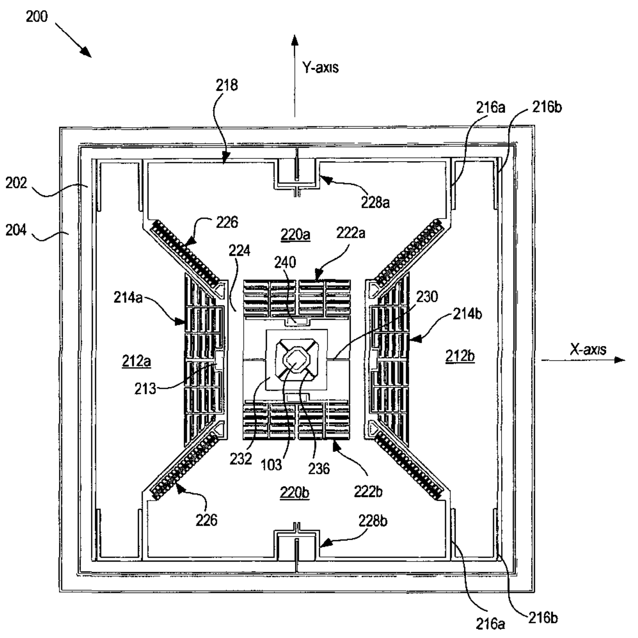

FIG. 2

(57) Abstract: A micromachined inertial sensor (200) with a single proof-mass (201) or measuring 6-degree-of-motions. The single proof-mass (201) includes a frame (202), an x-axis proof mass section (212a, 212b) attached to the frame by a first flexure, and a y-axis proof mass section (218) attached to the frame (202) by a second flexure (228a, 228b). The single proof-mass (201) is formed in a micromachined structural layer and is adapted to measure angular rates about three axes with a single drive motion and linear accelerations about the three axes.

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MICROMACHINED INERTIAL SENSOR DEVICES

BACKGROUND OF THE INVENTION

[001] The present invention generally relates to inertial sensor devices and, more particularly, to micromachined inertial sensor devices.

[002] With the rapid advance of modern electronic technology, various electronic devices, such as navigation systems, cell phones, and electronic games, require sensors that can accurately determine motions of the devices at low cost with small form factor. Conventional techniques have been developed to bump micro-electromechanical-systems (MEMS) chips on ASIC wafers or integrate MEMS with ASIC wafers. However, majority of the existing MEMS sensors measure either acceleration or rotation, but not the 6 degrees-of-freedom (three independent accelerations and three independent rotations) of an object. As such, the existing ASIC wafers for detecting the motion of an object in 6 DOF have large form factors to accommodate multiple MEMS sensors and extra circuits or algorithms to handle the data received from the multiple sensors. Furthermore, fabrication of multiple MEMS and packaging/integration of MEMS with ASIC wafers increase the manufacturing cost of the sensor devices. Thus, there is a need for a single MEMS device that can detect the motion of an object in 6 DOF so that the overall form factor and manufacturing cost of a sensor device that contains the MEMS can be significantly reduced.

SUMMARY OF THE INVENTION

[003] In one embodiment of the present disclosure, a sensor for measuring a motion includes a frame; a first planar proof mass section attached to the frame by a first flexure; and a second planar proof mass section attached to the frame by a second flexure. The frame, the first planar proof mass section, and the second planar proof mass section are formed in a micromachined layer and are adapted to measure angular rates about three axes and linear accelerations

about the three axes.

[004] In another embodiment of the present disclosure, a device for measuring a motion includes a first wafer, a device layer, and a second wafer, where the first and second wafers are bonded to the device layer to thereby encapsulate the device layer. The device layer includes a frame; a first planar proof mass section attached to the frame by a first flexure; and a second planar proof mass section attached to the frame by a second flexure. The frame, the first planar proof mass section, and the second planar proof mass section are formed in a micromachined layer and are adapted to measure angular rates about three axes and linear accelerations about the three axes.

[005] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[006] FIG. 1 shows a schematic cross sectional view of a multi-DOF device in accordance with one embodiment of the present invention;

[007] FIG. 2 shows a schematic top view of a sensor of the multi-DOF device in FIG. 1;

[008] FIG. 3A shows an enlarged view of a comb drive electrode of the sensor in FIG. 2;

[009] FIG. 3B shows an enlarged view of a y-axis accelerometer electrode of the sensor in FIG. 2;

[010] FIG. 4A shows the single mass in FIG. 2 under a gyroscope drive operational mode;

[011] FIG. 4B shows the single mass in FIG. 2 during the sense motion in response to rotation about the x-axis;

[012] FIG. 4C shows the single mass in FIG. 2 during the sense motion in response to rotation about the y-axis;

[013] FIG. 4D shows the single mass in FIG. 2 during the sense motion in

response to rotation about the z-axis;

[014] FIGS. 5A and 5B show the single mass under linear accelerations in the x and z directions, respectively;

[015] FIG. 6 shows a schematic top view of gyro electrodes underneath the device layer for measuring out-of-plane motions of the sensor in FIG. 2;

[016] FIG. 7 shows an enlarged view of the flexure structure that allows x-axis gyro sense and z-axis accelerometer sense motions;

[017] FIG. 8 shows a schematic top view of another embodiment of a sensor in accordance with the present invention;

[018] FIG. 9A shows a schematic top view of yet another embodiment of a sensor in accordance with the present invention; and

[019] FIG. 9B shows an enlarged view of the flexure structures of the sensor in FIG. 9A.

DETAILED DESCRIPTION OF THE INVENTION

[027] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention because the scope of the invention is best defined by the appended claims.

[028] FIG. 1 shows a schematic cross sectional view of a multi-DOF device 100. As depicted, the multi-DOF device 100 includes a cap wafer 102; a device layer (or, equivalent^, MEMS layer or micromachined structure layer) 106 that includes micromachined structures (or, MEMS structures); and a via wafer 108. The cap wafer 102 may be metal bonded to the device layer 106, where the metal bonding 104 can generate thermal stress between the cap wafer 102 and the device layer 106 during operation. To isolate the micromachined structures from the thermal stress, a stress reducing groove 120 can be formed around the perimeter of the device layer 106. The metal bond 104 may be a non-high temperature fusion bond and enable the application of getter to maintain a long

term vacuum and application of an anti-stiction coating to prevent stiction that could occur to low-g acceleration sensors. The via wafer 108 may be fusion bonded, such as silicon-silicon fusion bonded, to the device layer 106, obviating thermal stress between the via wafer 108 and the device layer 106.

[029] The via wafer 108 may include a protruding portion (or, equivalent^, anchor) 103 that is located substantially at the center of the via wafer 108 and provides an anchoring (attaching) structure for the device layer 106. The anchor 103 may be fusion bonded to the device layer 106, to thereby eliminate potential problems associated with metal fatigue.

[030] Sensors formed in the device layer 106 measure changes in capacitance to detect angular displacements. As such, any external electric or magnetic field may affect the accuracy in the measurement of the angular displacements. To shield the external electric and magnetic fields, the device layer 106 and the cap wafer 102 are electrically connected to each other and preferably grounded.

[031] The via wafer 108 includes multiple regions separated by an isolating trenches (or, equivalently, vias) 114. Each via 114 is filled with conductive non¬ crystalline material 118, such as polysilicon or metal. The conductive material 118 is electrically insulated by dielectric material 116, and can be electrically biased to the voltage at the electrode, to create a zero voltage differential and thereby to eliminate the shunt capacitance of the via.

[032] Each of the regions separated by the isolating trenches 114 has an electrical contact for data communication. For example, as depicted in FIG. 1C, the via wafer 108 may include three contacts 110, 111, and 112 that may be connected to an ASIC wafer by bumps or wire-bonds. In another example, the contact 110 may be an electrode contact that is connected to the via 114, while the contact 111 may be an anchor contact electrically connected to the anchor 103, and the contact 112 is a circular via contact electrically connected to an isolated region (or, island) 119. Detailed description of the vias and isolated regions is disclosed in a copending US Patent Application No. 12/849,787, entitled "Micromachined devices and fabricating the same," filed on August 3, 2010, which is hereby incorporate herein by reference in its entirety.

[033] The device layer 106 may include a micromachined structure that functions as gyroscopes and acceleration sensors. Electrical connections to the micromachined structure is achieved through anchors 103 and by capacitive coupling between isolated regions of the via wafer 108 and the device layer 106. Detailed description of the micromachined structure operation is given below in conjunction with FIGS. 4A - 5B

[034J FIG. 2 shows a schematic top view of a micromachined integrated 6-axis inertial measurement device (or, equivalents, micromachined device or sensor) 200 that is included in the device layer (or micromachined layer) 106 in FIG. 1. As depicted, the sensor 200 includes a seal frame 204 that is bonded to the via frame 108 and the cap frame 102; a proof-mass outer frame 202; a pair of x-axis planar proof mass sections (or, shortly, x-axis proof mass sections) 212a and 212b; and a y-axis planar proof mass section (or shortly, y-axis proof mass section) 218. Each of the x-axis proof mass sections 212a and 212b is attached/suspended to the proof-mass outer frame 202 by two pairs of z-axis gyroscope flexures 216a and 216b, and includes an x-axis accelerometer / z-axis gyroscope electrode 214a (or 214b). Each of the pair of x-axis proof mass sections 212a and 212b and the y-axis proof mass section 218 is formed in a substantially plate. Each of the z-axis gyroscope flexures 216a and 216b has a uniform bar or beam shape.

[035] The y-axis proof mass section 218 includes two wing portions 220a and 220b that are connected with the elongated portions 224 that form an integral body. The y-axis proof mass section 218 is attached to the frame 202 by a pair of x-axis gyroscope flexures 228a and 228b, where the flexures are described in conjunction with FIG. 7. The elongated portions 224 are attached to a drive decoupling frame 232 via two y-axis gyroscope flexures 230. The wing portion 220a (or 220b) includes a y-axis electrode 222a (or 222b) and comb drive electrodes 226. As discussed below, the proof-mass outer frame 202, the pair of planar x-axis proof mass sections 212a and 212b, and the y-axis proof mass section 218 are driven simultaneously during a driving operational mode. As such, hereinafter, the term "a single proof-mass" collectively refers to the proof-

mass outer frame 202, the pair of x-axis proof mass sections 212a and 212b; and the y-axis proof mass section 218.

[036] The sensor 200 also includes an anchor 103 that is disposed substantially at the center of the sensor and affixed to the via wafer 108. The drive decoupling frame 232 is connected to the anchor 103 by four drive suspension beams 236.

[037] FIG. 3A shows an enlarged view of the comb drive electrode 226 of the sensor 200 in FIG. 2, where the comb drive electrode 226 is used to drive the x-axis and y-axis proof mass sections to oscillate at a single drive frequency about the z-axis. As depicted, the comb electrode 226 includes stationary fingers 304 connected to an anchor 302 and moving comb fingers 306 connected to 220a. The anchor 302 is affixed to the via wafer 108, causing the stationary fingers 304 to be fixed in space during operation. The anchor 302 may have any suitable polygonal shape, such as rectangle, triangle, and pentagon. The moving fingers 306, which interdigitate with the stationary fingers 304. During operation, electrical signals at the drive frequency are applied to the stationary fingers 304 via the anchor 302. Then, due to the interaction between the stationary fingers 304 and the moving comb fingers 306, the y-axis proof mass section 218 and the x-axis proof mass sections 212a and 212b oscillate at the drive frequency, as discussed below in conjunction with FIG. 4A.

[038] FIG. 3B shows an enlarged view of the y-axis accelerometer electrode (or, equivalently, y-axis acceleration transducer or y-axis accelerometer comb fingers) 222b of the sensor 200 in FIG. 2, where the y-axis accelerometer electrode 222b monitors the motions of the y-axis proof mass section 218 in response to y-axis acceleration. As depicted, the y-axis accelerometer electrode 222b includes a plurality of spaced apart, parallel input electrodes or plates 312 and corresponding number of stationary electrodes or plates 314 that interdigitate with the input plates 312. The stationary plates 314 extend from a stator 310 that is secured to an anchor 240, while the input plates 312 extend from the elongated portions 224 of the y-axis proof mass section 218.

When the y-axis proof mass section 218 moves relative to the stationary plates 314, the electrical interaction (or, capacitance) between the stationary plates 314 and the input plates 312 changes. The change in capacitance is monitored to measure the motion of the y-axis proof mass section 218.

[039] The x-axis accelerometer electrodes (or, equivalently, x-axis acceleration transducers or x-axis accelerometer comb fingers) 214a and 214b have the similar structure as the y-axis electrode 222b. As such, for brevity, the detailed description of the x-axis electrodes 214a and 214b are not repeated. For instance, the x-axis accelerometer electrode 214a includes a plurality of spaced apart, parallel input electrodes or plates and corresponding number of stationary electrodes or plates that interdigitate with the input plates. The stationary plates are connected to the anchor 213, while the input electrodes extend from the x-axis proof mass section 212a.

[040] The x-axis accelerometer electrodes 214a and 214b can be used to measure rotational motions about the z-axis, as described in conjunction with FIG. 4D. Optionally, a separate z-axis gyro electrodes may be formed in the area where the x-axis accelerometer electrodes are disposed.

[041] FIG. 4A shows the single proof-mass 201 under the gyroscope drive operational mode, where the single proof-mass collectively refers to the proof-mass outer frame 202, the pair of planar x-axis proof mass sections 212a and 212b, and the y-axis proof mass section 218. As depicted, the comb drive electrodes 226 are driven to make the wing portions 220a and 220b of the y-axis proof mass section 218 oscillate in an anti-phase fashion along the X and Y directions respectively, resulting in torsional motions (or rotations) of the single proof-mass 201 with respect to the z-axis at a preset drive frequency. The torsional motions cause the drive suspension beams 236 (shown in FIG. 2) to bend in a flexible manner, to thereby provide restoring torques to the x-axis and y-axis proof mass sections.

[042] FIG. 4B shows the single proof-mass 201 during the sense motion in response to rotation about the x-axis. As discussed above with reference to FIG. 4A, x-axis proof mass sections 212a and 212b are driven to oscillate about

the z-axis by exciting the comb drive electrodes 226 at a preset drive frequency. When the x-axis proof mass sections 212a and 212b are rotated at an angular rate about the x-axis, i.e., the single proof-mass 201 is externally disturbed at an angular rate of Ωx, an out-of-plane Coriolis force is generated for the single proof-mass 201 by the combination of the driving oscillation and the rotation at Ωx. The Coriolis force causes the single proof-mass 201 to be torsionally excited about the y-axis. Also, as the x-axis proof mass sections 212a and 212b are suspended to the proof-mass outer frame 202 via the z-axis gyroscope flexures 216a and 216b, the Coriolis force causes the x-axis proof mass sections 212a and 212b to move in opposite directions, as indicated by arrows 402a and 402b.

[043] The motion of the x-axis proof mass sections 212a and 212b can be detected by x-axis gyro electrodes 606 and 608 (shown in FIG. 6). More specifically, the variation of the capacitance between the x-axis gyro electrodes 606 and 608 and the corresponding x-axis proof mass sections 212a and 212b are measured to detect the Coriolis force, to thereby measure the angular rate Ωx of the single proof-mass 201.

[044] FIG. 4C shows the single proof-mass 201 during the sense motion in response to rotation about the y-axis. As discussed above with reference to FIG. 4A, the y-axis proof mass section 218 is driven to oscillate about the z-axis by exciting the comb drive electrodes 226 at a preset drive frequency. When the single proof-mass 201 is rotated at an angular rate about the y-axis, i.e., the single proof-mass 201 is externally disturbed at an angular rate of Ωy, an out-of-plane Coriolis force is generated for the y-axis proof mass section 218 by the combination of the drive oscillation and rotation at Ωy. The Coriolis force causes the single proof-mass 201 to be torsionally excited about the x-axis. Also, as the y-axis proof mass section 218 is connected to the drive decoupling frame 232 (shown in FIG. 2) via the y-axis gyroscope flexures 230, the Coriolis force causes the y-axis gyroscope flexures 230 to rotate about the x-axis, as indicated by arrows 404a and 404b. The y-axis gyroscope flexures 230 provide a restoring torque to the y-axis proof mass section 218.

[045] The motion of the y-axis proof mass section 218 can be detected by y-axis gyro electrodes 602 and 604 (shown in FIG. 6). More specifically, the variation of the capacitance between the y-axis gyro electrodes 602 and 604 and the corresponding wing portions 220a and 220b of the y-axis proof mass section 218 are measured to detect the Coriolis force, to thereby measure the angular rate Ωy of the single proof-mass 201 .

[046] FIG. 4D shows the single proof-mass 201 during the sense motion in response to rotation about the z-axis. When the x-axis proof mass sections 212a and 212b are subject to an angular rate about the z-axis, at an angular rate of Ωz, the opposite velocities of the x-axis proof mass sections 212a and 212b induce opposing in-plane Coriolis forces in the x-direction, as indicated by arrows 406a and 406b. The x-axis proof mass section 212a and the x-axis proof mass section 212b oscillate in an anti-phase fashion in the x-direction due to the opposite directions of Coriolis forces. The motions of the x-axis proof mass sections 212a and 212b can be detected by the x-axis accelerometer electrodes 214a and 214b, or separate similar electrodes disposed in the same area.

[047] FIG. 5A shows the single proof-mass 201 under linear acceleration in the x direction. When the x-axis proof mass sections 212a and 212b are accelerated along the x-direction, the x-axis proof mass sections 212a and 212b move in-phase along the x-axis. The z-axis gyroscope flexures 216a and 216b deform under the linear acceleration along the x-direction. The variation of the capacitance of the x-axis accelerometer electrodes 214a and 214b are measured to detect the motions of the x-axis proof mass sections 212a and 212b. The x-axis accelerometer electrodes 214a and 214b can measure the acceleration in the x-direction as well as the angular rate in the z-direction.

[048] The linear acceleration of the single proof-mass 201 along the y-direction is measured by the similar manner as the linear acceleration along the x-direction is measured. The motion of the y-axis proof mass section 218 is detected by measuring variation of the capacitance of the y-axis accelerometer electrodes (or, y-axis comb finger sensors) 222a and 222b. The y-axis

accelerometer electrodes 222a and 222b can be dedicated to measure accelerations in the y-axis direction. The x-axis gyroscope flexures 228a and 228b deform under linear acceleration in the y-axis direction.

[049] FIG. 5B shows the single proof-mass 201 under linear acceleration in the z-direction. Each of the x-axis proof mass sections 212a and 212b is suspended to the proof-mass outer frame 202 via two z-axis gyroscope flexures 216a and 216b, while the proof mass outer fame 202 is suspended to the y-axis proof mass section 218 by x-axis gyroscope flexures 228a and 228b. Thus, when the single proof-mass 201 is accelerated along the z-direction, the x-axis proof mass sections 212a and 212b move in-phase in the z-direction, while the y-axis proof mass section 218 stays still. Accordingly, the motion or acceleration of the x-axis proof mass sections 212a and 212b can be measured by the x-axis gyroscope electrodes 606 and 608 (shown in FIG. 6). In an alternative embodiment, a dedicated z-axis electrode (not shown in FIG. 5B) can be included in the sensor 200 so that the acceleration in the z-direction can be measured without using the x-axis gyroscope electrodes 606 and 608.

[050] FIG. 6 shows a schematic top view of gyro electrodes 600 for measuring motions of the sensor. As depicted, the gyro electrodes 600 include x-axis gyro electrodes 606 and 608 and y-axis gyro electrodes 602 and 604. As discussed above, the variation of the capacitance between each of the gyro electrodes 600 and the corresponding component of the sensor 200 is used to measure the motion of the sensor. The gyro electrodes 600 may be mounted on the surface of the via wafer 108 (shown in FIG. 1) or within the via layer, and spaced apart from the sensor 200 by a predetermined distance.

[051] FIG. 7 shows an enlarged view of the flexure structure 228a that allows x-axis gyro sense and z-axis accelerometer sense motions. The flexure comprises an x-axis gyro spring 704, a z-axis accelerometer spring 702 and a frame connection spring 706. As depicted, the wing portion 220a of the y-axis proof mass section 218 is connected to the proof-mass outer frame 202 via the beam 704 and the x-axis gyro spring 704, where one end of the spring 704 is attached to the wing portion 220a and the other end of the spring 704 is

attached to the outer frame 202 via a linkage 703 and the z-axis accelerometer spring 702. The linkage 703 and the z-axis accelerometer spring 702 are separated from the wing portion 220a by grooves (or gaps) 705. The gaps 705 are large enough to permit the linkage 703, the x-axis gyro spring 704 and the z-axis accelerometer spring 702 to move through its design range without colliding with the wing portion 220a.

[052] The x-axis gyro spring 704 provides a restoring torque about the y-axis when the x-axis proof mass sections 212a and 212b are torsionally excited about the y-axis, as shown in FIG. 4B. The z-axis accelerometer spring 702 acts as a torsional hinge and provides a restoring torque about the y-axis when the y-axis proof mass section 218 is accelerated along the z-axis, as shown in FIG. 5B.

[053] FIG. 8 shows a schematic top view of another embodiment of a sensor 800 in accordance with the present invention, where the sensor 800 has similar functions as the sensor 200 (shown in FIG. 2). As depicted, the sensor 800 is similar to the sensor 200 in FIG. 2, with the difference that the sensor 800 does not include the drive decoupling frame 232, i.e., y-axis gyroscope flexures (or beams) 804 connect the y-axis proof mass section 818 directly to the anchor 802. In this embodiment, the y-axis gyroscope beams 804 can be utilized as drive suspension beams as well. In the y-axis angular rate response mode (which is similar to the mode described in FIG. 4C), the y-axis gyroscope beams 804 are twisted about the x-axis, to thereby act as torsional hinges about the x-axis. In the drive mode, the y-axis gyroscope beams 804 deflect as fixed-guided end beams, allowing the y-axis proof mass section 818 to rotate about the z-axis. It is noted that the sensor 800 does not include a drive decoupling frame to reduce the complexity of the suspension mechanism for the proof mass.

[054] FIG. 9A shows a schematic top view of yet another embodiment of a sensor 900 in accordance with the present invention. FIG. 9B shows an enlarged view of the x-axis and y-axis accelerometer flexures of the sensor 900 in FIG. 9A. As depicted, the sensor 900 is similar to the sensor 200 in FIG. 2,

with the difference that the sensor 900 includes x-axis accelerometer fixtures 908a, 908b and y-axis accelerometer flexures 910a, 910b. The sensor 900 includes a y-axis proof mass section 918 having a pair of wing portions 902a, 902b; elongated portions 904; and y-axis electrodes (or transducers) 906a, 906b for measuring the motions of the y-axis proof mass section 918. The sensor 900 also includes an anchor 946 disposed substantially at the center and a drive decoupling frame 948 connected to the anchor 946 by multiple drive beams 950.

[055] The x-axis accelerometer flexure 908a (or 908b) includes: an elongated slit (groove or gap) 930 formed in the elongated portion 904 of the y-axis proof mass section 918; and two slits (grooves or gaps) 932 that extend from the regions around anchors 905 toward the x axis. The distal ends of the slits 932 are spaced apart from each other to form a suspension linkage 934 having a substantially T-shape. The slits 932 separate the elongated portion 904 from the frame 952, where the frame 952 has a substantially rectangular shape. The slits 930 and 932 are large enough to permit the suspension linkage 934 to move through its design range without colliding with the elongated portion 904 and the frame 952. The anchors 905 are secured to the via wafer 108 (shown in FIG. 2) and holds the stationary plates of the y-axis electrodes 906a (or 906b) in place.

[056] The y-axis accelerometer flexure 910b (or, 910a) includes a long slit (groove or gap) 940 and two short slits (grooves or gaps) 942 that are arranged substantially parallel to the long slit 940. The gap between the two short slits 942 and the long slit 940 forms a suspension linkage 944 having a substantially T-shape. The frame 952 is separated from the drive decoupling frame 948 by the slits 940 and 942. The slits 940 and 942 are large enough to permit the suspension linakge 944 to move through its design range without colliding with the frame 952 and the drive decoupling frame 948. The x-axis accelerometer flexures 908a, 908b and the y-axis accelerometer flexures 910a, 910b are connected to the drive decoupling frame 948, and allow the accelerometer function to be decoupled from the gyroscope operation.

[057] It should be understood, of course, that the foregoing relates to exemplary embodiments of the invention and that modifications may be made without departing from the spirit and scope of the invention as set forth in the following claims.

What is claimed is:

1. A sensor for measuring a motion thereof, comprising:

a frame;

a first planar proof mass section attached to the frame by a first flexure; and

a second planar proof mass section attached to the frame by a second flexure;

wherein the frame, the first planar proof mass section, and the second planar proof mass section are formed in a micromachined layer and are adapted to measure angular rates about three axes and linear accelerations about the three axes.

2. A sensor as recited in claim 1, further comprising:

at least one comb electrode for driving the first and second planar proof mass sections at a drive frequency about an axis normal to a plane, the micromachined layer being substantially disposed on the plane when the sensor is not externally disturbed.

3. A sensor as recited in claim 2, wherein the comb electrode includes a plurality of stationary fingers and a plurality of moving comb fingers.

4. A sensor as recited in claim 3, wherein the plurality of stationary fingers are connected to an anchor that is secured to a wafer disposed beneath the micromachined layer.

5. A sensor as recited in claim 2, wherein the second planar proof mass section includes a pair of wing portions disposed symmetrically about a first axis and the wing portions are adapted to move in opposite directions when the sensor is disturbed at an angular rate along a second axis perpendicular to the first axis.

6. A sensor as recited in claim 5, further comprising:

a pair of gyro electrodes disposed beneath the micromachined layer,

wherein the angular rate along the second axis is detected by measuring a variation of capacitance between the pair of gyro electrodes and the pair of wing portions.

7. A sensor as recited in claim 5, further comprising:

a pair of accelerometer electrodes respectively connected to the pair of wing portions and disposed symmetrically about a first axis,

wherein a linear acceleration of the sensor along the second axis is detected by measuring a variation of capacitance of the pair of accelerometer electrodes.

8. A sensor as recited in claim 7, wherein each said accelerometer is connected to an anchor that is secured to a wafer disposed beneath the micromachined layer.

9. A sensor as recited in claim 2, wherein the first proof mass section includes a pair of masses disposed symmetrically about a second axis and the pair of masses are adap.ted to move in opposite directions when the sensor is disturbed at an angular rate along a first axis perpendicular to the second axis.

10. A sensor as recited in claim 9, further comprising:

a pair of gyro electrodes disposed beneath the micromachined layer,

wherein the angular rate along the first axis is detected by measuring a variation of capacitance between the pair of masses and the pair of gyro electrodes.

11. A sensor as recited in claim 8, wherein a linear acceleration of the sensor along the axis normal to the plane is detected by measuring a variation of capacitance between the pair of masses and the pair of gyro electrodes.

12. A sensor as recited in claim 9, wherein the pair of masses are adapted to move in opposite directions when the sensor is disturbed at an angular rate along the axis normal to the plane.

13. A sensor as recited in claim 12, further comprising:

a pair of accelerometer electrodes respectively connected to the pair of masses and disposed symmetrically about the second axis,

wherein the angular rate along the axis normal to the plane is detected by measuring a variation of capacitance in the pair of accelerometer electrodes.

14. A sensor as recited in claim 13, wherein each said accelerometer is connected to an anchor that is secured to a wafer disposed beneath the micromachined layer.

15. A sensor as recited in claim 13, wherein a linear acceleration of the sensor along the first axis is detected by measuring a variation of capacitance in the pair of accelerometer electrodes.

16. A sensor as recited in claim 1, further comprising:

an anchor secured to a wafer disposed beneath the micromachined layer, the anchor being located substantially at a center of the sensor.

17. A sensor as recited in claim 16, further comprising:

an inner frame connected to the anchor by a plurality of suspension beams; and

a plurality of flexures connected to the inner frame and second proof mass section and adapted to provide a restoring force to the second proof mass section.

18. A sensor as recited in claim 17, further comprising:

a pair of gyroscope flexures connected to the second planar proof mass section and to the frame and adapted to provide a restoring torque to the second planar proof mass section.

19. A sensor as recited in claim 1, wherein the first flexure includes two pairs of gyroscope flexures, each said gyroscope flexure having two elongated beams.

20. A sensor as recited in claim 1, further comprising:

a pair of flexures connected to the frame and the second planar proof mass section, each said flexure including a gyro spring for providing a restoring torque along a second axis and two accelerometer springs for providing a restoring torque along the second axis.

21. A sensor as recited in claim 20, wherein each said flexure includes a linkage, each end of the linkage being connected to a corresponding one of the two accelerometer springs, the gyro spring being connected to a midpoint of the linkage.

22. A device for measuring a motion thereof, comprising:

a first wafer;

a device layer including:

a frame;

a first planar proof mass section attached to the frame by a first flexure; and

a second planar proof mass section attached to the frame by a second flexure;

wherein the frame, the first planar proof mass section, and the second planar proof mass section are formed in a micromachined layer and are adapted to measure angular rates about three axes and linear accelerations about the three axes; and a second wafer, the first and second wafer being bonded to the device layer to thereby encapsulate the device layer.

23. A device layer as recited in claim 22, wherein the first wafer is a cap wafer.

24. A device layer as recited in claim 23, wherein the second wafer is a via wafer or an ASIC wafer.

25. A device as recited in claim 22, wherein the second wafer includes one or more electrodes for measuring an angular rate of at least one of the first and second planar proof mass sections.

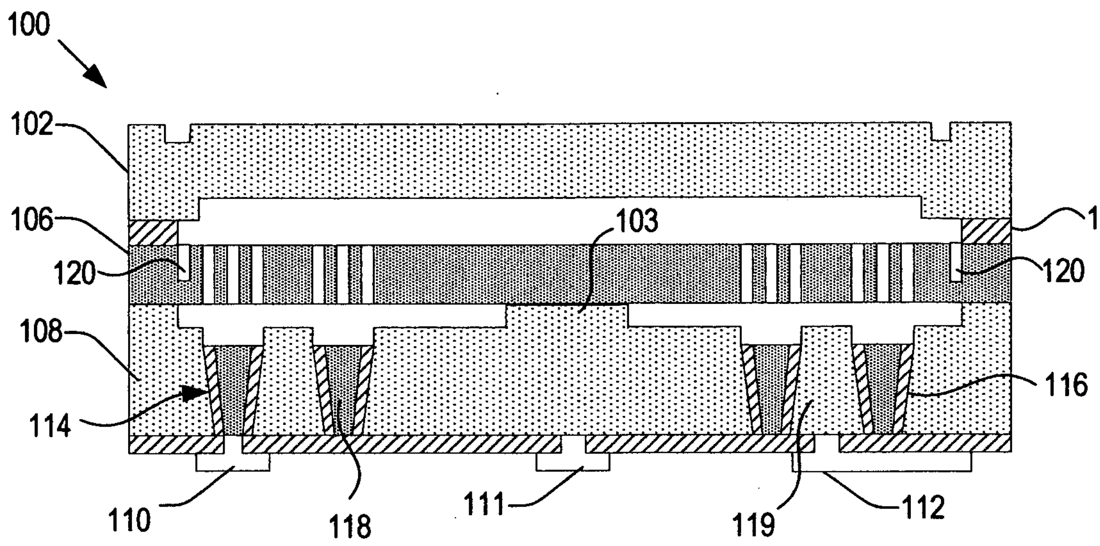

FIG. 1

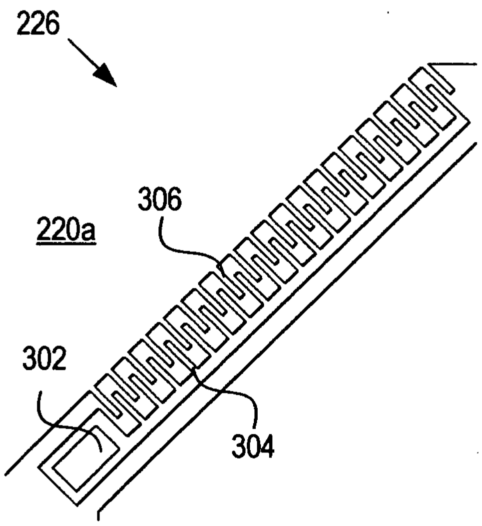

FIG. 3A

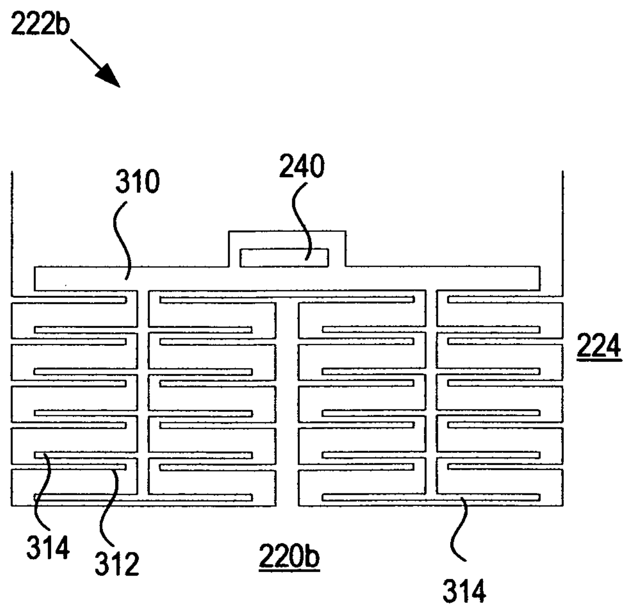

FIG. 3B

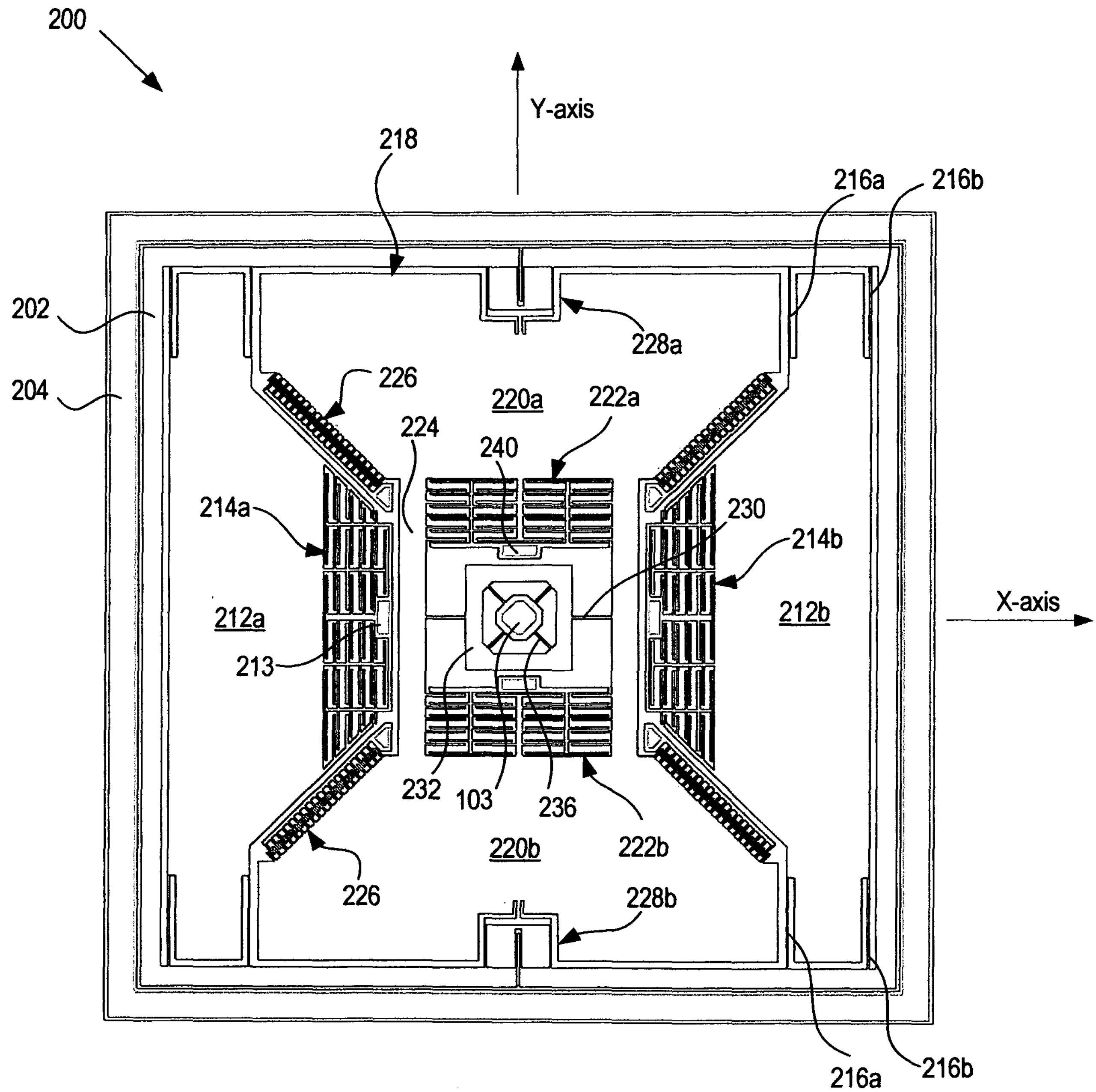
200
Y-axis
218
216a
216b
202
228a
204
226
220a
222a
224
240
214a
230
214b
212a
X-axis
212b
213
232
103
236
222b
220b
226
228b
216a
216b

FIG. 2

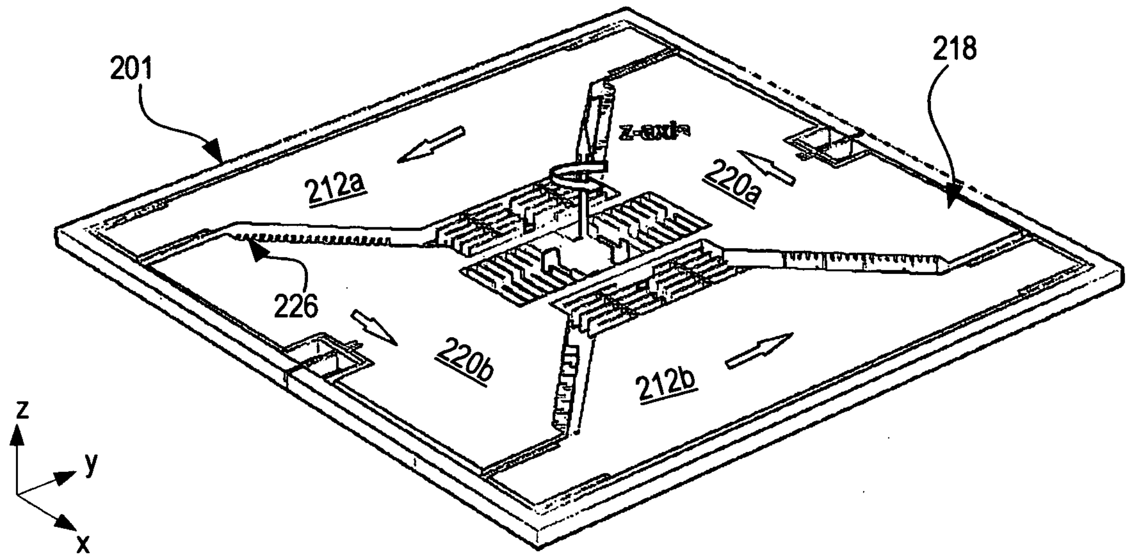
201
218
z-axis
212a
220a
226
220b
212b
z
y
x

FIG. 4A

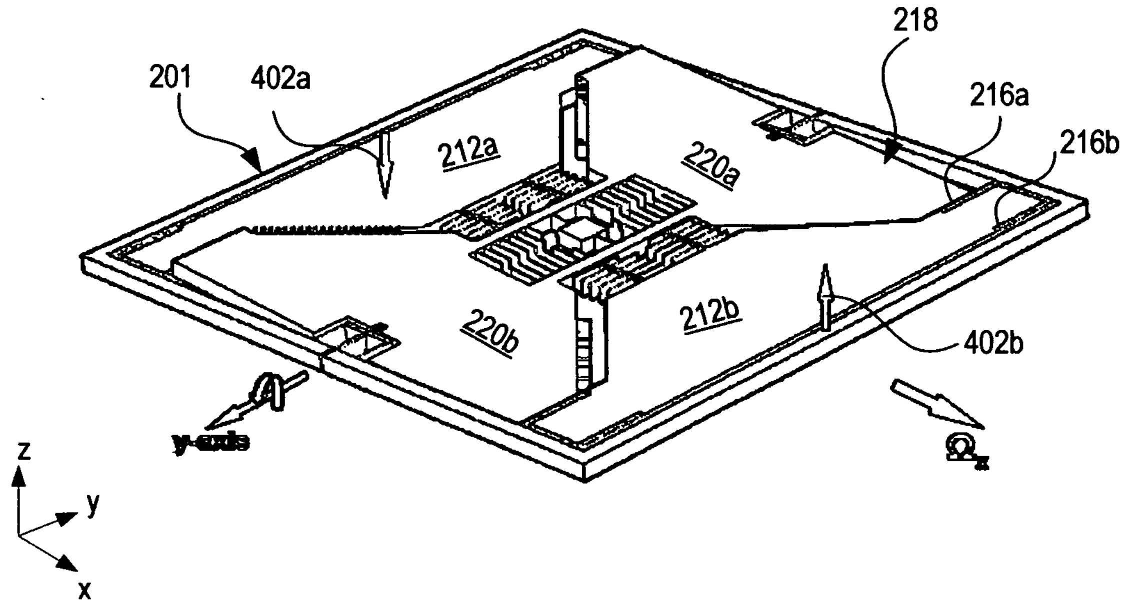
201
402a
218
216a
216b
212a
220a
220b
212b
402b
y-axis
Ω_x
z
y
x

FIG. 4B

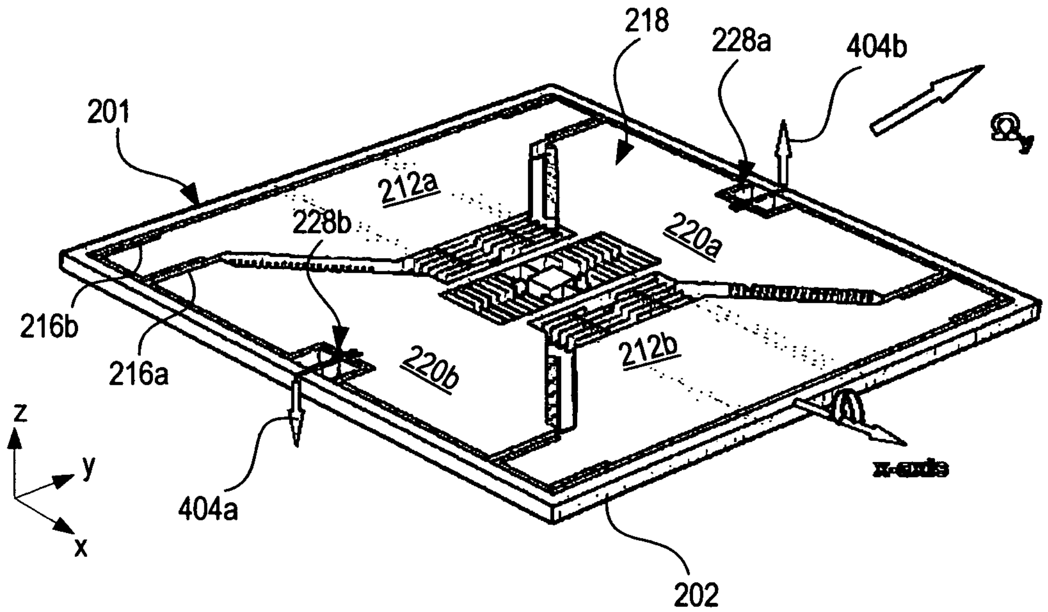
218
228a
404b
Ω_y
201
212a
228b
220a
216b
216a
220b
212b
z
y
x
404a
x-axis
202

FIG. 4C

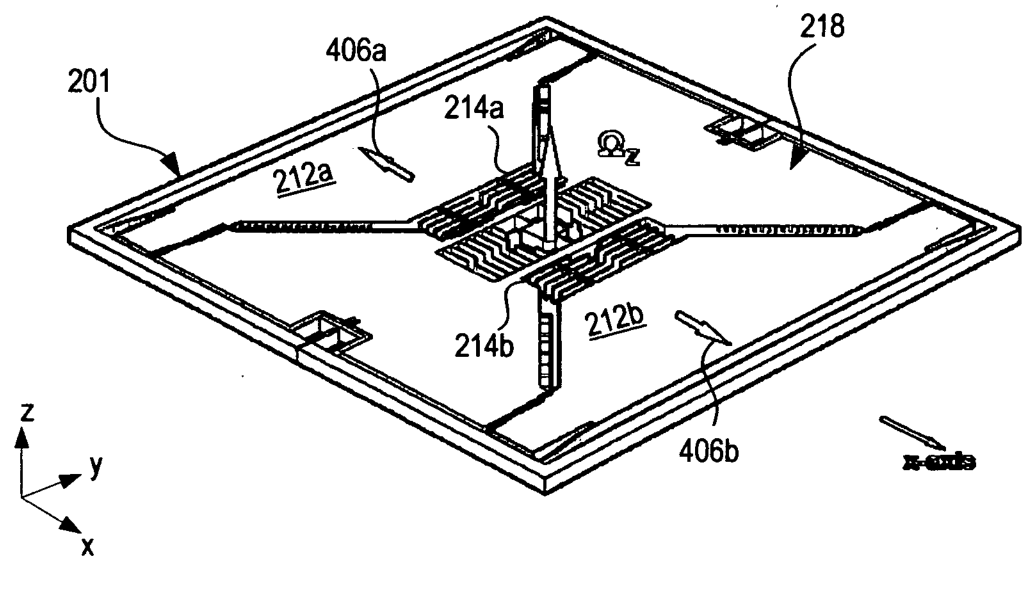
218
406a
201
214a
Ω_z
212a
214b
212b
z
y
x
406b
x-axis

FIG. 4D

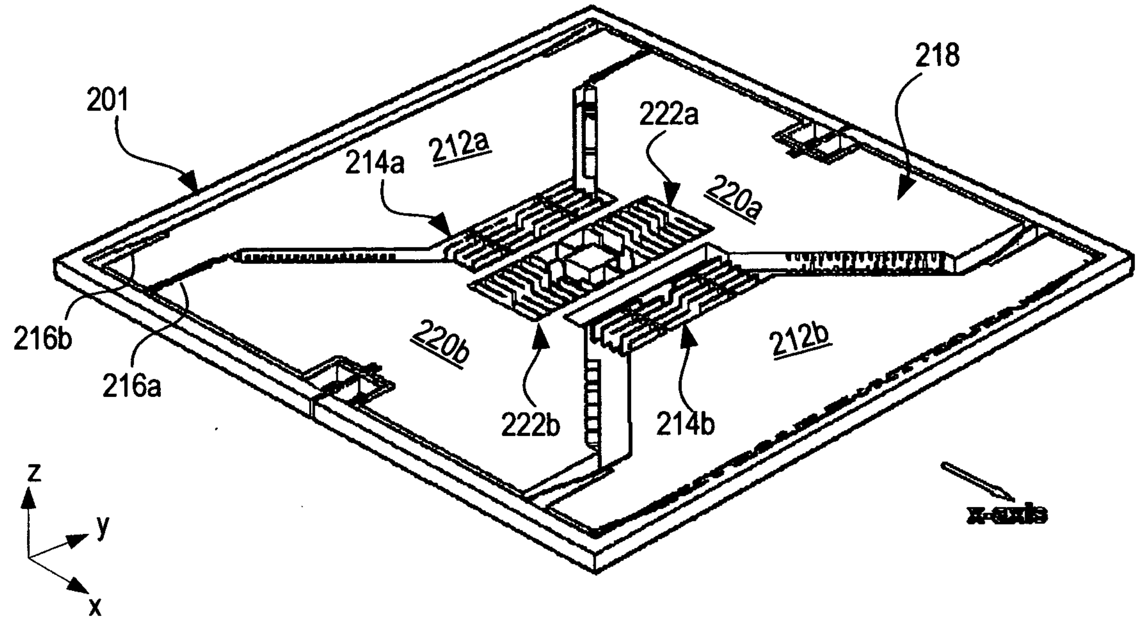
201
212a
214a
222a
220a
218
216b
216a
220b
222b
214b
212b
z
y
x
x-axis

FIG. 5A

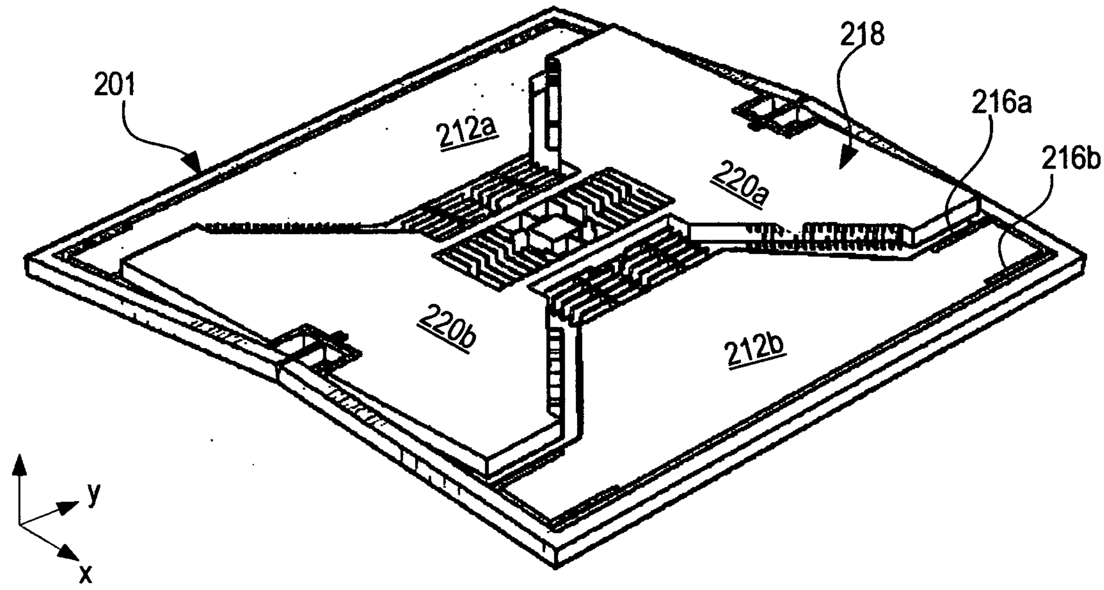
201
212a
218
220a
216a
216b
220b
212b
y
x

FIG. 5B

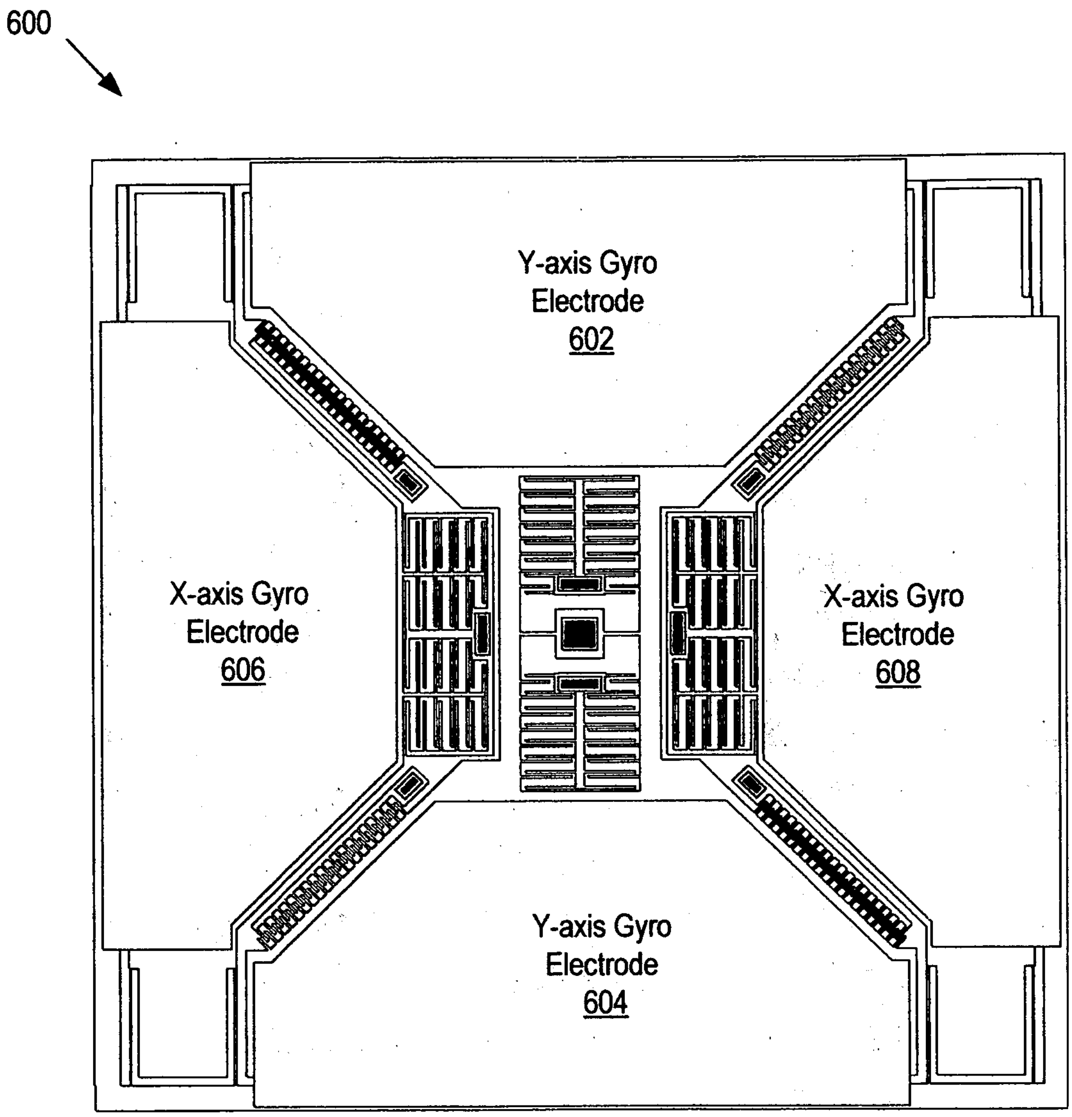
600
Y-axis Gyro
Electrode
602
X-axis Gyro
Electrode
606
X-axis Gyro
Electrode
608
Y-axis Gyro
Electrode
604

FIG. 6

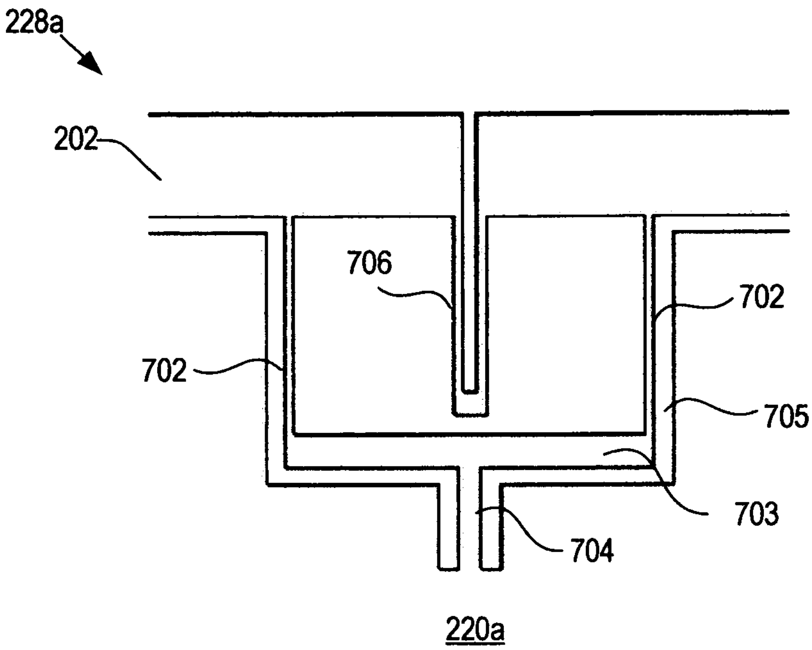
228a
202
706
702
702
705
703
704
220a

FIG. 7

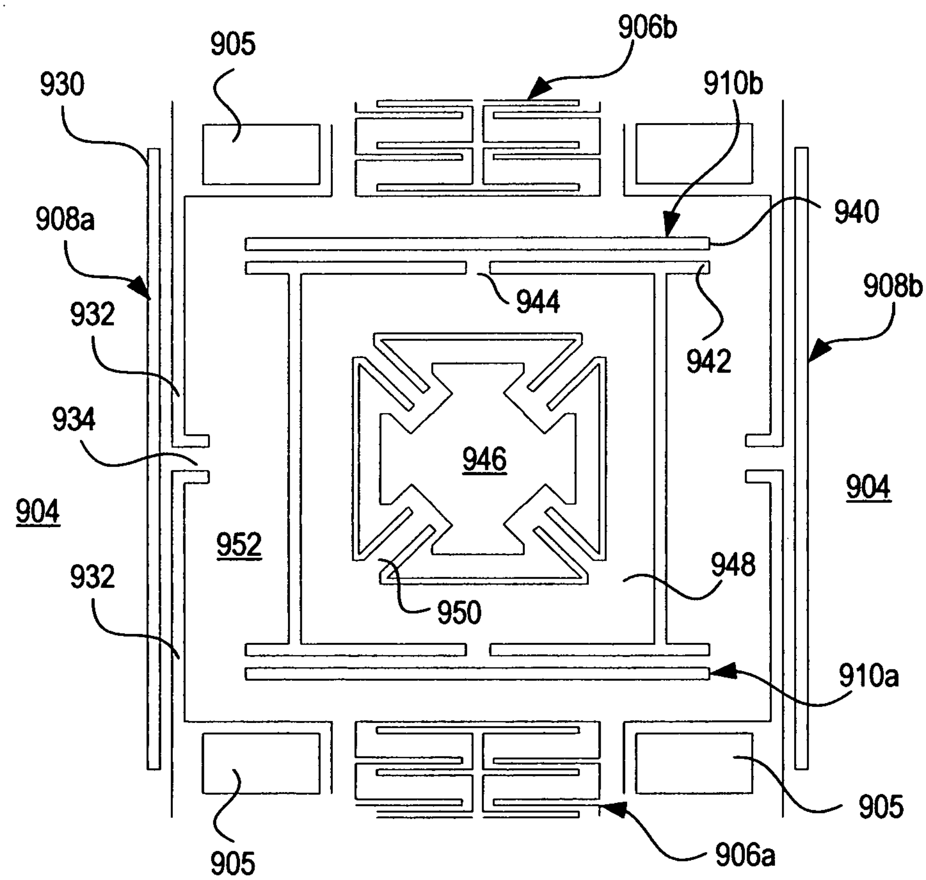
905
906b
930
910b
940
908a
944
942
908b
932
934
946
904
904
952
948
932
950
910a
905
905
906a

FIG. 9B

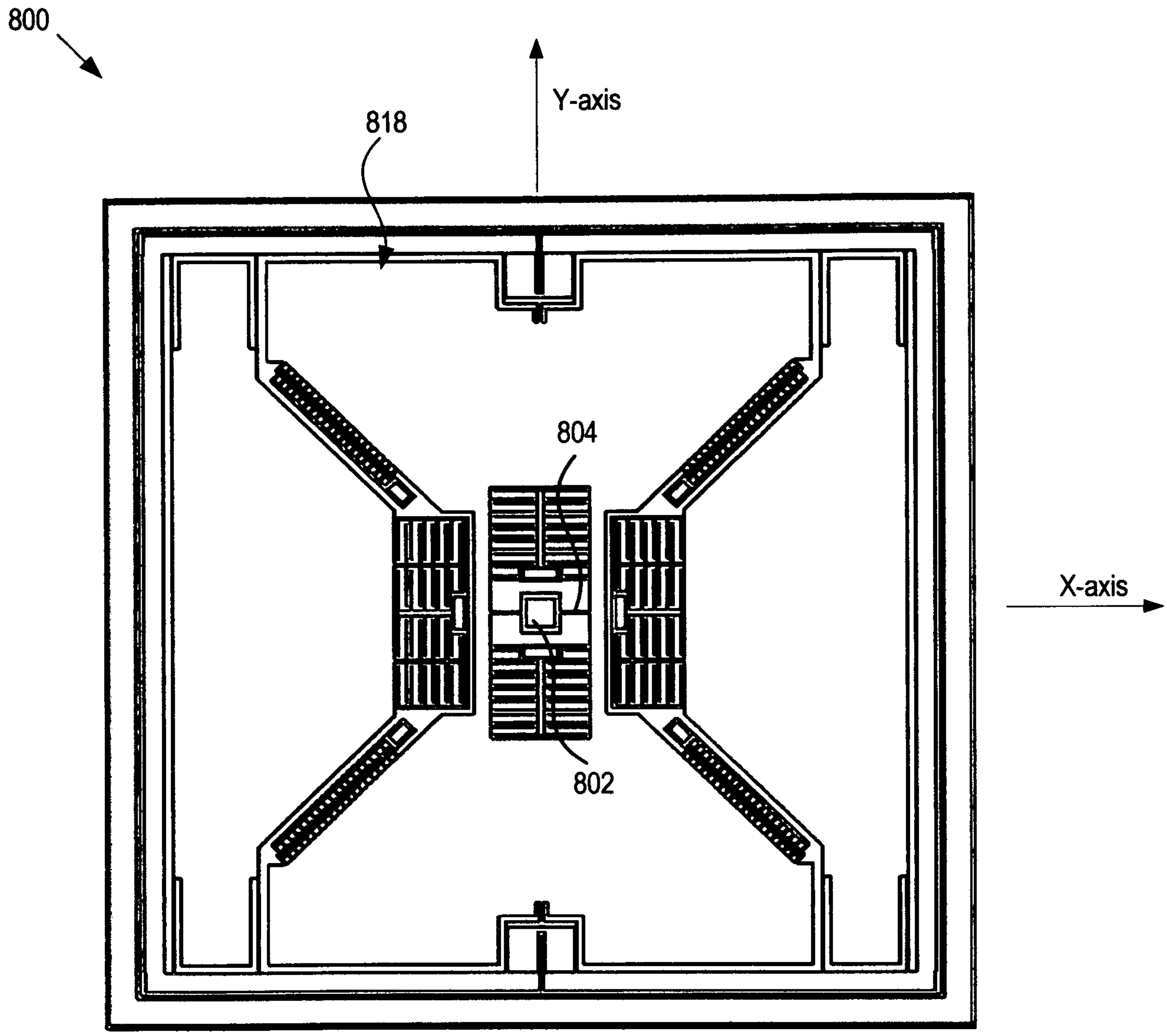

FIG. 8

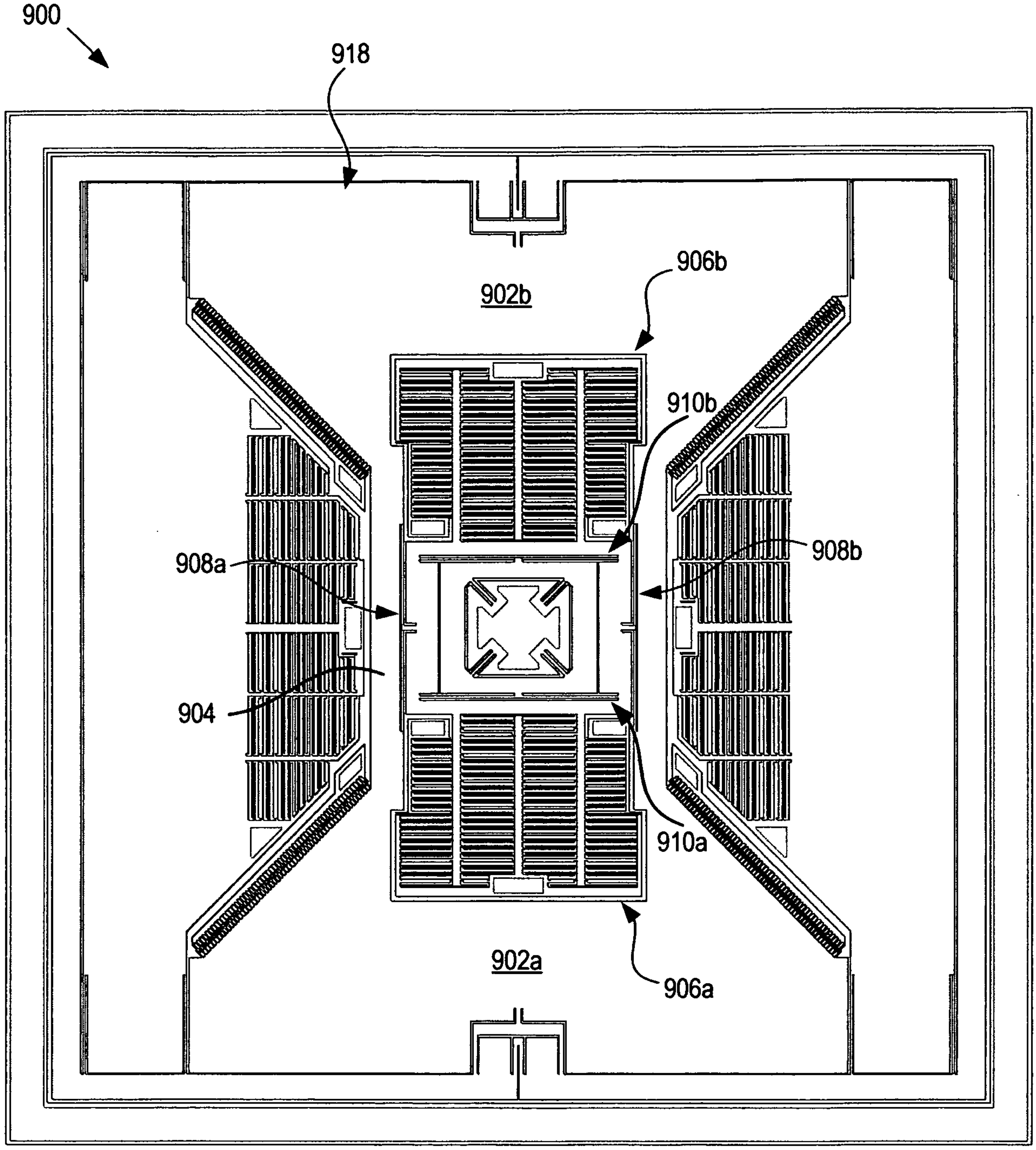

FIG. 9A