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(54) MICROELECTROMECHANICAL GYROSCOPE WITH FULLY DIFFERENTIAL STRUCTURE AND PITCH/ROLL SENSING

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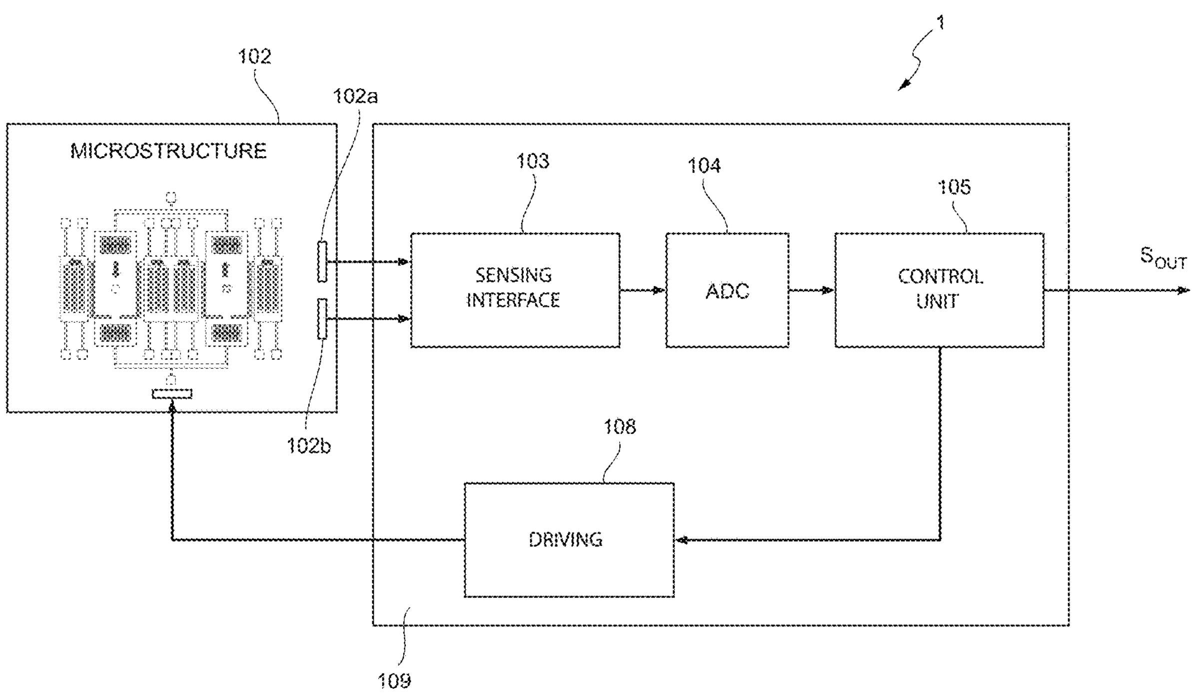
(57) **ABSTRACT**

A microelectromechanical gyroscope includes a support body having a main surface parallel to a reference plane defined by a first axis and a second axis perpendicular to each other. Transduction masses are constrained to the support body so as to be capable of oscillating along a driving direction parallel to the first axis and along a third axis perpendicular to the first axis and the second axis. Sensing masses are constrained to the support body at a distance from the substrate so as to be capable of oscillating in a direction parallel to the second axis. Motion conversion flexures connect the transduction masses to respective sensing masses and are configured so as to convert movements of the transduction masses along the third axis into movements of the respective sensing masses along the second axis.



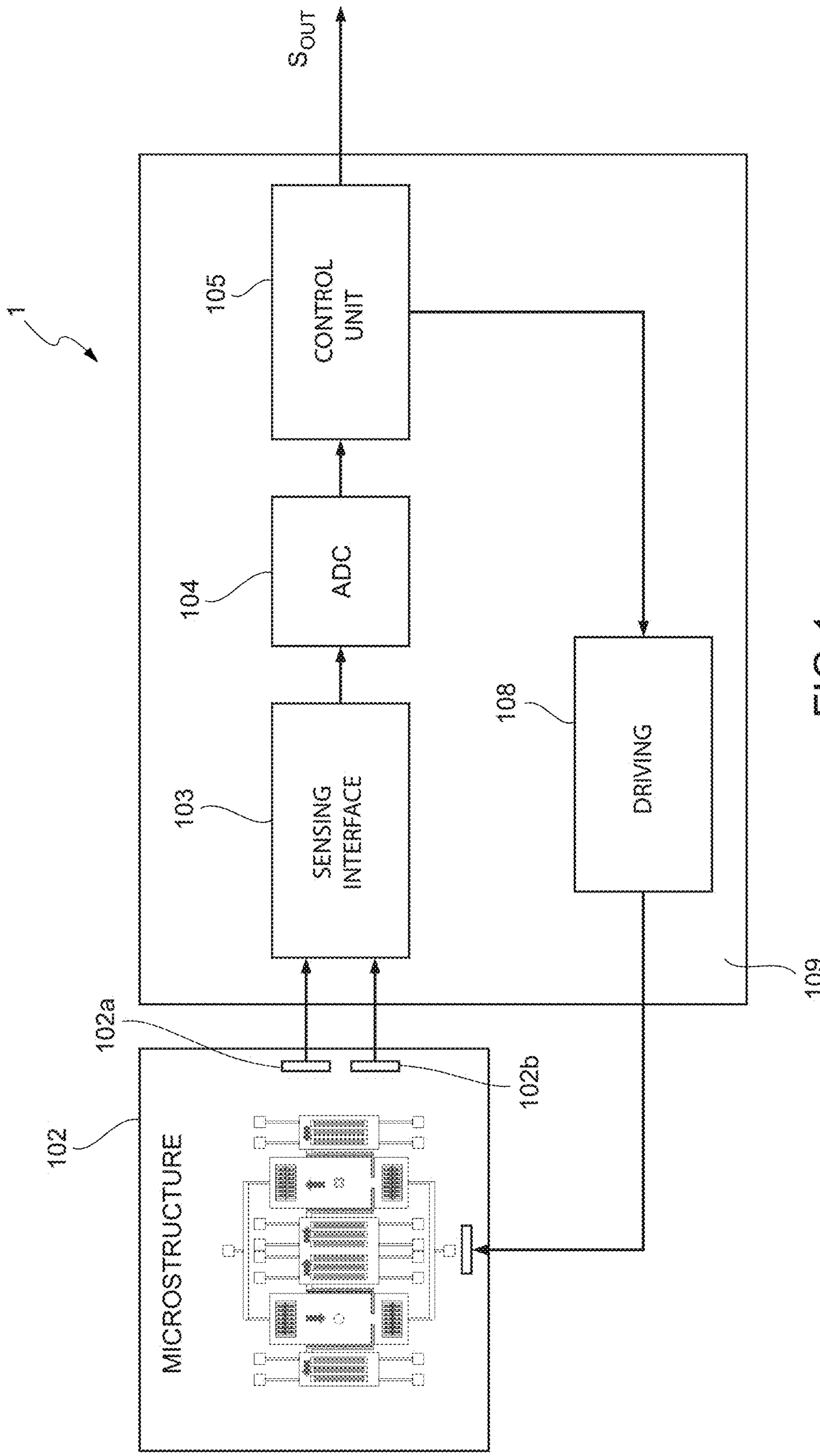

S_{OUT}
1
105
CONTROL UNIT
104
ADC
103
SENSING INTERFACE
108
DRIVING
109
102a
102b
102
MICROSTRUCTURE

FIG. 1

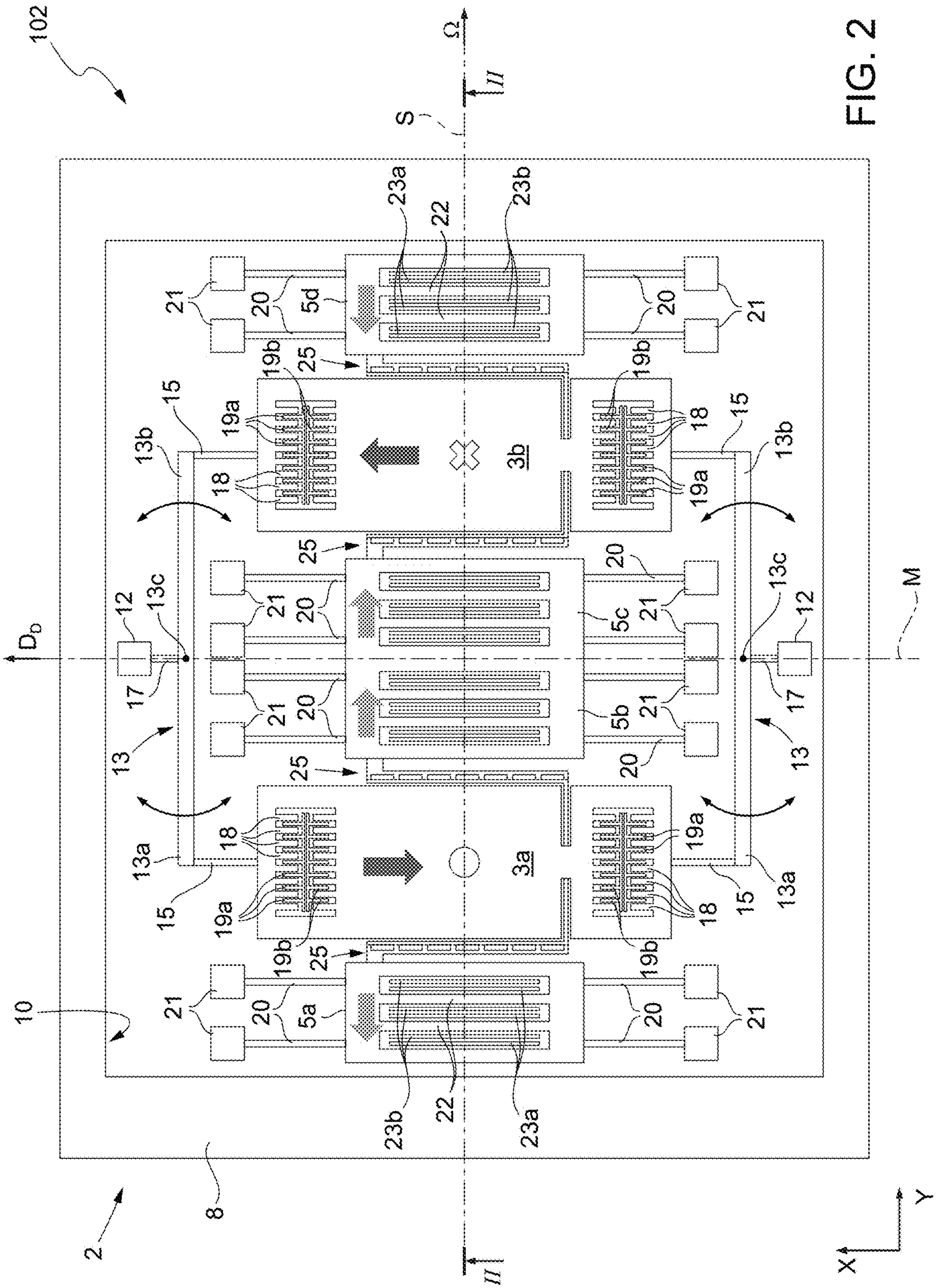


FIG. 2

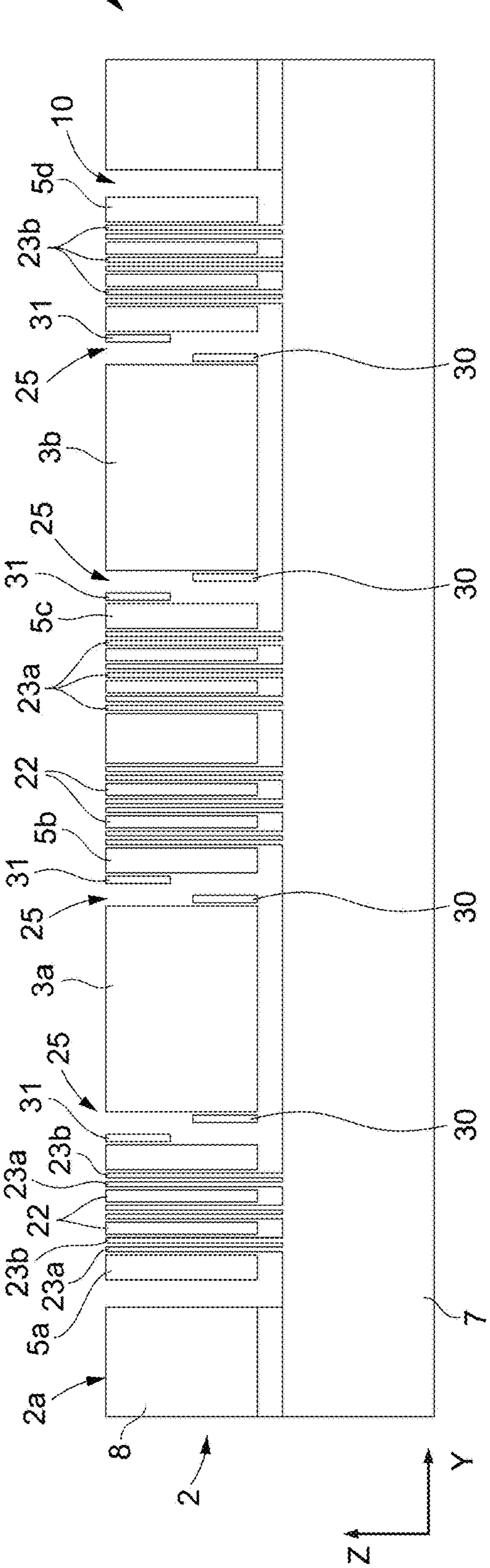

102
10
5d
23b
31
25
30
3b
25
31
5c
23a
22
5b
31
25
30
3a
25
31
30
23a
23b
22
23b
23a
5a
7
2a
8
2
Z
Y

FIG. 3

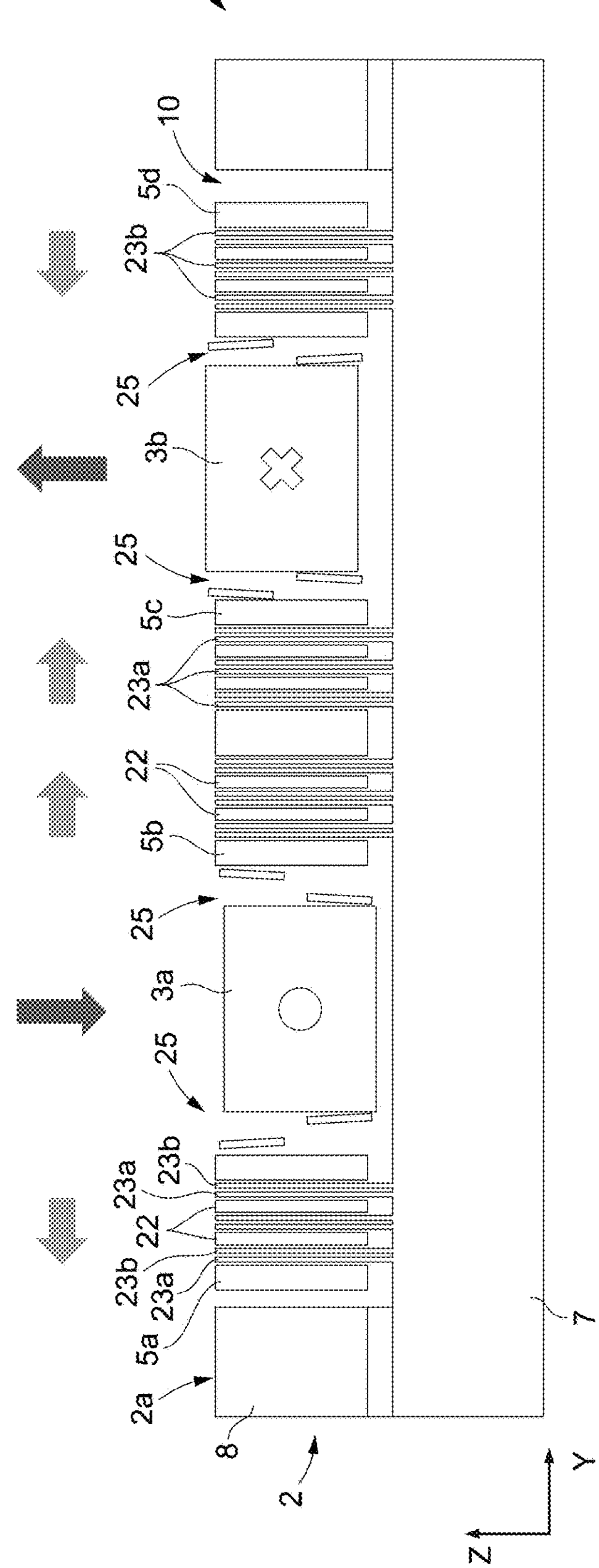

102
10
5d
23b
25
3b
25
5c
23a
22
5b
25
3a
25
23a
23b
22
23b
23a
5a
7
2a
8
2
Z
Y

FIG. 4

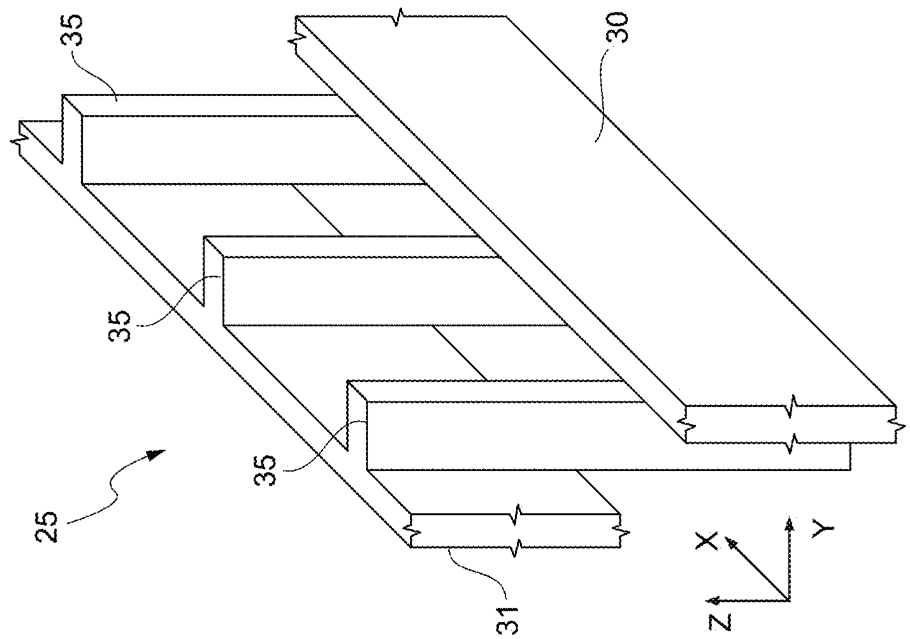


FIG. 6

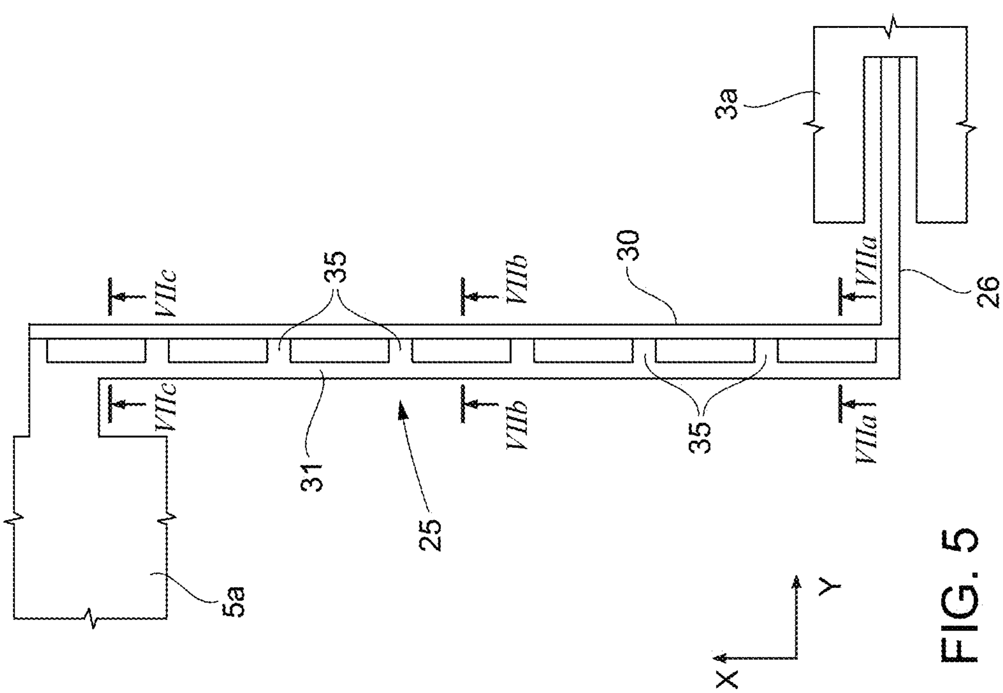


FIG. 5

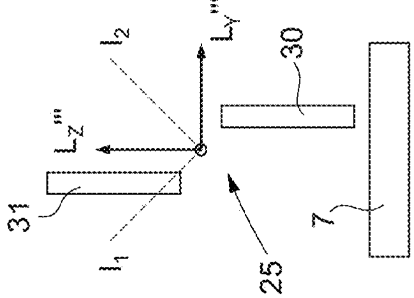


FIG. 7a

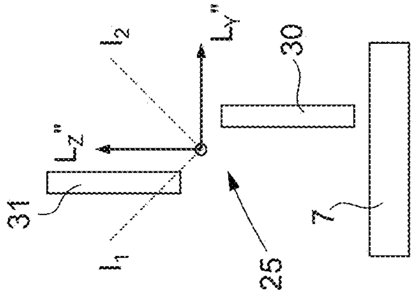


FIG. 7b

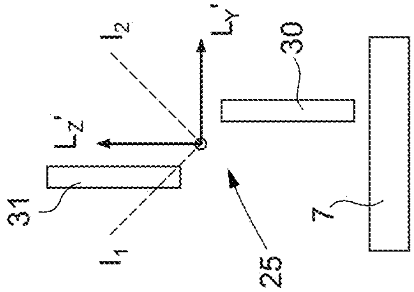


FIG. 7c

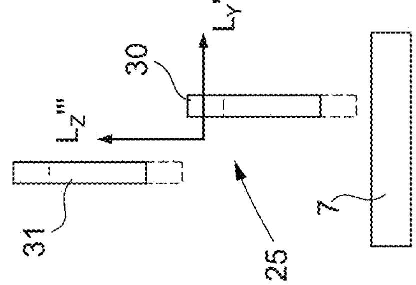


FIG. 8a

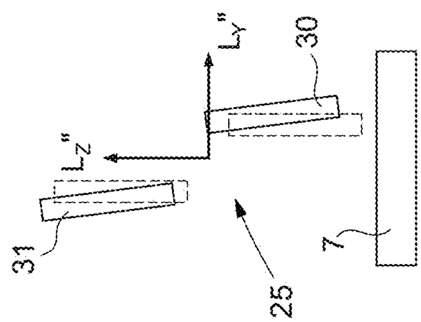


FIG. 8b

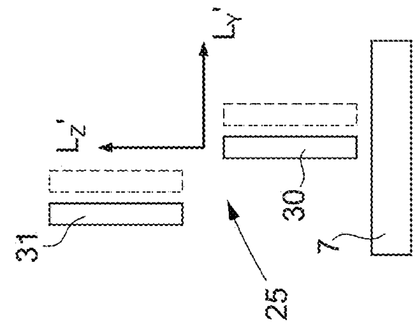


FIG. 8c

MICROELECTROMECHANICAL GYROSCOPE WITH FULLY DIFFERENTIAL STRUCTURE AND PITCH/ROLL SENSING

PRIORITY CLAIM

[0001] This application claims the priority benefit of Italian Application for Patent No. 102024000002890 filed on Feb. 12, 2024, the content of which is hereby incorporated by reference in its entirety to the maximum extent allowable by law.

TECHNICAL FIELD

[0002] This disclosure relates to a microelectromechanical gyroscope with fully differential structure and pitch/roll sensing.

BACKGROUND

[0003] As is known in the field of microelectromechanical gyroscopes, the design of the devices needs to meet increasingly stringent market demands, for example so as to the increase in scale factor stability and vibration rejection performance. Applications where scale factor stability and vibration rejection are particularly important include those relating to autonomous inertial navigation for the automotive sector. The scale factor defines the sensitivity of the gyroscope and should be stable during the life of the sensor. However, external factors such as variations in temperature (also during the production step due to soldering on printed circuit board—PCB) or humidity and mechanical stress may affect the scale factor and, consequently, the accuracy of the measurements.

[0004] In a MEMS gyroscope, the scale factor is directly correlated to the distance at rest between fixed or stator sensing electrodes and movable sensing electrodes. If the support body deforms, the distance at rest between fixed and movable sensing electrodes is altered and variations affect the sensitivity of the sensor.

[0005] A known solution to the scale factor stability issue envisages a fully differential sensing architecture that compensates for sensitivity variation. In a fully differential architecture, in fact, each movable sensing electrode is differentially coupled to two respective fixed sensing electrodes. This allows the pairs of fixed sensing electrodes to be placed at a short distance from the movable sensing electrode respectively associated, so as to reduce the effects of deformations of the support body. The rejection of common-mode contributions may thus be improved, and the differential contributions may thus be amplified.

[0006] This solution is easily practicable in gyroscopes that sense rotations around a yaw axis perpendicular to the support body and have a typically in-plane-type sensing structure. Gyroscopes that sense rotations around roll or pitch axes, instead, have an out-of-plane-type sensing structure and the available fully differential architectures may be less satisfactory in some respects. For the same silicon area occupied, in particular, the out-of-plane sensing structures have lower sensitivity with respect to in-plane sensing structures, because the sensing electrodes substantially develop in planes parallel to the main face of the support body. Conversely, in-plane sensing structures may generally also exploit the development of the sensing electrodes in a direction perpendicular to the support body. Furthermore, in-plane-type sensing structures still have fixed sensing electrodes that are on average closer and are therefore less subject to the effects of deformations of the support body, as already observed.

[0007] There is a need in the art to provide a microelectromechanical gyroscope which allows the limitations described to be overcome or at least mitigated.

SUMMARY

[0008] In an embodiment, a microelectromechanical gyroscope includes a support body having a main surface parallel to a reference plane defined by a first axis and a second axis perpendicular to each other. The gyroscope has a plurality of transduction masses constrained to the support body so as to be capable of oscillating along a driving direction parallel to the first axis and along a third axis perpendicular to the first axis and the second axis. The gyroscope has a plurality of sensing masses constrained to the support body at a distance from a substrate so as to be capable of oscillating in a direction parallel to the second axis. The gyroscope has a plurality of motion conversion flexures, each motion conversion flexure connecting one of the plurality of transduction masses to one of the plurality of sensing masses and configured to convert movements of the one of the plurality of transduction masses along the third axis into movements of the one of the plurality of sensing masses along the second axis.

[0009] The plurality of transduction masses may include a first transduction mass and a second transduction mass arranged symmetrically opposite to each other, in rest conditions, with respect to a reference axis parallel to the first axis. The gyroscope may include a plurality of first anchors fixed to the support body and a plurality of oscillating arms, each oscillating arm of the plurality of oscillating arms supported by one of the plurality of first anchors around a fulcrum so as to oscillate parallel to the reference plane, where the fulcrums are aligned along the reference axis in symmetrically opposite positions with respect to a median axis of the plurality of transduction masses parallel to the second axis. The first transduction mass and the second transduction mass may be supported by the plurality of oscillating arms so as to be movable parallel to the first axis and parallel to the third axis.

[0010] The plurality of oscillating arms may be coupled to the plurality of transduction masses so as to allow phase-opposition movements and prevent in-phase movements of the first transduction mass and the second transduction mass along the first axis. Each oscillating arm of the plurality of oscillating arms may have a first end connected to the first transduction mass and a second end connected to the second transduction mass through a plurality of first suspension flexures, where the plurality of first suspension flexures are configured to convey movements from the first and second ends of the plurality of oscillating arms to the first and second transduction masses in the direction of the first axis.

[0011] Each oscillating arm of the plurality of oscillating arms may be coupled to one of the plurality of first anchors with its fulcrum in a symmetrically opposite position with respect to the median axis. The gyroscope may include a plurality of second anchors and a plurality of second suspension flexures, where each sensing mass of the plurality of sensing masses is supported by one of the plurality of second anchors through one of the plurality of second suspension flexures, and where the plurality of second suspension

flexures are yielding in the direction of the second axis and rigid in the direction of the first axis and the third axis.

[0012] The plurality of sensing masses may include a first sensing mass and a second sensing mass coupled to the first transduction mass, and a third sensing mass and a fourth sensing mass coupled to the second transduction mass, where the first and second sensing masses are adjacent to opposite sides of the first transduction mass, and the third and fourth sensing masses are adjacent to opposite sides of the second transduction mass. The second sensing mass and the third sensing mass may form a single rigid body.

[0013] The motion conversion flexures connecting the first transduction mass to the first and second sensing masses may be configured to cause movements of the first and second sensing masses in phase-opposition in response to displacements of the first transduction mass along the third axis. The motion conversion flexures connecting the second transduction mass to the third and fourth sensing masses may be symmetrical to each other and may be configured to cause movements of the third and fourth sensing masses in phase-opposition in response to displacements of the second transduction mass along the third axis.

[0014] Each motion conversion flexure of the plurality of motion conversion flexures may have an elongated shape in the direction of the first axis, a first end connected to one of the plurality of transduction masses, and a second end connected to one of the plurality of sensing masses. The first end of each motion conversion flexure may be coupled to its associated transduction mass through a connection flexure that is rigid along the third axis and yielding along the driving direction parallel to the first axis.

[0015] The plurality of motion conversion flexures may be of a skew bending type. Each motion conversion flexure of the plurality of motion conversion flexures may include a first elastic body, a second elastic body, and a plurality of transverse elements. The first elastic body and the second elastic body may be defined by flat rectangular plates, in rest conditions perpendicular to the second axis and elongated in the direction of the first axis. The first elastic body and the second elastic body may be offset with respect to each other in the direction of the second axis and in the direction of the third axis.

[0016] The plurality of transverse elements may be defined by flat plates in rest conditions perpendicular to the first axis. The plurality of transverse elements may be uniformly spaced along the first axis. Each transverse element of the plurality of transverse elements may have a first side connected to the first elastic body and a second side, opposite to the first side, connected to the second elastic body.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] For a better understanding, embodiments are presented, by way of non-limiting example, with reference to the attached drawings, wherein:

[0018] FIG. **1** is a block diagram of a microelectromechanical gyroscope;

[0019] FIG. **2** is a top-plan view of a microstructure of the gyroscope of FIG. **1**;

[0020] FIG. **3** is a cross-section of the microstructure of FIG. **2**, taken along the line III-III of FIG. **2**, in a first operating configuration;

[0021] FIG. **4** shows the view of FIG. **3**, with the microstructure in a second operating configuration;

[0022] FIG. **5** is a top-plan view of an enlarged detail of the microstructure of FIG. **2**;

[0023] FIG. **6** is a partial perspective view of the detail of FIG. **5**;

[0024] FIGS. **7***a*-**7***c* are respectively a first, a second and a third cross-section of the detail of FIG. **5** in the first operating configuration; and

[0025] FIGS. **8***a*-**8***c* show the views respectively of FIGS. **7***a*-**7***c* in the second operating configuration.

DETAILED DESCRIPTION

[0026] The following description refers to the arrangement shown in the drawings; consequently, expressions such as "above", "below", "upper", "lower", "top", "bottom", "right", "left" and the like relate to the attached Figures and are not to be interpreted in a limiting manner.

[0027] With reference to FIG. **1**, a microelectromechanical gyroscope in accordance with an embodiment is indicated as a whole by the numeral **1** and comprises a microstructure **102**, a sensing interface **103**, an analog-to-digital converter **104**, a control unit **105** and a driving stage **108**. The sensing interface **103**, the analog-to-digital converter **104**, the control unit **105** and the driving stage **108** may be components of a dedicated integrated circuit or ASIC (Application Specific Integrated Circuit) **109** coupled to the microstructure **102**.

[0028] The sensing interface **103** receives sensing signals from a first sensing terminal **102***a* and a second sensing terminal **102***b* of the microstructure **2**, respectively, and provides amplified sensing signals, usable by the analog-to-digital converter **104** to generate digital sensing signals.

[0029] The control unit **105** processes the digital sensing signals and provides an output signal SOUT indicative of an angular velocity around a sensing axis (not shown), measured through the microstructure **102**.

[0030] The driving stage **108** is controlled by the control unit **105** and provides a driving voltage VD to maintain movable portions of the microstructure **102** oscillating with a driving frequency ωD that is constant and close to a resonance frequency of the same microstructure **102**.

[0031] With reference to FIGS. **2**-**4**, the microstructure **102** comprises a support body **2**, transduction masses **3***a*, **3***b* and sensing masses **5***a*-**5***d*, movable with respect to the support body **2**.

[0032] The support body **2** has a main surface **2***a* parallel to a plane XY defined by a first axis X and a second axis Y of a set of three Cartesian axes and perpendicular to a third axis Z of the set of three. The support body **2** may comprise, for example, a substrate **7** and a frame structure **8**, formed on the substrate **7** and laterally delimiting a cavity **10** where the transduction masses **3***a*, **3***b* and the sensing masses **5***a*-**5***d* are accommodated. The cavity **10** is also delimited at the bottom by the substrate **7**. The substrate **7** and the frame structure **8** are of semiconductor material, for example respectively monocrystalline and polycrystalline silicon.

[0033] The transduction masses **3***a*, **3***b* and the sensing masses **5***a*-**5***d*, also of semiconductor material, are elastically connected to the support body **2** so as to be capable of oscillating in accordance with respective predetermined degrees of freedom with respect to a reference axis M, which is parallel to the first axis X (and therefore to the main surface **2***a* of the support body **2**) and perpendicular to a sensing axis S. The sensing axis S is a median axis of the transduction masses **3**_a_, **3**_b_ (in rest conditions) and is parallel to the second axis Y.

[0034] In detail, the transduction masses comprise a first transduction mass **3**_a_ and a second transduction mass **3**_b_ arranged symmetrically opposite, in rest conditions, with respect to the reference axis M. The first transduction mass **3**_a_ and the second transduction mass **3**_b_ are suspended at a distance from the substrate **7** and are supported by anchors **12** and two oscillating arms **13** so as to be movable with respect to the support body along a driving direction DD parallel to the first axis X and along a transduction direction DT parallel to the third axis Z. In one embodiment, in particular, the anchors **12** are placed along the reference axis M and are symmetrically opposite to the sensing axis S. The oscillating arms **13**, having an elongated shape in the direction of the second axis Y, are also arranged symmetrically opposite with respect to the sensing axis S and each have a first end **13**_a_, a second end **13**_b_ and a fulcrum **13**_c_. The first ends **13**_a_ and the second ends **13**_b_ of the oscillating arms **13** are connected to the first transduction mass **3**_a_ and the second transduction mass **3**_b_, respectively, by suspension flexures **15** configured to convey movements from the ends **13**_a_, **13**_b_ of the oscillating arms **13** to the transduction masses **3**_a_, **3**_b_ in the direction of the first axis X. In the direction of the second axis Y, instead, the suspension flexures **15** are almost rigid and the deformations are limited to what is useful to accommodate the movements of the oscillating arms **13**. The fulcrums **13**_c_ of the oscillating arms **13** are coupled to the respective anchors **12** by suspension flexures **17** and are aligned along the reference axis M in positions symmetrically opposite with respect to the sensing axis S. The suspension flexures **17** are configured so that the oscillating arms **13** may oscillate in the plane XY parallel to the main surface **2**_a_ around the respective fulcrums **13**_a_. The suspension flexures **17** instead prevent the translation of the fulcrums **13**_c_ in a direction parallel to the first axis X. Consequently, the oscillating arms **13** coordinate and allow the phase-opposition or differential movement of the first transduction mass **3**_a_ and the second transduction mass **3**_b_ parallel to the first axis X (in practice, discordant displacements of equal amplitude, but in opposite directions along the first axis X). Conversely, in-phase or common-mode movements are prevented (i.e., the oscillating arms **13** prevent the first transduction mass **3**_a_ and the second transduction mass **3**_b_ from moving simultaneously in a concordant manner in the same direction along the first axis X).

[0035] The transduction masses **3**_a_, **3**_b_ are also provided with movable sensing electrodes **18**, capacitively coupled, for example in comb fingered configuration, to respective groups of fixed driving electrodes **19**_a_, **19**_b_ rigidly anchored to the support body **2**. In particular, the movable driving electrodes **18** and the fixed driving electrodes **19**_a_, **19**_b_ are shaped and coupled so as to apply, in response to the driving voltage VD provided by the driving stage **108**, electrostatic forces to the transduction masses **3**_a_, **3**_b_ oriented according to the first axis X, in the driving direction DD. The driving voltage VD is applied to the first transduction mass **3**_a_ and the second transduction mass **3**_b_ with opposite polarities, so that the electrostatic forces are also opposite and cause oscillations of the first transduction mass **3**_a_ and the second transduction mass **3**_b_ at the driving frequency and in phase-opposition. Due to the driving and the degrees of freedom, the transduction masses **3**_a_, **3**_b_ transduce rotations around the sensing axis S, which is parallel to the plane XY and perpendicular to the reference axis M, into movements along the transduction direction DT, parallel to the third axis Z. In other words, when the support body **2** rotates around the sensing axis with an angular velocity Ω, the transduction masses **3**_a_, **3**_b_ oscillate along the third axis Z at the driving frequency ωD and with an amplitude modulated by the angular velocity Ω.

[0036] The sensing masses, identical to each other, comprise a first sensing mass **5**_a_ and a second sensing mass **5**_b_, coupled to the first transduction mass **3**_a_, and a third sensing mass **5**_c_ and a fourth sensing mass **5**_d_, coupled to the second transduction mass **3**_b_. The first sensing mass **5**_a_ and the second sensing mass **5**_b_ are adjacent to respective opposite sides of the first transduction mass **3**_a_; similarly, the third sensing mass **5**_c_ and the fourth sensing mass **5**_d_ are adjacent to respective opposite sides of the second transduction mass **3**_b_. In the direction of the second axis Y, therefore, the first transduction mass **3**_a_ is interposed between the first sensing mass **5**_a_ and the second sensing mass **5**_b_; and the second transduction mass **3**_b_ is interposed between the third sensing mass **5**_c_ and the fourth sensing mass **5**_d_. The second sensing mass **5**_b_ and the third sensing mass **5**_c_ are further interposed between the first transduction mass **3**_a_ and the second transduction mass **3**_b_ and, in one embodiment, form a single rigid body.

[0037] The sensing masses **5**_a_-**5**_d_ are suspended at a distance from the substrate **7** and are supported by respective anchors **20** and suspension flexures **21**. In particular, the suspension flexures **21** are yielding in the direction of the second axis Y and substantially rigid in the direction of the first axis X and the third axis Z. As a result, the sensing masses **5**_a_-**5**_d_ are movable with respect to the support body **2** in the direction parallel to the second axis Y and the sensing axis S.

[0038] The sensing masses **5**_a_-**5**_d_ are provided with movable sensing electrodes **22** capacitively coupled to respective first fixed sensing electrodes **23**_a_ and second fixed sensing electrodes **23**_b_, which are rigidly anchored to the support body **2**. More precisely, the movable sensing electrodes **22** and the fixed sensing electrodes **23**_a_, **23**_b_ are defined by plates or flat surfaces perpendicular to the second axis Y and form capacitors having variable capacitance depending on the position of the sensing masses **5**_a_-**5**_d_ with respect to the second axis Y. Furthermore, the first fixed sensing electrodes **23**_a_ and the second fixed sensing electrodes **23**_b_ are coupled to the first sensing terminal **102**_a_ and the second sensing terminal **102**_b_ of the microstructure **102**, respectively.

[0039] The sensing masses **5**_a_-**5**_d_ are connected to the respective transduction masses **3**_a_, **3**_b_ through motion conversion flexures **25** having skew bending, configured so as to convert the motion of the transduction masses **3**_a_, **3**_b_ along the third axis Z into a motion of the sensing masses **5**_a_-**5**_d_ along the sensing axis S, i.e., in a direction parallel to the second axis Y. The skew bending is a strain to which a body may be subject when the axis of an applied moment does not coincide with a main axis of inertia. In this case, the inflection plane of the body does not coincide with the stress plane. The skew bending may be considered composed of two straight bendings having a moment axis coincident with a main axis of inertia.

[0040] The motion conversion flexures **25** have an elongated shape in the direction of the first axis X and each connect a respective transduction mass **3**_a_, **3**_b_ and a respective sensing mass **5***a*-**5***d*. More precisely, the motion conversion flexures **25** have a first end connected to the respective transduction mass **3***a*, **3***b* and a second end connected to the respective sensing mass **5***a*-**5***d*. Furthermore, the motion conversion flexures **25** connecting the first transduction mass **3***a* to the first sensing mass **5***a* and to the second sensing mass **5***b* are symmetrical to each other and are configured to cause movements of the first sensing mass **5***a* and the second sensing mass **5***b* in phase-opposition (i.e., of equal amplitude, but in opposite directions along the second axis Y) in response to displacements of the first transduction mass **3***a* along the third axis Z; similarly, the motion conversion flexures **25** connecting the second transduction mass **3***b* to the third sensing mass **5***c* and the fourth sensing mass **5***d* are symmetrical to each other and are configured to cause movements of the third sensing mass **5***c* and the fourth sensing mass **5***d* in phase-opposition in response to movements of the second transduction mass **3***b* along the third axis Z. Furthermore, the motion conversion flexures **25** which connect the second sensing mass **5***b* to the first transduction mass **3***a* and the third sensing mass **5***c* to the second transduction mass **3***b* are symmetrical to each other with respect to the reference axis M (in rest conditions).

[0041] In detail, in one embodiment the first ends of the motion conversion flexures **25** are coupled to the respective transduction masses **3***a*, **3***b* through connection flexures **26**, yielding in the direction of the first axis X and rigid in the direction of the second axis Y and the third axis Z. In practice, the connection flexures **26** convey the movement of the transduction masses **3***a*, **3***b* along the third axis Z to the first ends of the respective motion conversion flexures **25** in an almost rigid manner. The first ends of the motion conversion flexures **25** therefore follow the movement of the respective transduction masses **3***a*, **3***b* along the transduction direction DT and the third axis Z. The connection flexures **26** instead allow the relative movement of the transduction masses **3***a*, **3***b* with respect to the motion conversion flexures **25** along the driving direction DD, parallel to the first axis X. The transduction masses **3***a*, **3***b* may therefore oscillate due to the driving along the first axis X without altering the state of the motion conversion flexures **25**, while the motion along the third axis Z is conveyed and converted into a corresponding motion along the sensing axis S, in a direction parallel to the second axis Y. Recesses **28** obtained in the sides of the transduction masses **3***a*, **3***b* and extending longitudinally in the direction of the second axis Y accommodate part of the connection flexures **26**, which may therefore have the desired length and yielding in accordance with the design preferences.

[0042] In rest conditions, the first ends of the motion conversion flexures **25** are aligned in a direction parallel to the second axis Y.

[0043] Both by arrangement and by action of the motion conversion flexures **25**, the sensing masses **5***a*-**5***d*, the movable sensing electrodes **22** and the fixed sensing electrodes **23***a*, **23***b* form a fully differential sensing structure of in-plane type.

[0044] For example, the motion conversion flexures **25** may be formed substantially as described in U.S. Pat. No. 11,993,509 (corresponding to European Patent No. 3,872, 451), in the name of the Applicant, the contents of both of which are incorporated by reference in their entirety. Hereinafter, for simplicity, reference will be made to only one of the motion conversion flexures **25**, for example the one connecting the first transduction mass **3***a* to the first sensing mass **5***a*, meaning however that what has been stated also applies to all the others.

[0045] With reference also to FIGS. **5** and **6**, the motion conversion flexure **25** comprises a first elastic body **30**, a second elastic body **31** and a plurality of transverse elements **35**, all of which are formed for example of the same semiconductor material as the substrate **7** and the frame structure **8** and form a single piece.

[0046] The first elastic body **30** and the second elastic body **31** are defined by flat rectangular plates of the same shape, in rest conditions perpendicular to the second axis Y and elongated in the direction of the first axis X. The first elastic body **30** and the second elastic body **31** are offset with respect to each other both in the direction of the second axis Y and in the direction of the third axis Z. For example, the first elastic body **30** extends adjacent to the respective transduction mass **3***a*, **3***b* (for example the first transduction mass **3***a*, as in FIG. **6**) and at a greater distance from the respective sensing mass **5***a*-**5***d* (for example the first sensing mass **5***a*); vice versa, the second elastic body **31** extends adjacent to the respective sensing mass **5***a*-**5***d* (here the first sensing mass **5***a*) and at a greater distance from the respective transduction mass **3***a*, **3***b* (here the first transduction mass **3***a*). Furthermore, the first elastic body **30** is closer to the substrate **7** than the second elastic body **31** (see also FIG. **3**). For example, a lower edge of the first elastic body **30** is aligned in rest conditions, to a face of the first transduction mass **3***a* arranged facing the substrate **7**; an upper edge of the second elastic body **31** is aligned with a face of the first sensing mass **5***a* arranged facing outwards. The first elastic body **30** and the second elastic body **31** have dimension, along the third axis Z, smaller than the transduction masses **3***a*, **3***b* and the sensing masses **5***a*-**5***d*. The first elastic body **30** is connected to the respective connection flexure **26** at the first end of the motion conversion flexure **25**; the second elastic body **31** is connected to the respective sensing mass **5***a*-**5***d* (here the first sensing mass **5***a*) at the second end of the motion conversion flexure **25**.

[0047] The transverse elements **35** are defined by flat plates of the same shape, for example rectangular, in rest conditions perpendicular to the first axis X. The elements are uniformly spaced along the first axis X and have first sides connected to the first elastic body **30** and second sides, opposite to the first sides, connected to the second elastic body **31**.

[0048] FIGS. **7***a*-**7***c* show, by way of example, cross-sections of the motion conversion flexure **25** along planes parallel to the plane YZ at the first end, at a median portion and at the second end, respectively. In each of the FIGS. **7***a*-**7***c* the main axes of inertia I**1**, I**2** of the corresponding section of the first motion conversion flexure **25** are also shown, in the hypothesis that this section has infinitesimal thickness. In rest conditions, in particular, the main axes of inertia I**1**, I**2** have a same orientation in each section and are misaligned and transverse with respect to both the second axis Y and the third axis Z. FIGS. **7***a*-**7***c* also show, in rest conditions, pairs of local axes (indicated respectively by Ly'-Lz', Ly"-Lz" and Ly'"-Lz'"), each pair being formed by axes parallel to the second axis Y and the third axis Z, respectively, and passing through the barycenter of the section shown.

[0049] For each section of the first motion conversion flexure **25**, a centrifugal moment of inertia Ic may be calculated, with respect to the corresponding pair of local axes, through the integral:

$$I_C = \int\int r_1 r_2 dA$$

[0050] where r**1** and r**2** represent the distance of each point of the section from a first and a second axis of the pair of local axes respectively, while dA is the area unit of the section. The centrifugal moment of inertia Ic is non-zero, since the local axes are not axes of symmetry of the section and therefore do not coincide with the main axes of inertia **I1**, **I2**. In particular, the main axes of inertia **I1**, **I2** form an angle β with the local axis parallel to the third axis Z and with the local axis parallel to the second axis Y, respectively.

[0051] Consequently, as may be seen in FIGS. **8***a*-**8***c*, a force applied on the motion conversion flexure **25**, for example along the local axis Lz", causes a skew bending of the motion conversion flexure **25**. In particular, this force causes a deformation along the local axis Lz", which entails a resulting deformation along the local axis Ly". Compared to the rest positions, represented with a dashed line, in response to a displacement of the first end of the motion conversion flexure **25** along the third axis Z (FIG. **7***a*), the skew bending causes a rototranslation of the median section (FIG. **7***b*) and the translation of the second end in the direction of the second axis Y. Due to the skew bending, the motion along the third axis Z caused by the transduction masses **3***a*, **3***b* to the first ends of the motion conversion flexures **25** in response to a rotation around the sensing axis S is converted into a corresponding motion along the second axis Y of the second ends of the motion conversion flexures **25** and therefore of the sensing masses **5***a*-**5***d*.

[0052] The constraints represented by the suspension flexures **17**, **21** and by the connection flexures **26** favor the skew bending of the motion conversion flexures **25** and facilitate the correct movement of the sensing masses **5***a*-**5***d*.

[0053] When the support body **2** rotates around the sensing axis S, the transduction masses **3***a*, **3***b* oscillate along the transduction direction DT and the third axis Z at the driving frequency ωD, in phase-opposition (i.e., in opposite directions) and with amplitude proportional to the angular velocity Ω. The motion conversion flexures **25** convert the oscillations of the transduction masses **3***a*, **3***b* along the third axis Z into corresponding oscillations of the sensing masses **5***a*-**5***d* along the second axis Y, which may be read through the capacitive coupling between the movable sensing electrodes **22** and fixed sensing electrodes **23***a*, **23***b*. In more detail, the first sensing mass **5***a* and the second sensing mass **5***b* oscillate in phase-opposition with each other, as well as the third sensing mass **5***c* and the fourth sensing mass **5***d*. Furthermore, the first sensing mass **5***a* and the fourth sensing mass **5***d* oscillate in-phase with each other. Similarly, the second sensing mass **5***b* and the third sensing mass **5***c* oscillate in-phase with each other both due to the action of the motion conversion flexures **25** and, in addition, obviously due to the fact that they are constrained to each other to form a single rigid body. The movement of the second sensing mass **5***b* and the third sensing mass **5***c* would still be in-phase even in the absence of a rigid constraint therebetween.

[0054] The gyroscope described herein may therefore be used to sense rotations around pitch or roll axes of the support body, in addition implementing also a fully differential structure in the plane thanks to the conversion of the out-of-plane motion of the transduction masses **3***a*-**3***b* into the in-plane motion of the sensing masses **5***a*-**5***d*. This therefore allows the advantages of fully differential structures to be extended also to gyroscopes wherein the transduction of the rotation originally generates an out-of-plane movement (in fact, when rotations around pitch or roll axes are sensed). In particular, the gyroscope described herein allows improvement of the rejection of common-mode contributions and the stability of the scale factor following external events, such as thermal or mechanical stresses, that may deform the substrate.

[0055] Finally, it is clear that modifications and variations may be made to the gyroscope described and illustrated herein without thereby departing from the scope of this disclosure, as defined in the attached claims.

1. A microelectromechanical gyroscope, comprising:

a support body having a main surface parallel to a reference plane defined by a first axis and a second axis perpendicular to each other;

a plurality of transduction masses constrained to the support body so as to be capable of oscillating along a driving direction parallel to the first axis and along a third axis perpendicular to the first axis and the second axis;

a plurality of sensing masses constrained to the support body at a distance from a substrate so as to be capable of oscillating in a direction parallel to the second axis; and

a plurality of motion conversion flexures, each motion conversion flexure connecting one of the plurality of transduction masses to one of the plurality of sensing masses and configured to convert movements of the one of the plurality of transduction masses along the third axis into movements of the one of the plurality of sensing masses along the second axis.

2. The microelectromechanical gyroscope according to claim **1**, wherein the plurality of transduction masses comprise a first transduction mass and a second transduction mass arranged symmetrically opposite to each other, in rest conditions, with respect to a reference axis parallel to the first axis.

3. The microelectromechanical gyroscope according to claim **2**, comprising:

a plurality of first anchors fixed to the support body; and

a plurality of oscillating arms, each oscillating arm of the plurality of oscillating arms supported by one of the plurality of first anchors around a fulcrum so as to oscillate parallel to the reference plane, wherein the fulcrums are aligned along the reference axis in symmetrically opposite positions with respect to a median axis of the plurality of transduction masses parallel to the second axis;

wherein the first transduction mass and the second transduction mass are supported by the plurality of oscillating arms so as to be movable parallel to the first axis and parallel to the third axis.

4. The microelectromechanical gyroscope according to claim **3**, wherein the plurality of oscillating arms are coupled to the plurality of transduction masses so as to allow phase-opposition movements and prevent in-phase movements of the first transduction mass and the second transduction mass along the first axis.

5. The microelectromechanical gyroscope according to claim **3**, wherein each oscillating arm of the plurality of oscillating arms has:

a first end connected to the first transduction mass; and

a second end connected to the second transduction mass through a plurality of first suspension flexures, wherein the plurality of first suspension flexures are configured to convey movements from the first and second ends of the plurality of oscillating arms to the first and second transduction masses in the direction of the first axis.

6. The microelectromechanical gyroscope according to claim **3**, wherein each oscillating arm of the plurality of oscillating arms is coupled to one of the plurality of first anchors with its fulcrum in a symmetrically opposite position with respect to the median axis.

7. The microelectromechanical gyroscope according to claim **3**, comprising:

a plurality of second anchors; and

a plurality of second suspension flexures;

wherein each sensing mass of the plurality of sensing masses is supported by one of the plurality of second anchors through one of the plurality of second suspension flexures, and wherein the plurality of second suspension flexures are yielding in the direction of the second axis and rigid in the direction of the first axis and the third axis.

8. The microelectromechanical gyroscope according to claim **2**, wherein the plurality of sensing masses comprise:

a first sensing mass and a second sensing mass coupled to the first transduction mass; and

a third sensing mass and a fourth sensing mass coupled to the second transduction mass;

wherein the first and second sensing masses are adjacent to opposite sides of the first transduction mass, and the third and fourth sensing masses are adjacent to opposite sides of the second transduction mass.

9. The microelectromechanical gyroscope according to claim **8**, wherein the second sensing mass and the third sensing mass form a single rigid body.

10. The microelectromechanical gyroscope according to claim **8**, wherein:

the motion conversion flexures connecting the first transduction mass to the first and second sensing masses are configured to cause movements of the first and second sensing masses in phase-opposition in response to displacements of the first transduction mass along the third axis; and

the motion conversion flexures connecting the second transduction mass to the third and fourth sensing masses are symmetrical to each other and are configured to cause movements of the third and fourth sensing masses in phase-opposition in response to displacements of the second transduction mass along the third axis.

11. The microelectromechanical gyroscope according to claim **8**, wherein each motion conversion flexure of the plurality of motion conversion flexures has:

an elongated shape in the direction of the first axis;

a first end connected to one of the plurality of transduction masses; and

a second end connected to one of the plurality of sensing masses.

12. The microelectromechanical gyroscope according to claim **11**, wherein the first end of each motion conversion flexure is coupled to its associated transduction mass through a connection flexure that is rigid along the third axis and yielding along the driving direction parallel to the first axis.

13. The microelectromechanical gyroscope according to claim **1**, wherein the plurality of motion conversion flexures are of a skew bending type.

14. The microelectromechanical gyroscope according to claim **1**, wherein each motion conversion flexure of the plurality of motion conversion flexures comprises:

a first elastic body;

a second elastic body; and

a plurality of transverse elements;

wherein:

the first elastic body and the second elastic body are defined by flat rectangular plates, in rest conditions perpendicular to the second axis and elongated in the direction of the first axis; and

the first elastic body and the second elastic body are offset with respect to each other in the direction of the second axis and in the direction of the third axis.

15. The microelectromechanical gyroscope according to claim **11**, wherein each motion conversion flexure of the plurality of motion conversion flexures comprises:

a first elastic body;

a second elastic body; and

a plurality of transverse elements;

wherein:

the first elastic body and the second elastic body are defined by flat rectangular plates, in rest conditions perpendicular to the second axis and elongated in the direction of the first axis; and

the first elastic body and the second elastic body are offset with respect to each other in the direction of the second axis and in the direction of the third axis; and

wherein for each motion conversion flexure of the plurality of motion conversion flexures:

the first elastic body is connected to the associated transduction mass at the first end of the motion conversion flexure; and

the second elastic body is connected to the associated sensing mass at the second end of the motion conversion flexure.

16. The microelectromechanical gyroscope according to claim **14**, wherein:

the plurality of transverse elements are defined by flat plates in rest conditions perpendicular to the first axis;

the plurality of transverse elements are uniformly spaced along the first axis; and

each transverse element of the plurality of transverse elements has a first side connected to the first elastic body and a second side, opposite to the first side, connected to the second elastic body.

17. The microelectromechanical device according to claim **15**, wherein each actuator comprises:

fixed electrodes anchored to the substrate; and

movable electrodes interdigitated with the fixed electrodes to form capacitive coupling elements.

18. The microelectromechanical device according to claim **17**, wherein:

the first pair of actuators comprises rows of the capacitive coupling elements offset along a first direction; and

the second pair of actuators comprises rows of the capacitive coupling elements offset along a second direction perpendicular to the first direction.

19. The microelectromechanical device according to claim **17**, wherein a capacitance value of each actuator depends on displacement along a single coordinate axis parallel to the substrate.

20. The microelectromechanical device according to claim **17**, wherein each actuator comprises multiple rows of the capacitive coupling elements, with fixed and movable electrodes in each row being offset from each other along a direction perpendicular to the row's direction.

21. A method of operating a microelectromechanical gyroscope, comprising:

driving first and second transduction masses to oscillate in phase-opposition along a driving direction parallel to a first axis at a driving frequency;

in response to rotation of the microelectromechanical gyroscope about a sensing axis parallel to a second axis perpendicular to the first axis, generating out-of-plane motion of the first and second transduction masses along a third axis perpendicular to both the first and second axes;

converting, through motion conversion flexures, the out-of-plane motion of the first and second transduction masses along the third axis into in-plane motion of sensing masses along the second axis; and

sensing the in-plane motion of the sensing masses through a differential sensing structure to determine an angular velocity of the rotation.

22. The method according to claim **21**, wherein:

the sensing masses comprise first and second sensing masses coupled to the first transduction mass and third and fourth sensing masses coupled to the second transduction mass; and

converting the out-of-plane motion comprises:

converting motion of the first transduction mass to cause the first and second sensing masses to move in phase-opposition along the second axis; and

converting motion of the second transduction mass to cause the third and fourth sensing masses to move in phase-opposition along the second axis.

23. The method according to claim **22**, wherein:

the first sensing mass and the fourth sensing mass move in-phase with each other along the second axis; and

the second sensing mass and the third sensing mass move in-phase with each other along the second axis.

24. The method according to claim **21**, wherein converting the out-of-plane motion comprises:

applying a force to a first end of each motion conversion flexure to cause skew bending of the motion conversion flexure; and

generating, through the skew bending, a displacement of a second end of each motion conversion flexure along the second axis in response to displacement of the first end along the third axis.

25. The method according to claim **24**, wherein:

each motion conversion flexure comprises a first elastic body and a second elastic body offset from each other in the direction of the second axis and the third axis; and

the skew bending comprises deformation of the first and second elastic bodies along main axes of inertia that are misaligned with the second and third axes.

26. The method according to claim **21**, further comprising:

applying a driving voltage to the first and second transduction masses with opposite polarities to generate electrostatic forces causing the phase-opposition oscillation along the first axis.

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