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Re: JPH0942973A

To Whom It May Concern:

This is to certify that the above-referenced documents (**390-45460_JPH0942973A_JA into EN**) have been translated from Japanese into English by a professional translator on our staff who is skilled in the Japanese language.

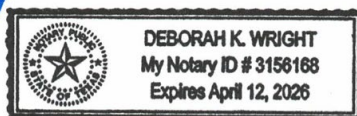
The English translation conforms essentially to the original Japanese except for those words or phrases for which there are no equivalents. Such words or phrases are noted in the translation along with the best English meaning.

All statements made in this declaration of our own knowledge are true, and all statements made on information and belief are believed to be true. We certify these statements under the understanding that willful false statements and the like are punishable by fine or imprisonment, or both (18 U.S.C. 1001). To the best of our knowledge, the aforementioned documents are a true, full, and accurate translation into English of the specified document.

Tonja Shepard
TONJA SHEPARD

Subscribed and sworn to before me on September 1, 2023.

Deborah K. Wright
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My commission expires on April 12, 2026

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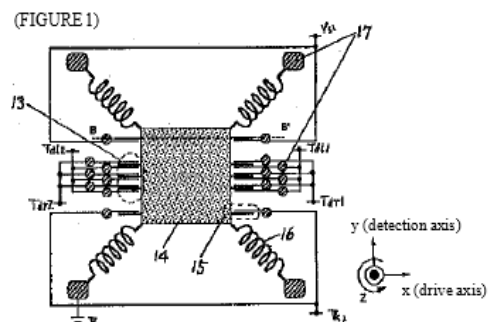
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(54) [Title of Invention] ANGULAR VELOCITY SENSOR

(57) [Abstract]

[Problem] To mass-produce and provide at low cost a compact and lightweight angular velocity sensor which is not susceptible to the effects of noise acceleration and other types of noise and achieves high sensitivity and high precision using semiconductor technology.

[Solution] The present invention comprises a substrate; a vibrating mass, which is formed so as to be isolated from a main surface of the substrate, and which vibrates in first and second orthogonal axial directions; at least two supports which support the vibrating mass, are arranged symmetrically to the first and second axes, and have spring constants which are equal in both axial directions; driving electrodes and drive means, which are affixed to the substrate and drive the vibrating mass in the first axial direction; and detection electrodes and detection means, which are affixed to the substrate and detect displacement of the vibrating mass in the second axial direction. wherein the vibrating mass and the supports are maintained at a common potential, the driving electrodes are segmented in a manner allowing application of multiple voltage values, and when the vibrating mass is rotated around a third axis, which is perpendicular to the main surface of the substrate, while vibrating in the first axial direction, the Coriolis force produced in the second axial direction is detected, and the angular velocity around the third axis is measured.



13...driving electrode pairs 14...vibrating mass 15...detection electrode pairs
16...supports 17...securing sections

[SCOPE OF THE PATENT CLAIMS]

[Claim 1] A angular velocity sensor, comprising: a substrate; a vibrating mass which is formed so as to be isolated from a main surface of the substrate and which vibrates in first and second orthogonal axial directions within the main surface of the substrate; at least two supports which support the vibrating mass, one end of each being affixed to the vibrating mass and the other end being affixed to the substrate, are arranged symmetrically to the first and second axes, and have spring constants which are equal in both axial directions; driving electrodes and drive means which are affixed to the substrate and drive the vibrating mass in the first axial direction; and detection electrodes and detection means which are affixed to the substrate and detect displacement of the vibrating mass in the second axial direction; wherein the vibrating mass and the supports are maintained at a common potential, the driving electrodes are segmented so that a plurality of voltage values can be applied, and when the vibrating mass is rotated around a third axis which is perpendicular to the main surface of the substrate while vibrating in the first axial direction, the Coriolis force produced in the second axial direction is detected, and the angular velocity around the third axis is measured.

[Claim 2] The angular velocity sensor as claimed in claim 1, wherein the supports can displace and deform within the main surface of the substrate, have a structure symmetrical to axes bisecting the angles formed by the first and second axes within the main surface of the substrate, and have spring constants which are equal to each other in the first and second axial directions.

[Claim 3] The angular velocity sensor as claimed in claim 2, wherein the supports are configured such that a plurality of elastic structures capable of displacement and deformation within the main surface of the substrate are disposed symmetrically to axes bisecting the angles formed by the first and second axes within the main surface of the substrate and have spring constants which are equal to each other in the first and second axial directions.

[Claim 4] The angular velocity sensor as claimed in claim 1, wherein the driving electrodes are pairs of electrodes arranged opposite side surfaces of the vibrating mass so as to produce driving force in the positive and negative directions of the first axis, and are two capacitance terminals connected to the common potential of the vibrating mass and the supports.

[Claim 5] The angular velocity sensor as claimed in claim 1, wherein the Coriolis force detection electrodes are pairs of electrodes disposed opposing side surfaces of the vibrating mass to detect displacement in the positive and negative directions of the second axis, being pairs of capacitance terminals connected to the common potential of the vibrating mass and the supports.

[Claim 6] The angular velocity sensor as claimed in claim 4, further comprising a means for detecting the amplitude of the vibration of the vibrating mass when driven and controlling the amplitude of the vibration so as to be constant.

[Claim 7] The angular velocity sensor as claimed in claim 5, wherein a reference capacitance is connected to each of the detection electrode terminals, a read-out signal is input into the detection electrodes via the reference capacitances, and displacement of the vibrating mass in the second axial direction is detected based on signals produced in the detection electrode terminals.

[Claim 8] The angular velocity sensor as claimed in claim 6, wherein a reference capacitance is connected to each of the driving electrode terminals in the first axial direction of the vibrating mass, drive voltage is input into the driving electrodes via the reference capacitances, the drive amplitude is detected based on the

voltage produced in the detection electrode terminals, the drive voltage is controlled based on the voltage produced in the detection electrodes, and the drive amplitude is controlled so as to be constant.

[Claim 9] The angular velocity sensor as claimed in claim 1, wherein the vibrating mass and the supports are made of deposited polysilicon, and the substrate is a semiconductor substrate.

[Claim 10] The angular velocity sensor as claimed in claim 9, wherein the drive means for the vibrating mass and the displacement detection means for the vibrating mass are integrated on the same semiconductor substrate.

[Claim 11] The angular velocity sensor as claimed in claim 1, wherein the vibrating mass, the supports, and the substrate are configured using a semiconductor substrate.

[Claim 12] The angular velocity sensor as claimed in claim 1, wherein the vibrating mass and the supports are made of metal deposited using a plating method, and the substrate is a semiconductor substrate.

[Claim 13] The angular velocity sensor as claimed in claim 11 or 12, wherein the drive means for the vibrating mass and the displacement detection means for the vibrating mass are integrated on the same semiconductor substrate.

[Claim 14] A angular velocity sensor, provided with a pair of the angular velocity sensors as claimed in claim 1, wherein the vibrating masses are driven in opposite phases in the first axial direction, the angular velocity around the third axis is measured using the difference in detected output in the second axial direction, and acceleration in the second axial direction is measured by the sum of the detected output in the second axial direction.

[Claim 15] The angular velocity angular velocity sensor as claimed in claim 1, wherein the driving electrodes are opposing electrodes made up of at least four electrically independent electrodes, drive voltages V1 and V2 are simultaneously applied to at least two of the four electrodes to drive the vibrating mass in the first axial direction using the electrostatic force produced between the opposing electrodes, and information relating to the drive amplitude in the first axial direction of the vibrating mass is detected from the sum of C1 and C2 and information relating to displacement of the vibrating mass in the second axial direction due to the Coriolis force is detected from the difference between C1 and C2, where C1 and C2 are the electrostatic capacitances between the vibrating mass and at least two of the electrodes making up the opposing electrodes.

[Claim 16] The angular velocity sensor as claimed in claim 15, comprising a control mechanism, which detects information relating to displacement of the vibrating mass in the second axial direction due to the Coriolis force from the difference between C1 and C2, where C1 and C2 are the electrostatic capacitances between the vibrating mass and at least two of the electrodes making up the opposing electrodes, uses the information thus obtained to adjust the amplitudes of the drive voltages V1 and V2 applied simultaneously to at least two of the electrodes making up the opposing electrodes relative to the potential of the vibrating mass, and cancels out the Coriolis force produced in the vibrating mass.

[Claim 17] The angular velocity sensor as claimed in claim 15 or 16, comprising a control mechanism, which detects information relating to the drive amplitude in the first axial direction of the vibrating mass from the sum of C1 and C2, where C1 and C2 are the electrostatic capacitance between the vibrating mass and at least two of the electrodes making up the opposing electrodes, uses the information thus obtained to adjust the amplitude of the drive voltages V1 and V2 applied simultaneously to at least two of the electrodes

making up the opposing electrodes relative to the potential of the vibrating mass, and makes the drive amplitude of the vibrating mass constant.

[Claim 18] The angular velocity sensor as claimed in any one of claims 15 to 17, wherein the drive voltage applied to the vibrating mass is the sum signal of a voltage that varies over time at a first frequency and a voltage that varies over time at a second frequency which is higher than the first frequency, a reference capacitance C_{ref} is connected to at least two of the electrodes making up the opposing electrodes, the drive voltage is applied to the opposing electrodes via the reference capacitance C_{ref} , and the potential of the connection points between at least two of the electrodes making up the opposing electrodes and the reference capacitance C_{ref} is detected in sync with the second frequency and the first frequency, thereby measuring the electrostatic capacitances $C1$ and $C2$ between the vibrating mass and at least two of the electrodes making up the opposing electrodes.

[Claim 19] The angular velocity sensor as claimed in any one of claims 15 to 17, wherein the drive voltage of the vibrating mass is a voltage which varies over time at a first frequency, a first time band being provided during which the drive voltage is not applied and instead a carrier voltage is applied; a reference capacitance C_{ref} is connected to at least two electrodes making up the opposing electrodes; the drive voltage is applied to the opposing electrodes via the reference capacitances C_{ref} ; and the potential of the connection points between at least two of the electrodes making up the opposing electrodes and the reference capacitances C_{ref} is detected in sync with the carrier voltage, thereby measuring the electrostatic capacitances $C1$ and $C2$ between the vibrating mass and at least two of the electrodes making up the opposing electrodes.

[Claim 20] The angular velocity sensor as claimed in any one of claims 15 to 17, wherein the drive voltage of the vibrating mass is a voltage which varies over time at a first frequency and is provided with a first time band during which the voltage is not applied; a reference capacitance C_{ref} is connected to at least two of the electrodes making up the opposing electrodes; the drive voltage is applied to the opposing electrodes via the reference capacitances C_{ref} ; the carrier voltage is applied to the vibrating mass during the first time band; and the potential at the connection points between the reference capacitances C_{ref} and at least two of the electrodes making up the opposing electrodes is detected in sync with the carrier voltage[sic; not mentioned in the cited claims 15 to 17], thereby measuring the electrostatic capacitances $C1$ and $C2$ between the vibrating mass and at least two of the electrodes making up the opposing electrodes.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field of the Invention] The present invention relates to an angular velocity sensor, which is lightweight, mass-producible, and highly accurate.

[0002]

[Prior Art] The first conventional example shown in Figure 30 is an example of a conventional angular velocity sensor. Figure 2 shows an oscillator which has a square cross-section, is formed from a constant-elasticity metal such as Elinvar, and is supported by supports 3. A piezoelectric drive element 4 and a piezoelectric detection element 1 are affixed to side surfaces of the oscillator. The oscillator is driven and oscillated in the x-axis direction in the figure by applying an AC voltage having a resonant frequency in the x-axis direction to the piezoelectric drive element 4, causing it to become strained. In this state, if the oscillator is rotated at an angular velocity Ω around the z-axis direction in the figure, a Coriolis force is

produced in the y-axis direction in the figure. The Coriolis force $F_c(t)$ produced in the entire oscillator is represented by equation (1) below.

[0003]

$$F_c(t) = 2 \cdot \Omega \cdot \int dm(r) \cdot V_m(r, t) \dots\dots (1)$$

Here, $V_m(r, t)$ is the velocity in the x-axis direction of a differential element with mass $dm(r)$, produced by driving the oscillator. The integration range is the entire oscillator. The oscillator flexes in the y-axis direction due to the produced Coriolis force, and the strain produced by this flexing is detected by the detection piezoelectric element 1.

It can be seen from equation (1) that, in order to produce a greater Coriolis force, it is useful to a: increase the mass of the oscillator, b: drive at the resonant frequency to increase V_m , and c: make the resonant frequency the same for the drive axis and the detection axis to increase displacement along the detection axis, and that to precisely detect the produced Coriolis force, it is necessary to d: keep the oscillation amplitude of the oscillator constant. However, the angular velocity sensor in this first conventional example entails the following problems, among others, a: there is a limit to how small it can be made since the oscillator and supports are fabricated by machining, and b: it is difficult to adjust the resonant frequencies in the various axial directions of the oscillator, which increases mechanical adjustment costs.

[0004] To solve these problems, JP H5-248872 A discloses an angular velocity sensor as shown in Figure 31 and Figure 32 (which is a cross-sectional view along line A-A' in Figure 31). This configuration is described with reference to these drawings. In this second conventional example, an oscillator is configured on a substrate 12 made out of silicon or the like. The oscillation system consists of a vibrating mass 10, intermediate supports 11, and supports 8. The vibrating mass 10, the intermediate supports 11, and the supports 8 are formed from a polysilicon layer. The supports 8 are affixed to the silicon substrate 12 by anchors 7 and electrically connected to a conductive pattern. 5 indicates securing sections. Wiring is left out of the figure for the sake of simplicity. The intermediate supports 11 are supported between the anchors 7 by the supports 8. The vibrating mass 10 is supported by the supports 8 arranged in a cross shape in the x- and y-axis directions with the vibrating mass at the center. A pair of driving electrodes 6 for driving the vibrating mass 10 in the x-axis direction using electrostatic force are formed on side surfaces of the intermediate supports 11. Detection electrodes 9 for detecting displacement in the y-axis direction due to the Coriolis force are formed on side surfaces of the other pair of intermediate supports.

[0005] Next, the operation of the second conventional example will be described. The vibration system is driven using electrostatic force by applying drive voltages $V_p + v_d \cdot \sin \omega t$ and $V_p - v_d \cdot \sin \omega t$ to the pair of driving electrodes 6. Note that V_p is a DC bias power supply and $v_d \cdot \sin \omega t$ is a drive AC power supply. The drive frequency ω is made to match the resonant frequency of the vibration system in the x-axis direction. In this state, if the vibration system made up of the vibrating mass, the intermediate supports, and the supports is rotated at an angular velocity Ω around the z-axis direction, a Coriolis force is produced in the y-axis direction. The Coriolis force produced is represented by equation (2) below.

[0006]

$$F_c(t) \approx 2 \cdot m \cdot V_m(t) \cdot \Omega \dots\dots (2)$$

Here, m is the mass of the vibrating mass 10, and $V_m(t)$ is the velocity of the vibrating mass 10 driven by electrostatic force. Note that the mass of the intermediate supports is assumed to be significantly less than

the vibrating mass. The angular velocity Ω can thus be detected from the capacitance values between the detection electrodes 9.

[0007] The configuration of this second conventional example provides the following advantages, among others, over the problems described above with respect to the first conventional example a: semiconductor manufacturing technology makes it possible to realize an inexpensive and lightweight angular velocity sensor (for problem a in the first conventional example); b: the vibration system is configured as a flat structure formed from a polysilicon layer and the directions of driving and detection are horizontal to the plane of the substrate, so a three-dimensional structure is not needed, making it possible to simplify the structure (for problem a in the first conventional example); c: the vibration system is a flat structure formed from a polysilicon layer and is symmetrical to the directions of driving and detection, so the resonant frequencies are the same in each direction, improving sensitivity (for problem b in the first conventional example); d: the driving and detection directions are horizontal to the plane of the substrate, so the dependencies on the cross-sectional shape of the supports are the same in the drive axis and detection axis directions, meaning there is no relative variation in the values of the resonant frequencies in each direction due to fabrication process variations (for problem b in the first conventional example); and e: the drive axis and the detection axis are both horizontal to the plane of the substrate, so in a vibrating state the effect of air viscosity is reduced, the Q value during resonance is greater, and detection sensitivity is improved.

[0008] However, in the second conventional example, the vibrating mass is supported by the supports in a manner allowing displacement in only one direction, so the second conventional example entails the following problems, among others a: the vibrating mass is connected to the intermediate supports via pairs of supports extending in the y-axis direction, so the intermediate supports on either side in the x-axis direction are drawn in the direction of the vibrating mass together with the supports when driven in the x-axis direction (see Figure 33), resulting in the intermediate supports 11 vibrating in the y-axis direction at twice the drive frequency in positions offset towards the vibrating mass from their positions when at rest, which causes a difference in the vibration modes in the detection direction and the drive direction, making the vibration control of the vibrating mass needed for high-precision measurement of the angular velocity difficult, and any differences arising in the left-right vibration due to manufacturing variations, etc., in the supports will produce a drive signal-induced output signal, resulting in a drop in the detection signal S/N ratio; b: the drive and detection directions have the same resonance frequency, so there is the possibility of resonance in the detection axis direction due to any detection-direction components in the driving force caused by asymmetry in the structure due to manufacturing variations, etc., in the supports, and in the case of this second conventional example, such drive-induced vibration cannot be controlled and might be detected as an output signal, reducing the measurement precision.

[0009] A angular velocity sensor utilizing semiconductor technology is disclosed in JP H5-312576 A. This third conventional example is described with reference to Figure 34 and Figure 35 (a cross-sectional view along line A-A' in Figure 34). In the figures, 63 and 65 are silicon substrates and 64 is an oxide film. The oxide film 64 is formed on the silicon substrate 65, patterned, and joined to the silicon substrate 63 using a direct bonding method, after which the silicon substrate 63 is polished to a prescribed thickness. 59 indicates trenches formed by etching the silicon substrate 63 using semiconductor manufacturing technology. The vibrating mass, first and second supports, and frame described hereafter are formed by these trenches 59. 61 is a vibrating mass which is supported by first supports 60. The sides of the first supports 60 opposite

the connections to the vibrating mass 61 form connections to the frame 57. The frame 57 is supported by second supports 56. Comb electrodes 62 are configured on the frame 57 for driving the vibrating mass 61 to vibrate in the x-axis direction using electrostatic force. To detect displacement of the vibrating mass 61 caused by the Coriolis force, resistor bridges are configured by piezo resistors 55 disposed in parallel pairs on each support near where the first supports 60 connect to the frame 57, and detection electrodes 58 are configured on the vibrating mass 61 and the frame 57 (detailed electrical wiring is left out of the diagram for the sake of simplicity).

[0010] The frame 57 supported by the second supports 56 is driven by electrostatic force in the x-axis direction when voltage is applied to the comb electrodes 62 (detailed electrical wiring is left out of the diagram for the sake of simplicity). When the entire system is rotated at an angular velocity Ω around the z-axis direction, which is perpendicular to the plane of the substrate in this state, the same Coriolis force as represented in equation (2) above is produced in the y-axis direction. The displacement of the vibrating mass 61 in the y-axis direction due to the Coriolis force produced is detected as the difference in resistance between the piezo resistors 55 and changes in the capacitance between the detection electrodes 58.

[0011] This third conventional example provides the following advantages, among others a: semiconductor technology is used, so an inexpensive, lightweight angular velocity sensor can be realized; b: the drive axis and the Coriolis force detection axis are both parallel to the plane of the substrate, so the resonant frequency in the drive axis and detection axis directions can be determined using a flat structure; and c: the drive axis and the detection axis are both parallel to the plane of the substrate, so in a vibrating state the effect of air viscosity is reduced, the Q value during resonance is greater, and detection sensitivity is improved. However, because the vibrating mass consists of a semiconductor in the third conventional example, the mass m in equation (2) is small, making the Coriolis force that is produced small enough to be practically undetectable by the resistor bridges configured using the piezo resistors 55, meaning displacement of the vibrating mass has to be measured using changes in the electrostatic force of the detection electrodes 58. But since the detection electrodes 58 are formed on side surfaces of the vibrating mass 61 and the frame 57, the area of opposition is small, making it impossible to achieve a sufficiently large capacitance value. This results in the problem of being unable to achieve a sufficiently high S/N ratio when measuring displacement of the vibrating mass. It is also difficult to achieve a sufficiently large area of opposition even for the comb electrodes 62 which are for driving the vibrating mass, resulting in the problem of being unable to obtain sufficiently large drive amplitude. Furthermore, electrical connections have to be established via the supports to the comb electrodes 62 and either the piezo resistors 55 (which detect displacement of the vibrating mass 61 due to the produced Coriolis force) or the detection electrodes 58 (which detect displacement of the vibrating mass relative to the frame 57), and moreover the various parts also have to be electrically isolated, but making the supports and driving electrodes sufficiently fine is difficult, which is a problem. Moreover, if a metal such as aluminum is used in the aforementioned electrical connections, differences arise in the thermal expansion coefficients between the metal and the insulation film or silicon, which are the structures forming the supports, thereby producing warping, etc., in the structure due to any heat stress that might be generated and resulting in possible offsets in the output, as well as plastic deformation in the metal parts due to significant deformation of the supports, possibly creating deterioration over time in the output, which are also problems.

[0012]

[Problem to be Solved by the Invention] The present invention provides an angular velocity sensor that is compact and lightweight, provides accurate detection results, and can easily be mass-produced, thereby solving the various problems of the prior art described above.

[0013]

[Means for Solving the Problem] To solve this problem, the present invention comprises: a substrate; a vibrating mass, which is formed so as to be isolated from a main surface of the substrate, and which vibrates in first and second orthogonal axial directions within the main surface of the substrate; at least two supports which support the vibrating mass, one end of each being affixed to the vibrating mass and the other end being affixed to the substrate, are arranged symmetrically to the first and second axes, and have spring constants which are equal in both axial directions; driving electrodes and drive means which are affixed to the substrate and drive the vibrating mass in the first axial direction; and detection electrodes and detection means which are affixed to the substrate and detect displacement of the vibrating mass in the second axial direction; wherein the vibrating mass and the supports are maintained at a common potential, the driving electrodes are segmented so that a plurality of voltage values can be applied, and when the vibrating mass is rotated around a third axis which is perpendicular to the main surface of the substrate while vibrating in the first axial direction, the Coriolis force produced in the second axial direction is detected, and the angular velocity around the third axis is measured.

[0014] Instead of separately providing the driving electrodes which drive in the first axial direction and the detection electrodes which detect displacement in the second axial direction, as described above, it is also possible, while keeping the configuration of using opposing electrodes consisting of two [sic? pairs of?] electrically independent electrodes, to apply drive voltages V_1 and V_2 simultaneously to these two electrodes so as to use the electrostatic force produced between the opposing electrodes to drive the vibrating mass in the first axial direction, and to detect information relating to the drive amplitude of the vibrating mass in the first axial direction from the sum of C_1 and C_2 , and to detect information relating to displacement of the vibrating mass due to the Coriolis force in the second axial direction from the difference between C_1 and C_2 , where C_1 and C_2 are the electrostatic capacitances between the two fixed electrodes comprising the opposing electrodes and the electrodes on the vibrating mass, thereby using one type of electrode for both driving and Coriolis force detection.

[0015]

[Operation] The driving electrodes are segmented to allow a plurality of voltage values to be applied independently, so problems can be avoided even if the vibrating mass or supports are formed asymmetrically to the first axial direction during the manufacturing process.

[0016]

[Embodiments] The present invention will now be described below in further detail with reference to embodiments.

[0017] First embodiment: The first embodiment is described with reference to Figure 1 and Figure 2 (a cross-sectional view along line B-B' in Figure 1). This embodiment corresponds to claims (1), (2), and (4)-(15). The basic configuration is described first. 14 is a vibrating mass formed from a thin-film structural material. The vibrating mass 14 is connected at each of four corners to supports 16 which are formed from the same thin-film structural material and have spring constants which are equal in the x (first axis) and y

(second axis) axial directions. Note that in the diagrams, the supports are shown schematically. The supports 16 are arranged symmetrically to the x- and y-axes as shown in the diagram. The other ends of the supports are affixed to the substrate at securing sections 17 and are electrically connected to a conductive material (the wiring is not shown in order to simplify the drawings). Comb-shaped electrodes are formed on side surfaces of the vibrating mass 14, with driving electrode pairs 13 being formed for driving the vibrating mass 14 in the x-axis direction using the electrostatic force between themselves and the comb-shaped opposing electrodes which are connected to the securing sections 17. The driving electrode pairs 13 are shown enlarged in Figure 5(a). The comb-shaped driving electrodes affixed to the substrate consist of electrodes 21 facing the right sides of the comb-shaped driving electrodes on the vibrating mass and electrodes 20 facing the left sides, to which drive voltages can be applied independently. Comb-shaped electrodes are also formed on side surfaces of the vibrating mass 14 (only one set is shown in the drawings), detection electrode pairs 15 being formed for detecting displacement of the vibrating mass 14 in the y-axis direction based on changes in the capacitance between themselves and the comb-shaped electrodes connected to the securing sections 17. Figure 6 is an enlargement of the detection electrode pairs. As shown in Figure 6, the comb electrodes are arranged such that $d1 \ll d2$ so that the opposing comb electrode pairs do not interfere with each other.

[0018] The supports in the present embodiment are discussed in detail next. The supports, which have spring constants which are equal in the x- and y-axial directions, can displace and deform within the x-y plane in the diagrams, and can be realized using a structure which is symmetrical to the axial directions bisecting the angles formed by the x- and y-axes. Figures 14 and 15 show some examples. Figure 14 shows examples in which a symmetrical structure is realized using one structural element. An axis of symmetry is set along a direction bisecting the angle formed by the x- and y-axes, so the mode of deformation of the structure in the x- and y-axial directions is the same, having a spring constant which is the same in both axial directions. Figure 15 shows examples in which a symmetrical structure is realized using multiple structural elements. An axis of symmetry is set along a direction bisecting the angle formed by the x- and y-axes, so the mode of deformation of the structure in the x- and y-axial directions is the same, having a spring constant which is the same in both axial directions. Compared to the example in Figure 14, the effect is that of being able to easily modify the spring constant by increasing or decreasing the number of structural elements.

[0019] There are various fabrication processes, which will be described below.

1. Figure 8 shows an example of a fabrication process when the structural material is polysilicon.

(a) A high-concentration diffusion layer 22 is formed, then an oxide film 24 is formed by oxidizing the silicon substrate, and then a silicon nitride film 23 is deposited over the entire surface of the oxide film 24.

(b) A PSG or other type of passivation film 27 is deposited over the entire surface. A contact hole reaching the high-concentration diffusion layer is formed, impurities are diffused if necessary, and then a polysilicon film 25 is deposited and patterned.

(c) A contact hole reaching the high-concentration diffusion layer is formed, and then metal wiring 26 is deposited and patterned.

(d) A PSG or other type of passivation film 27 is deposited over the entire surface and patterned, and then a silicon nitride film 28 for protecting the metal wiring and peripheral circuits is deposited and patterned.

(e) A fluoric acid-based solution is used to remove the PSG or other type of passivation film, which is a sacrificial layer, and the polysilicon structural material is formed. Note that although left out of this description, integrating peripheral circuitry on the same substrate not only makes very fine signal processing possible, it is also advantageous for making the sensor compact and less costly.

[0020] 2. Figure 9 shows an example of a fabrication process when the structural material is an SOI layer. This fabrication process uses an SOI substrate in which a first silicon substrate is oxidized, a second silicon substrate is joined thereto using a direct bonding method with the oxide film in between, and then the second silicon substrate is polished to a prescribed thickness.

(a) A high-concentration diffusion layer 29 is formed on an SOI layer, and then oxidation is performed to cover the entire surface with an oxidation film 24.

(b) A PSG or other type of passivation film 30 is deposited over the entire surface, and a contact hole reaching the high-concentration diffusion layer 29 is formed. Metal which will constitute the wiring is deposited over the entire surface and patterned, thus forming the metal wiring 26.

(c) A PSG or other type of passivation film 30 is again deposited over the entire surface, and the passivation film 30 and the oxidation film 24 are patterned.

(d) A silicon nitride film 23 is deposited over the entire surface and patterned, thus forming a protective film for the metal wiring and peripheral circuitry. Thereafter, a trench 31 is formed in the SOI layer using a technology such as RIE.

[0021] (e) The oxidation film under the SOI layer is used as a sacrificial layer and removed using a fluoric-acid based solution, and a vibrating mass and supports are formed. Note that although left out of this description, integrating peripheral circuitry on the same substrate not only makes very fine signal processing possible, it is also advantageous for making the sensor compact and less costly.

[0022] 3. Figure 10 shows a fabrication process when the structural material is a plated metal.

(a) First, a high-concentration diffusion layer 22 is formed on a silicon substrate, and then an oxidation film 24 is formed over the entire surface. A silicon nitride film 23 is then deposited over the entire surface as a passivation film.

(b) A metal film is deposited over the entire surface and patterned, a PSG or other type of passivation film is deposited over the entire surface, a contact hole is formed to metal film wiring, a metal film is deposited over the entire surface and patterned, a PSG or other type of passivation film is deposited over the entire surface and patterned, and a silicon nitride film for protecting the metal wiring and peripheral circuitry is deposited over the entire surface and patterned.

(c) A metal film 33 is deposited using plating as a sacrificial layer and patterned, and a metal film 32 is deposited using a plating method as a structural material and patterned.

(d) A fluoric acid-based solution is used to remove the sacrificial metal film 33, thus configuring the vibrating mass and supports. Note that although left out of this description, integrating peripheral circuitry on the same substrate not only makes very fine signal processing possible, it is also advantageous for making the sensor compact and less costly.

[0023] The operation of the present embodiment will now be described. Figure 11 shows an example of a vibrating mass drive and signal detection circuit. A prescribed drive voltage is alternately applied to driving electrode terminals Td1 and Td2 relative to a potential Vm of the vibrating mass 14 to drive the vibrating mass 14 supported by the supports 16 in the x-axis direction and cause it to vibrate. A resonant

frequency f_{xr} of the vibrating mass in the x-axis direction is determined by the mass of the vibrating mass and the x-axis direction spring constants of the supports connected to the four corners of the vibrating mass. Accordingly, a resonant state can easily be realized by electrically adjusting the applied frequency of a drive power supply OSC1 34.

[0024] The vibrating mass has to be driven at a constant frequency and with a constant amplitude in order to ensure high-precision measurement of the Coriolis force. Since the vibration frequency is the same as the drive frequency, all that is needed is to keep the frequency of OSC1 constant. The configuration in Figure 11 is one example for controlling the amplitude so as to be constant. Reference capacitors Cr2 are connected in series between the drive power supply and the driving electrode terminals Td1 and Td2. The impedance of the electrical capacitance is represented by equation (3) below.

$$Z_c = 1 / j \omega C \quad \dots (3)$$

Accordingly, almost all loss of the drive voltage at Cr2 is negligible as long as Cr2 is made sufficiently greater than electrical capacitances Cd1 and Cd2 between the vibrating mass and the driving electrode terminals. In practice, the values of Cd1 and Cd2 are in the pF range, making it easy to realize Cr2 on a single substrate. When drive voltages D and D⁻ (representing the logical negation of D) are applied via the reference capacitances Cr2, the potentials of the driving electrode terminals Td1 and Td2 are obtained via buffers 38, and by detecting the difference therebetween in sync with the drive frequency of the drive power supply OSC1 using a demodulator 37, information relating to the vibration amplitude of the vibrating mass can be obtained. Accordingly, negative feedback can be applied to the drive power supply OSC1 so that the obtained amplitude information is a prescribed value, allowing constant amplitude driving of the vibrating mass. During the fabrication process, it is possible for variations to occur in the gaps between the driving electrodes due to variations in residual stress produced in the supports. For example, Figure 4(a) shows an ideal state where $d_3 = d_4$. In this case, the y-axis direction electrostatic forces cancel each other out, so the driving force produced in the vibrating mass 14 acts only in the x-axis direction. If for the reasons given above, however, a situation arises where $d_3 \neq d_4$ as in Figure 4(b), and the deviation of the gap from the ideal state is $\delta(d_3 - d_4 = 2 * \delta)$, then the x-axis direction driving force remains the same as in the ideal state, but electrostatic force represented by equation (4) below occurs in each pair of driving electrodes in the y-axis direction.

[0025]

$$F_y = \epsilon_0 \cdot (L \cdot t) / d_0^2 \cdot V_d^2 \cdot 4 \cdot (\delta / d_0) \dots (4)$$

Where

ϵ_0 : dielectric constant

L: distance between the electrodes in a driving electrode pair

t: thickness of the driving electrodes

d_0 : gap between electrodes in the ideal state

V_d : drive voltage

The electrostatic force represented in equation (4) has a resonant frequency in the direction of the drive axis. In the structure in the present embodiment, the resonant frequency is the same for the drive axis and the resonance axis, so it is possible that this electrostatic force might induce vibration in the direction of the detection axis and produce unwanted signals in the output.

[0026] However, the distribution of the driving force can be adjusted using the method shown in Figure 5 to remove the effects of variations in the gaps. Figure 5(a) is an enlarged schematic diagram of a driving electrode, in which the driving electrode affixed to the substrate is divided into electrodes 21 opposing the right sides of the vibrating mass-side electrodes and electrodes 20 opposing the left sides. If variations occur in the gaps, the drive voltage applied to the electrodes 20 and 21 can be adjusted using adjustment resistors R_t as shown in Figure 5(b) to suppress vibration in the direction of the detection axis induced by the drive voltage.

[0027] If the vibrating mass is rotated around the z-axis shown in Figure 1 at an angular velocity Ω , while vibrating at a constant amplitude, the Coriolis force shown in equation (2) below is produced in the y-axis direction.

$$F_c(t) \approx 2 \cdot m \cdot V_m(t) \cdot \Omega \quad \cdots \cdots (2)$$

Here, m is the mass of the vibrating mass, and $V_m(t)$ is the velocity of the vibrating mass in the x-axis direction. If a triangular wave driving force is applied and the vibrating mass vibrates at the resonant frequency f_{xr} , the displacement of the vibrating mass in the x-axis direction will lag behind the driving force by a phase of $\pi/2$ driving force. Accordingly, $V_m(t)$, which is the differential amount of the displacement of the vibrating mass, and the Coriolis force $F_c(t)$ in the y-axis direction, which is proportional thereto, will vary with the same frequency and phase as the driving force. Therefore, if the resonant frequency f_{yr} in the y-axis direction of the vibrating mass which is supported by the supports is made the same as the x-axis direction resonant frequency f_{xr} , the y-axis displacement due to the Coriolis force can be increased.

[0028] In the present embodiment, the y-axis direction resonant frequency f_{yr} is the same as the x-axis direction resonant frequency f_{xr} , as the vibrating mass is supported by four supports which have a structure which can displace and deform within the x-y plane and is symmetrical to the direction of the axes bisecting the angles formed by the x- and y-axes, and therefore have spring constants which are equal in the x- and y-axes. It is possible that the spring constant of any one support might be slightly different in the positive and negative direction of the x- and y-axes, but by arranging the supports which support the vibrating mass symmetrically to the x- and y-axes, as in the present embodiment, the aforementioned effects can be eliminated. The vibration mode can also be made the same in both directions (although the displacement in the direction of the y-axis will lag behind the Coriolis force by a phase of $\pi/2$, which is the driving force).

[0029] If the vibrating mass, supports, and comb electrode structures are made using a thin film having a prescribed thickness as in the present embodiment, the mass of each part is determined by the density of the structural material and the area in the x-y plane. The spring constants of the supports in the x- and y-axis directions are only determined by the stiffness coefficient of the support members and their shape in the x-y plane, as well as their cross-sectional shape, i.e., second moment of area. Accordingly, the resonant frequencies in the x- and y-axis directions can be determined by the thickness of the structural material and the structural design in the x-y plane. If variations in the manufacturing process result in deviations in the thickness and length of the structural material and the cross-sectional shape as shown in Figure 7, the changes in the resonant frequencies in each axial direction are represented in equation (5) below for the x- and y-axis directions and equation (6) for the z-axis direction.

[0030]

$$\Delta f / f_{x, y} = - (3/4) \times \delta - (5/2) \times (\Delta L / L) \quad \dots (5)$$

$$\Delta f / f_z = - \Delta t / t - (1/4) \times \delta - (5/2) \times (\Delta L / L) \quad \dots (6)$$

Where

 $\delta = (b-a) / b$: change in the cross-sectional shape of the support $\Delta t / t$: deviation in the thickness of the structural material $\Delta L / L$: deviation in the length of the structural material

Accordingly, as can be seen from equation (5), if the deviation is constant within the same angular velocity sensor, the relative values of the resonant frequencies in the x- and y-axis directions will not change even if the absolute values do, making it possible to achieve high sensitivity just by adjusting the drive frequency of the drive power supply OSC1.

[0031] Changes in the electric capacitance between the detection electrode pairs due to the Coriolis force shown in equation (2) can be detected as shown in Figure 11. Reference capacitances Cr1, which are substantially the same as the electrical capacitance between the detection electrodes and the vibrating mass-side electrodes, are connected in series between detection electrode terminals Vs1 and Vs2 and a detection power source OSC2 35, which has a substantially higher frequency than the drive power supply OSC1 34. By using the demodulator 37 to detect the difference between the potentials of the detection electrode terminals Vs1 and Vs2 via the buffers 38 in sync with the drive frequency from the detection power supply OSC2 when a detection voltage C is applied via the reference capacitances Cr1, the amount of displacement in the y-axis direction due to the Coriolis force, which varies at the frequency of the drive power supply OSC1 34, can be obtained. Therefore, if the signal is processed in sync with the drive frequency of OSC1 again, as shown in Figure 11, a DC signal is obtained which corresponds to the amount of displacement in the y-axis direction.

[0032] Figure 12 shows an example of another detection method. By using the demodulator 37 to detect the difference between the potentials of the detection electrode terminals Vs1 and Vs2 via the buffers 38 in sync with the drive frequency of the detection power supply OSC2 when the detection voltage C is applied to the detection electrode terminals via the reference capacitances Cr1, like in the case of Figure 11, the amount of y-axis direction displacement due to the Coriolis force, which varies at the frequency of the drive power supply OSC1, can be obtained. If the signal thus obtained is input into a peak hold circuit 39 to detect the maximum signal, a DC signal is obtained which corresponds to the amount of y-axis direction displacement due to the Coriolis force.

[0033] Figure 13 shows an example of yet another detection method. Like in the case of Figure 11, the detection voltage C is applied to the detection electrode terminals Vs1 and Vs2 via the reference electric capacitances Cr1. In this case, a detection voltage source OSC3 has the same frequency as the drive power supply OSC1 and a phase delay δ relative to OSC1. When running, a certain amount of phase delay occurs between the x-axis direction displacement due to the driving force and the y-axis direction displacement due to the Coriolis force. Accordingly, by adjusting the OSC3 to adjust the phase difference relative to the OSC1 and using the demodulator 37 to detect the potentials of the detection electrode terminals Vs1 and Vs2 via the buffers 38 in sync with the frequency of the detection power supply OSC3 40 (which has the same frequency as OSC1 and only differs in phase) to find the difference between the x-axis direction and

y-axis direction displacements, a DC signal is obtained which corresponds to the y-axis direction displacement due to the Coriolis force.

[0034] Input of DC-type x-axis direction noise acceleration affects the output in the form of variations in the vibration amplitude of the vibrating mass. This effect can be eliminated by monitoring the vibration amplitude and using the configurations shown in Figures 11, 12, and 13 to make it constant.

[0035] Input of DC-type z-axis direction noise acceleration affects the output in the form of variations in the vibration amplitude of the vibrating mass and variations in the area of opposition between detection electrodes. The effect of variations in the vibration amplitude can be eliminated using the same procedure as in the x-axis direction case. Effects on output due to variations in the area of opposition between the detection electrodes can be eliminated using the circuit configurations in Figures 11, 12, and 13 to detect the differential capacitance of the detection electrode pairs.

[0036] Input of DC-type y-axis direction noise acceleration can be eliminated by installing a pair of the angular velocity sensors 1 as in the present embodiment in a row, driving the vibrating masses thereof in opposite phases, and finding the difference in the outputs of the pair of angular velocity sensors 1, which also makes it possible to achieve even greater precision in detecting angular velocity. By finding the sum of the outputs of the angular velocity sensors, input of DC-type noise acceleration in the direction of the detection axis (y-axis direction) can be detected.

[0037] In particular, when AC-type noise acceleration is further added in the x- and y-axis directions, vibration due to resonance in the x- and y-axis directions is induced, affecting the output, but if the resonant frequencies in the axial directions are designed to be high enough, the mounting structure of the sensor can be used to configure a low-pass filter and suppress input of AC-type noise acceleration.

[0038] In the drawings describing the present embodiment, only the angular velocity detection portion is shown, but if the drive and signal processing circuitry of the entire detection portion is formed on the same substrate as shown in Figures 11, 12, and 13, the effects of outside noise mixed in while inputting very fine signals, which are produced when detecting the angular velocity, into the processing circuitry can be dramatically reduced. Moreover, the pairing of the electrical capacitances of the pairs of reference capacitances Cr1 and Cr2 can be improved, making it possible to reduce driving force and output signal offset.

[0039] The effects of the first embodiment are described below.

a: Because the supports, which have equal spring constants in the drive axis and detection axis directions, are arranged symmetrically relative to the two axial directions and support the vibrating mass, the resonant frequencies and vibration modes in the two axial directions are the same, making it possible to achieve high precision when measuring angular velocity.

b: A configuration is used in which the driving electrodes oppose the vibrating mass and drive it using electrostatic force, and the drive voltage can be applied to each independently, so the drive vibration can be controlled very precisely.

c: The vibrating mass is driven and vibrates in the plane direction and detection is done in the plane direction, so that designing the relative resonant frequencies along the drive and detection axes is easy.

d: The vibrating mass, which has a flat structure, vibrates parallel to the plane of the substrate, so a high Q value is obtained during resonance.

- e: The vibrating mass is driven and vibrates in the plane direction and detection is done in the plane direction, so that the electrodes can be configured two-dimensionally, simplifying the structure.
- f: The angular velocity sensor is realized using semiconductor fabrication technology, so it can be made small, lightweight, and low-cost, allowing mass-production of sensors with uniform characteristics.
- g: The sensor characteristics can be designed using only a two-dimensional structure.
- h: Using electrostatic force for driving and detection makes it possible to make the potential the same for the vibrating mass and the supports, thus simplifying the electrical wiring.
- i: Using electrostatic force for driving and detection makes it possible to make the potential the same for the vibrating mass and the supports, eliminating the need for metal, polysilicon, or high-concentration diffusion layer electrical wiring on the supports, and making it possible to eliminate the adverse effects of differences in the thermal expansion coefficients of the various structural members on output.
- j: Using electrostatic force for driving and detection makes it possible to make the potential the same for the vibrating mass and the supports, eliminating the need for metal, polysilicon, or high-concentration diffusion layer electrical wiring on the supports. But if metal wiring is used on the supports, a certain amount of offset or hysteresis caused by plastic deformation of the metal wiring can be eliminated.
- k: The vibrating mass is directly driven, allowing even more precise control of the vibration amplitude of the vibrating mass.
- l: The vibrating mass and supports are formed from surface microstructures, so the resonant frequency of the mechanical system can be designed to be high. Accordingly, using the mounting structure of the sensor to configure a low-pass filter against input of AC-type noise acceleration can eliminate the adverse effects of input of such AC-type noise acceleration on output.
- m: Control making the vibration amplitude constant is possible without using vibration amplitude monitoring electrodes.
- n: Controlling the vibration amplitude from the driving so as to be constant and detecting the differential capacitance in the detected capacitances makes it possible to eliminate the adverse effects on output of input of DC-type noise acceleration into the drive axis of the vibration amplitude and the angular velocity input axis.
- o: Using a pair of the angular velocity sensors 1 in which the vibrating masses are driven at opposite phases and finding the difference in the outputs thereof makes it possible to eliminate the adverse effects on output of input of DC-type noise acceleration in the direction of the detection axis and to achieve even greater precision when detecting angular velocity.
- p: Using a pair of the angular velocity sensors 1 in which the vibrating masses are driven at opposite phases and finding the sum of the outputs thereof makes it possible to detect acceleration in the direction of the detection axis.
- q: Forming the detection portion, the drive circuitry for the detection portion, and the signal processing circuitry on the same substrate dramatically decreases the effects of outside noise mixed in when inputting very fine signals into the processing circuitry. Moreover, pairing of the reference capacitance pairs Cr1 and Cr2 can be improved, making it possible to reduce the offset in the driving force and output signals.
- r: Even greater sensitivity can be achieved by adding an AC servo mechanism and outputting the feedback amount.

Second embodiment: The second embodiment of the present invention will be described with reference to Figure 3. This embodiment corresponds to claims 1 and 3-15. The basic configuration can be realized as shown in Figure 3, in which multiple elastic structures which can displace and deform within the x-y plane and have spring constants which are equal in the x- and y-axis directions are arranged as supports 18 symmetrically to the axial directions bisecting the angles formed by the x- and y-axes. Figure 16 shows two examples. The multiple elastic structures may also be those shown in Figure 14 and Figure 15. In these figures, 14 indicates the vibrating mass, 17 indicates securing sections, and 18 indicates the supports. Because axes of symmetry are set in directions bisecting the angles formed by the x- and y-axes, the mode of deformation of the structures in the x- and y-axis directions is the same, which ensures the same spring constants in both axial directions.

[0040] Fabrication steps are the same as in the first embodiment. Operation is also the same as in the first embodiment, but in the second embodiment, the vibrating mass is supported by supports in which multiple elastic structures which are able to displace and deform within the x-y plane and have the same spring constants in the x- and y-axis directions are arranged in sets symmetrical to the directions bisecting the angles formed by the x- and y-axis directions, so the y-axis direction resonant frequency f_{yr} and the x-axis direction resonant frequency f_{xr} are the same. It is possible that the spring constant of any one support might be slightly different in the positive and negative directions of the x- and y-axes, but by arranging the supports which support the vibrating mass symmetrically to the x- and y-axes, as in the present embodiment, the aforementioned effects can be eliminated. The vibration mode can also be made the same in both directions (although the displacement in the direction of the y-axis will lag behind the Coriolis force by a phase of $\pi/2$, which is the driving force). The same effects are obtained with the second embodiment as with the first embodiment.

[0041] Third embodiment: The third embodiment differs from the first and second embodiments described above in that there is only one type of electrode arranged on the sides of the vibrating mass, with no distinction made between electrodes for driving in the x-axis direction and electrodes for detecting y-axis direction displacement due to the Coriolis force. That said, to deal with unequal gaps between electrodes, the fixed electrodes are divided into sets of two to which different potentials can be applied, like in the first and second embodiments.

[0042] The third embodiment is first described with respect to the state of the comb electrode pairs making up the vibrating mass-side electrodes and fixed-side electrodes, with reference to Figures 17 and 18. These figures show plan schematic diagrams of the vibrating mass and opposing (fixed) electrodes of the angular velocity sensor formed from a thin-film structural material. In the figures, 66 is the vibrating mass which is supported by supports described below (not shown in the diagrams for the sake of simplicity). The vibrating mass is connected to a common potential via the supports. 70 indicates the comb electrodes extending from side surfaces of the vibrating mass. Opposing electrodes face the comb electrodes 70 across a prescribed electrode gap. Opposing electrodes 68 and 69 oppose both side surfaces of each of the comb electrodes 70 in Figure 17. In Figure 18, an opposing electrode 68 or 69 opposes one side surface of each of the comb electrodes 70. The opposing electrodes 68 and 69 are connected to lead-out electrodes 71 at connection sections 67 and are connected to peripheral circuitry (the peripheral circuitry is not shown in the figures for the sake of simplicity). The opposing electrodes 68 and 69 are electrically independent and form electrostatic capacitances with the vibrating mass. The vibrating mass and opposing electrodes shown in

the diagrams can be fabricated using a known technique and monocrystalline or polycrystalline silicon. The thickness of the vibrating mass and opposing electrodes is typically in the range of a few micrometers.

[0043] Figures 19 and 20 show a general plan view of a method for supporting the vibrating mass (these diagrams show the opposing electrode structure shown in Figure 17, but the structure can also be realized using the opposing electrodes shown in Figure 18). In Figure 19, 72 is a vibrating mass formed from a thin-film structural material. The four corners of the vibrating mass 72 are connected to supports 73 formed from the same thin film structural material and having the same spring constants in the x- and y-axis directions (the supports are shown schematically). The supports are arranged symmetrically to the x- and y-axes. The other ends of the supports are secured to the substrate by securing sections 74 and are also electrically connected to a conductive material (the wiring is not shown in the drawings for the sake of simplicity). The vibrating mass is supported by the supports 73 which have the same spring constants in the x- and y-axis directions, and therefore can be displaced in the x- and y-axis directions and have the same resonant frequency in both directions. Area 75 indicated by the dotted line is the electrode section. In Figure 20, the supports 76 are configured by arranging multiple elastic structures, which can be displaced within the x-y plane, in the x- and y-axis directions symmetrically to the directions bisecting the angles formed by the x- and y-axes. Because axes of symmetry are set in directions bisecting the angles formed by the x- and y-axes, the supports 76 have the same spring constant in both axial directions. The vibrating mass 72 thus supported can be displaced in the x- and y-axis directions and has the same resonant frequency in both directions.

[0044] Next, the configuration of the detection circuit is described with reference to Figure 21. In this diagram, opposing electrode terminals R1, R2, L1, and L2 shown in Figures 19 and 20 and the electrostatic capacitances between them and the vibrating mass are designated as CR1, CR2, CL1, and CL2. Area 77 indicated by the dotted line represents the vibrating mass, nodes connecting CR1, CR2, CL1, and CL2 represent the potential of the vibrating mass, and these are connected to a common potential via the supports. The opposing electrode terminals R1, R2, L1, and L2 are maintained at substantially mutually equal DC bias values VR1, VR2, VL1, and VL2. Reference capacitances Cref 79 are connected to the opposing electrode terminals R1, R2, L1, and L2, and drive voltages V1, V2, V1⁻, and V2⁻ are applied to CR1, CR2, CL1, and CL2 via the reference capacitances Cref. Note that 78 is the detection capacitance. Accordingly, the sum of the DC bias values VR1, VR2, VL1, and VL2 and the drive voltages V1, V2, V1⁻, and V2⁻ via the reference capacitances Cref is applied to the opposing electrode terminals R1, R2, L1, and L2. The voltages of the opposing electrode terminals R1, R2, L1, and L2 are input into the buffers 80 where impedance transformation is carried out, after which signal processing is carried out. Although left out of Figure 21 for the sake of simplicity, resistors are connected in parallel to each of the reference capacitances CR1, CR2, CL1, and CL2 to stabilize the DC bias values of the output voltages as shown in Figure 25 (one of the four capacitances in Figure 25).

[0045] The voltages of R1 and R2 and of L1 and L2 are added by an adder 81, and a subtractor 82 finds the difference, and these are then input into a demodulator 83 via a high-pass filter 89. After carrying out synchronous detection with an oscillator 86 using the demodulator 83, the signal passes through the low-pass filter 84, part is returned to the oscillator 85 for self-excited oscillation of the vibrating mass, and the other part is once again input into the demodulator 83. This time synchronous detection with the oscillator 85 is carried out, and the signal passes through the low-pass filter 84 and is input into a control

circuit 87 as amplitude information of the vibrating mass. Output proportional to the angular velocity is output by the control circuit 87, and a voltage signal synced to the oscillator 85 is also output. Part of the voltage signal synced to oscillator 85 is input into an inverter 88 and the other part is input as-is into the adder 81. Both signals are added to the output from the oscillator 86 and the output of each is applied to the reference capacitances Cref to drive the vibrating mass. The voltages of L1 and R1 and of L2 and R2 are added by the adder 81, and the subtractor 82 finds the difference, and these are input to the demodulator 83 via the high-pass filter 89. This time synchronous detection is carried out with the oscillator 86, and the signal passes through the low-pass filter 84 and is input into the control circuit 87 as displacement information of the vibrating mass due to the Coriolis force.

[0046] The control circuit 87 is realized as shown in Figure 26, for example. The displacement information and the amplitude information are input into arithmetic units 91. In the arithmetic units 91, the displacement information and the amplitude information are calculated as modulation amounts of the drive voltage, based on a deviation from zero level for the displacement information and based on a deviation from a set reference level for the amplitude information. In the diagrams, the modulation amounts are indicated as a for the displacement information and b for the amplitude information. The modulation amount a is output as the angular velocity which is input via an amplifier 93. Part of the modulation amount a is added to the modulation amount b in the adder 81 as-is and part with the sign inverted by the inverter 88 to calculate Δ_1 and Δ_2 . In other words,

$$\Delta_1 = a + b \quad \dots\dots (7)$$

$$\Delta_2 = -a + b \quad \dots\dots (8)$$

The calculated modulation amounts Δ_1 and Δ_2 are input into an amplitude modulator 92 where the amplitude of the oscillator 85 is modulated according to each, and the drive voltages Vd1 and Vd2 are output.

[0047] Returning to Figure 21, synchronous detection using the oscillator 86 in the demodulator 83 may also be done by detecting the frequency of the signal using a PLL element 89 as shown in Figure 23, and using that frequency to carry out detection using the homodyne method which performs synchronous detection. The signals synchronously detected with the oscillator 85 in the demodulator 83 are input into the control circuit 87 as amplitude and displacement information, but the demodulator may be replaced with an integrating circuit.

[0048] Operation of this circuit will now be described, with regard to driving of the vibrating mass. When a voltage V is applied to the opposing electrodes R1, R2, L1, and L2 via the reference capacitances Cref, and electrostatic force Fd is produced as shown in equation (9) below in the drive axis direction of the vibrating mass.

[0049]

$$F_d = -n/2 \cdot \epsilon_0 \cdot t/d_0 \cdot V^2 \quad \dots\dots (9)$$

Where,

n: number of electrodes opposing the comb electrodes on the vibrating mass

ϵ_0 : dielectric constant

t: thickness of the comb electrodes

d_0 : electrode gap

The minus sign indicates that the driving force is produced so as to increase overlapping of the electrodes. The impedance of the capacitance is represented by equation (3)

$$Z_c = 1 / j \omega C \quad \dots\dots (3)$$

discussed above, so when an AC drive voltage is applied to the vibrating mass via the reference capacitances Cref as shown in Figure 21, the AC drive voltage applied to the capacitances CR1, CL1, CR2, and CL2 between the vibrating mass and the opposing electrodes is represented by equation (10) below.

[0050]

$$V_{\sim} = 1 / (C_s / C_{ref} + 1) \times V_{\sim drive} \quad \dots\dots (10)$$

Where $V_{\sim}$: AC voltage applied to the capacitances CR1, CL1, CR2, and CL2 between the vibrating mass and the opposing electrodes

$V_{\sim drive}$: the drive voltages V1, V2, V1⁻, and V2⁻ applied via the capacitances Cref

C_s : capacitances CR1, CL1, CR2, and CL2 between the vibrating mass and the opposing electrodes

Accordingly, if Cref is made significantly greater than the capacitances CR1, CL1, CR2, and CL2 between the vibrating mass and the opposing electrodes, almost all loss of the drive voltage at Cref can be ignored. Even if the capacitances CR1, CL1, CR2, and CL2 change due to the vibrating plate being driven and vibrating, the AC drive voltage that is applied is proportional to the drive voltages V1, V2, V1⁻, and V2⁻ via the capacitances Cref. Since the actual CR1, CL1, CR2, and CL2 values are in the pF range, the Cref can easily be realized on the same substrate. As shown in Figure 24, the sum of the outputs of the oscillator 85, which has a period matching the resonant frequency of the vibrating mass, and the oscillator 86 (OSC2, s amplitude; vc), which has a higher frequency and smaller output amplitude than the oscillator 85 (OSC1, amplitude; vd), is used for the drive voltage. More specifically, in Figure 21, the output from the oscillator 85 (OSC1) is input to the control circuit 87, and the adder 81 adds the output from the oscillator 86 (OSC2) to the output from the control circuit 87, producing a sum. The drive voltages V1 and V2 which are produced are applied to R1 and R2 in Figures 19 and 20 via the reference capacitances Cref, and the drive voltages V1⁻ and V2⁻ are applied to L1 and L2 in Figures 19 and 20 via the reference capacitances Cref. The output of the oscillator 85 (OSC1) has opposite phases for V1 and V2 and for V1⁻ and V2⁻. The voltage in equation (9) applied to R1 and R2 and to L1 and L2 is the sum of the DC biases and the AC voltages V1, V2, V1⁻, and V2⁻ applied via the reference capacitances Cref, i.e., as shown in equations (11) and (12).

[0051]

$$V1, V2 = V_{bias} + vd \cdot \sin \omega_1 t + vc \cdot \sin \omega_2 t \quad \dots\dots (11)$$

$$V1^-, V2^- = V_{bias} - vd \cdot \sin \omega_1 t + vc \cdot \sin \omega_2 t \quad \dots\dots (12)$$

Where, V_{bias} : DC bias voltage of opposing electrode terminals R1, R2, L1, and L2

ω_1 : oscillation frequency of oscillator 85 (OSC1)

vd: output amplitude of oscillator 85 (OSC1)

ω_2 : oscillation frequency of oscillator 86 (OSC2)

vc: output amplitude of oscillator 86 (OSC2)

If equations (11) and (12) are substituted into equation (9), the resulting electrostatic force is in opposite directions for R1 and R2 and for L1 and L2, ultimately producing an electrostatic driving force represented by equation (13) below in the vibrating mass.

[0052]

$$F_{drive} \propto V_{bias} \cdot v_d \cdot \sin \omega_1 t + v_d \cdot v_c \cdot \sin \omega_1 t \cdot \sin \omega_2 t \dots (13)$$

The second term can be ignored if $v_d \gg v_c$. It has a frequency which is sufficiently higher than ω_1 , so the drive system which has a resonant frequency near ω_1 is unaffected. Accordingly, the vibrating mass vibrates at ω_1 .

[0053] The change in C_s due to x-axis direction driving of the vibrating mass and y-axis direction displacement due to the Coriolis force is represented by equation (14) below, where C_s is the electrostatic capacitance between the vibrating mass and the opposing electrode terminals R1, R2, L1, and L2, L is the overlap of the comb electrodes at rest, and d is the comb electrode gap.

[0054]

$$C_s = C_s^0 (1 + x/L) / (1 + y/d) \dots (14)$$

Where, C_s^0 : electrostatic capacitance when at rest

The AC voltages V_{R1} , V_{R2} , V_{L1} , V_{L2} of the opposing electrode terminals R1, R2, L1, and L2 when the sum of the output v_d from the oscillator 85 (OSC1) and the output v_c of the oscillator 86 (OSC2) via the reference capacitances is applied to the opposing electrodes as shown in the detection circuit in Figure 21 become as shown in equations (15) to (18) below after equation (14) is substituted into equation (10). Note that only the first-order terms in x/L and y/d have been expanded.

[0055]

$$V_{R1} = 1/B \cdot (1 - A \cdot x/L + A \cdot y/d) \cdot (v_d + v_c) \dots (15)$$

$$V_{R2} = 1/B \cdot (1 - A \cdot x/L - A \cdot y/d) \cdot (v_d + v_c) \dots (16)$$

$$V_{L1} = 1/B \cdot (1 + A \cdot x/L + A \cdot y/d) \cdot (-v_d + v_c) \dots (17)$$

$$V_{L2} = 1/B \cdot (1 + A \cdot x/L - A \cdot y/d) \cdot (-v_d + v_c) \dots (18)$$

Where, $A = (C_s^0 / C_r) / ((C_s^0 / C_r) + 1)$ $B = (C_s^0 / C_r) + 1$

C_r : reference capacitance

The displacement x due to driving of the vibrating mass is found as follows. The voltages of V_{R1} and V_{R2} and of V_{L1} and V_{L2} undergo impedance conversion in the buffers 80, are added in the adder 81, and the difference is found by the subtractor 82. The result is shown in equation (19) below.

[0056]

$$(V_{R1} + V_{R2}) - (V_{L1} + V_{L2}) = 4/B \cdot (v_d - A \cdot x/L \cdot v_c) \dots (19)$$

The first term is removed by the high-pass filter 89 and input into the demodulator 83. Synchronous detection with the oscillator 86 is carried out by the demodulator 83 and smoothing is done thereafter with the low-pass filter 84. The smoothed signal has the same frequency as the oscillator 85 (OSC1), and the amplitude is proportional to the drive amplitude of the vibrating mass. This signal is fed back to the oscillator 85 (OSC1) for self-excited oscillation. At the same time, in order to realize AGC functionality, synchronous detection is again carried out with the oscillator 85 by the demodulator 83, after which the signal is smoothed by the low-pass filter 84 and then input into the control circuit 87 which controls the amplitude of the drive voltages V_1 and V_2 .

[0057] The displacement y of the vibrating mass due to the Coriolis force is found as follows. The Coriolis force which is produced is proportional to the vibration velocity of the vibrating mass as shown in

equation (2) above, so in the third embodiment the signal has the same frequency as the oscillator 85 (OSC1) and an amplitude proportional to the displacement due to the Coriolis force.

[0058] The voltages of VR1 and VL1 and of VR2 and VL2 undergo impedance conversion in the buffers 80 and are then added in the adder 81 and the difference is found in the subtractor 82. The result is shown in equation (20) below.

$$(VR1 + VL1) - (VR2 + VL2) = 4A/B \cdot y/d \cdot v_c \dots (20)$$

This is input into the demodulator 83 through the high-pass filter 89. After synchronous detection is carried out with the oscillator 86 by the demodulator 83, the low-pass filter 84 performs smoothing. The smoothed signal has the same frequency as the oscillator 85 (OSC1) and has an amplitude proportional to the displacement due to the Coriolis force. The signal is once again input into the demodulator 83 and synchronous detection is carried out, this time with the oscillator 85, after which smoothing is performed using the low-pass filter 84. The smoothed signal is proportional to the displacement of the vibrating mass due to the Coriolis force, and is input into the control circuit 87 for modulation of the voltages V1 and V2. In the synchronous detection by the demodulator 83 using the oscillator 86, the PLL element 89 shown in Figure 23 is used to detect the frequency of the signal, and homodyne detection which carries out synchronous detection at that frequency is carried out, making high-precision demodulation possible.

[0059] The drive voltages V1 and V2 are modulated in the control circuit 87 as follows. Application of the drive voltage via the reference capacitances Cref causes the electrostatic force shown in equations (21) and (22) below to be applied between the vibrating mass and the opposing electrodes in the direction of the detection axis of the Coriolis force in Figures 17 and 18. That direction narrows the electrode gap.

[0060]

$$F_{s1} = \epsilon_0 m \cdot L t / (d_0)^2 \cdot (C V_1)^2 \dots (21)$$

$$F_{s2} = \epsilon_0 m \cdot L t / (d_0)^2 \cdot (C V_2)^2 \dots (22)$$

Where, m: number of opposing electrode pairs

C: coefficient representing the drop in the drive voltage due to the reference capacitance Cref

ϵ_0 : dielectric constant

L: distance between opposing electrodes

t: thickness of the electrodes

The drive voltages are modulated so that $V_1 = V_1^0 (1 + \Delta_1)$ and $V_2 = V_2^0 (1 + \Delta_2)$. Canceling out the produced Coriolis force Fc requires only satisfying the relationship in equation (23) below.

[0061]

$$F_c = F_{s1} - F_{s2} \approx \epsilon_0 m \cdot (C V^0)^2 / d^2 \cdot (\Delta_1 - \Delta_2) \dots (23)$$

Note, however, that for simplicity's sake we have made $V^0 = V_1^0 = V_2^0$. The drive voltage applied to the vibrating mass at this point is represented by equation (24) below.

$$F_d \approx \epsilon_0 m t \cdot (C V^0)^2 / d \cdot \{1 + (\Delta_1 + \Delta_2)\} \dots (24)$$

Accordingly, by modulating the drive voltage as shown in equations (7) and (8) and applying a modulation slightly larger than the absolute value and with the opposite sign, the produced Coriolis force can be compensated without affecting the drive amplitude of the vibrating mass as shown in equation (25).

[0062]

$$F_c \approx \epsilon_0 m \cdot (C V^0)^2 / d^2 \cdot 2a \dots (25)$$

If noise input or the like causes variations in the drive amplitude of the vibrating mass, modulating the drive voltage as shown in equations (7) and (8) and applying the modulation b which has the same absolute value and the same sign makes it possible to change the driving force and control the amplitude without producing electrostatic force on the vibrating mass in the direction of the detection axis as shown in equation (26) below.

[0063]

$$F_d \approx \epsilon_0 m t \cdot (CV^0)^2 / d \cdot \{1 + 2b\} \dots\dots (26)$$

By inputting the amplitude information of the vibrating mass and the displacement information due to the Coriolis force in the control circuit 87, the drive voltage can be modulated as described above, and the drive amplitude can be equalized and the Coriolis force can be compensated simultaneously, making it possible to achieve high-precision detection with an angular velocity sensor having a simple structure.

[0064] The following effects are obtained with the third embodiment.

a: The detection electrodes and driving electrodes are the same, and driving of the vibrating mass and displacement due to the Coriolis force can be measured simultaneously, so the potential and capacitance of the electrodes opposing the vibrating mass can be achieved efficiently.

b: The electrodes opposing the vibrating mass are segmented in two and voltages can be applied independently to each segment, the driving amplitude of the vibrating mass can be kept constant while at the same time compensating the produced Coriolis force.

c: The Coriolis force is compensated using the drive voltage, so the measurement range for the angular velocity is expanded.

d: The Coriolis force is compensated by the drive voltage, so the vibrating mass does not vibrate in the direction of the detection axis, allowing even greater precision in measuring angular velocity.

[0065] Fourth embodiment: This embodiment relates to claim 19. The configuration of the angular velocity sensor is the same as in the third embodiment. Figure 22 shows the detection circuit configuration in the present embodiment. Only those parts which are different from the third embodiment (Figure 21) will be discussed. In the present embodiment, synchronous detection with the oscillator 86 (OSC2) is performed in the demodulator 83, the waveform is shaped by the low-pass filter, and the resulting signals are input into the control circuit 87 as displacement information and amplitude information. The outputs V_{d1} and V_{d2} from the control circuit are input into an ideal diode circuit 90, part as-is and part via the inverter 88. The output from the oscillator 86 (OSC2) is added to the output from the ideal diode circuit 90 and applied to the vibrating mass via reference capacitances 79 as drive voltages V_1 , V_2 , V_1^- , and V_2^- .

[0066] Figure 28 shows the drive voltages V_1 , V_2 , V_1^- , and V_2^- applied via the reference capacitances 79. The drive voltages are made up of a voltage v_d for generating the driving force and a voltage v_c which is for reading out the displacement due to the Coriolis force and has an amplitude which is significantly smaller than v_d and the amplitude of the vibrating mass. v_d is the output of the oscillator 85 (OSC1) via the inverter 88 and the ideal diode circuit 90. v_c is the output of the oscillator 86 (OSC2). v_c may either be the unipolar pulse shown in Figure 28(a) or the bipolar pulse shown in Figure 28(b). v_d and v_c are applied alternately. A time band during which no voltage is applied during application of v_d and v_c is provided, but the essential functionality remains the same even if this time band is not present. v_d is applied with the opposite phase of V_1 and V_2 and of V_1^- and V_2^- . v_c is applied simultaneously to V_1 and V_2 and to V_1^- and V_2^- during a time band τ during which v_d is not applied. The vibrating mass is oscillated at the same

frequency as the oscillator 85 (OSC1) by the electrostatic force produced in accordance with equation (9) discussed above by application of v_d . The read-out voltage v_c is applied simultaneously to V_1 and V_2 and to V_1^- and V_2^- , so if the vibrating mass is not being displaced by the Coriolis force, the electrostatic force produced is canceled out by v_c . v_c has an amplitude that is significantly smaller than v_d , so even if the vibrating mass is displaced, the electrostatic force which is produced is negligible.

[0067] As shown in Figure 22, the sum and difference of the voltages of the opposing electrode terminals R1, R2, L1, and L2 are found via the buffers 80. These signals are synchronously detected with the oscillator 86 (OSC2), thereby obtaining information on the amplitude due to driving the vibrating mass and the displacement due to the Coriolis force, like in the third embodiment. Subsequent processing is the same as in the third embodiment and therefore omitted here.

[0068] The fourth embodiment provides the effects of the third embodiment as well as the following effects. a: Synchronous detection using the oscillator 86 (OSC2) is sufficient to obtain displacement information and amplitude information, so the signal processing circuitry can be kept simple.

Fifth embodiment: This embodiment relates in particular to claim 20. The configuration of the angular velocity sensor is the same as in the third embodiment. Figure 27 shows the detection circuit configuration in this embodiment. Only those parts that are different from the fourth embodiment (Figure 22) will be discussed. In the fifth embodiment, the potential V_m of the vibrating mass is connected to the oscillator 86 (OSC2). The outputs V_{d1} and V_{d2} from the control circuit are output, part as-is and part through the inverter 88, and applied to the vibrating mass via the reference capacitances 79 as the drive voltages V_1 , V_2 , V_1^- , and V_2^- .

[0069] Figure 29 shows the drive voltages V_1 , V_2 , V_1^- , and V_2^- applied via the reference capacitances 79. The drive voltage is made up of voltage v_d for generating the driving force. v_d is the output from the oscillator 85 (OSC1) (part via the inverter 88). v_d has the opposite phase of V_1 and V_2 and of V_1^- and V_2^- , and is applied such that there is a time band τ during which v_d is not applied. v_c is the output of the oscillator 86 (OSC2) which has an amplitude significantly smaller than v_d , and is applied to the vibrating mass during the time band τ . v_c may either be the unipolar pulse shown in Figure 28(a) or the bipolar pulse shown in Figure 28(b). The vibrating mass is oscillated at the same frequency as the oscillator 85 (OSC1) by the electrostatic force produced in accordance with equation (9) discussed above by applying v_d . The read-out voltage v_c is applied to the vibrating mass during the time band τ . If the vibrating mass is not displaced by the Coriolis force, the electrostatic force produced by v_c is canceled out. v_c also has an amplitude which is significantly smaller than v_d , so even if the vibrating mass is displaced, the produced electrostatic force is negligible.

[0070] As shown in Figure 27, the sum and difference of the voltages of the opposing electrode terminals R1, R2, L1, and L2 are found via the buffers 80. Like in the third embodiment, synchronous detection with the oscillator 86 (OSC2) allows information on the amplitude due to driving of the vibrating mass and displacement due to the Coriolis force to be obtained from these signals. Subsequent processing is the same as in the third embodiment and is therefore not described. The effects of the fifth embodiment are the same as the effects of the fourth embodiment.

[0071]

[Effects of the Invention] As described above, the present invention is fabricated using semiconductor technology, so the effect provided is that of being able to easily and cheaply mass-produce high-sensitivity

and high-precision angular velocity sensors which are compact and lightweight and are not readily susceptible to noise acceleration and other types of noise. Note that the effects are described in detail in the embodiments.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Figure 1] is a schematic plan view of a first embodiment.

[Figure 2] is a schematic cross-sectional view of a first embodiment.

[Figure 3] is a schematic plan view of a first embodiment.

[Figure 4] is a view for describing effects on driving force of unequal gaps between opposing electrodes formed between a vibrating mass and securing sections, and means to relieve these effects.

[Figure 5] is a view describing segmenting the securing section-side opposing electrodes into two sets to which voltages can be applied independently in order to relieve the effects on driving force of unequal gaps between the opposing electrodes formed between the vibrating mass and the securing sections.

[Figure 6] is an enlarged plan view of detection electrode pairs for detecting y-axis direction displacement due to the Coriolis force.

[Figure 7] is a view showing an example of deviation produced in the cross-sectional shape of a structural material in an embodiment due to variations in the manufacturing process.

[Figure 8] is a view describing a fabrication process when the structural material is polysilicon.

[Figure 9] is a view describing a fabrication process when the structural material is an SOI layer.

[Figure 10] is a view describing a fabrication process when the structural material is plated metal.

[Figure 11] is a view showing one example of a vibrating mass drive and signal detection circuit according to the first embodiment.

[Figure 12] is a view showing one example of a vibrating mass drive and signal detection circuit according to the first embodiment.

[Figure 13] is a view showing one example of a vibrating mass drive and signal detection circuit according to the first embodiment.

[Figure 14] is a view showing an example in which one structural element is used to realize a support having a structure which is symmetrical in an axial direction bisecting an angle formed by the x- and y-axes in the first embodiment.

[Figure 15] is a view showing an example in which multiple structural elements are used to realize a support having a structure which is symmetrical in an axial direction bisecting an angle formed by the x- and y-axes in the first embodiment.

[Figure 16] is a view showing an example in which multiple elastic structures are arranged symmetrically to an axial direction bisecting an angle formed by the x- and y-axes in the second embodiment.

[Figure 17] is a plan view describing the state of comb electrodes made up of vibrating mass-side electrodes and securing-side electrodes in the third embodiment.

[Figure 18] is a plan view describing the state of simpler comb electrodes made up of vibrating mass-side electrodes and securing-side electrodes in the third embodiment.

[Figure 19] is a general plan view for describing a method for supporting the vibrating mass using simple support members in the third embodiment.

[Figure 20] is a general plan view for describing a method for supporting the vibrating mass using multiple elastic structures in the third embodiment.

[Figure 21] is a view describing a configuration of an angular velocity detection circuit in the third embodiment.

[Figure 22] is a view describing a configuration of an angular velocity detection circuit in the fourth embodiment.

[Figure 23] is a view showing an example of a circuit when using a PLL element to detect a signal frequency in an angular velocity detection circuit and applying a homodyne method, which carries out synchronous detection at that frequency.

[Figure 24] is a view describing a drive voltage applied between opposing electrodes using an oscillator having a period which is equal to the resonant frequency of the vibrating mass and an oscillator which has a significantly higher frequency and smaller amplitude, in the third embodiment.

[Figure 25] is a view describing a detection electrode circuit in which resistors are connected in parallel to reference capacitances or electrostatic capacitances between the opposing electrode terminals and the vibrating mass to stabilize the DC bias value of the output voltage in the third embodiment.

[Figure 26] is a view showing an example configuration of a control circuit used in the angular velocity detection circuit shown in Figure 21.

[Figure 27] is a view describing the configuration of an angular velocity detection circuit in the fifth embodiment.

[Figure 28] is a view describing the drive voltages applied between the opposing electrodes via the reference capacitances in the fourth embodiment.

[Figure 29] is a view describing the drive voltages applied between the opposing electrodes via the reference capacitances in the fifth embodiment.

[Figure 30] is an oblique view of a first conventional example of an angular velocity sensor.

[Figure 31] is a plan view of a second conventional example of an angular velocity sensor.

[Figure 32] is a cross-sectional view of a second conventional example of an angular velocity sensor.

[Figure 33] is a drawing for describing problems which occur with the second conventional example.

[Figure 34] is a plan view of a third conventional example of an angular velocity sensor.

[Figure 35] is a lateral cross-sectional view of a third conventional example of an angular velocity sensor.

[Explanation of the Reference Numerals]

1...piezoelectric detection element

2...oscillator

3...support

4...piezoelectric drive element

5...securing section

6...driving electrode

7...anchor

8...support

9...detection electrode

10...vibrating mass

11...intermediate support

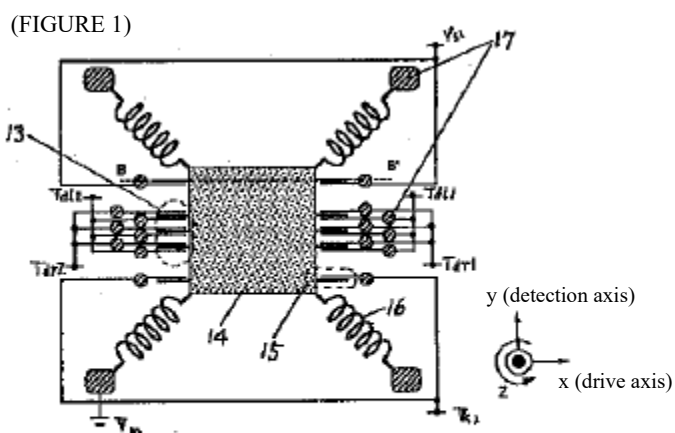
12...silicon substrate

13...driving electrode pair

14...vibrating mass
15...detection electrode pair
16...support
17...securing section
18...support
19...driving electrode
20...driving electrode affixed to substrate opposing left side of vibrating mass-side electrode
21...driving electrode secured to substrate opposing right side of vibrating mass-side electrode
22...high-concentration diffusion layer
23...silicon nitride film
24...oxidation film
25...polysilicon film
26...metal wiring
27...passivation film
28...silicon nitride film
29...high-concentration diffusion layer
30...passivation film
31...trench
32...plated metal film
33...sacrificial metal film
34...drive power supply OSC1
35...detection power supply OSC2
36...amplifier
37...demodulator
38...buffer
39...peak hold circuit
40...detection voltage supply OSC3
66...vibrating mass
67...connection section
68...opposing electrodes
69...opposing electrodes
70...comb electrodes
71...lead-out electrode
72...vibrating mass
73...support
74...securing section
75...electrode portion
76...support
77...vibrating mass
78...detection capacitance
79...reference capacitance Cref

- 80...buffer
- 81...adder
- 82...subtractor
- 83...demodulator
- 84...low-pass filter
- 85...oscillator OSC1
- 86...oscillator OSC2
- 87...control circuit
- 88...inverter
- 89...high-pass filter
- 90...ideal diode circuit
- 91...arithmetic unit
- 92...amplitude modulator
- 93...amplifier

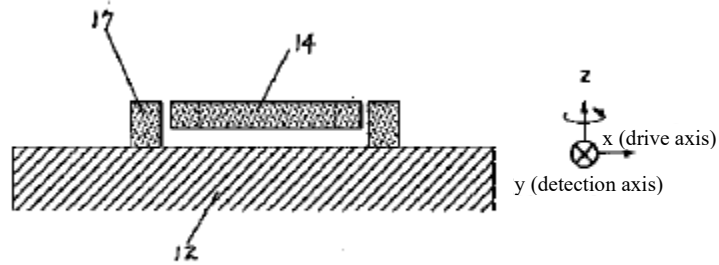
[FIGURE 1]



- 13...driving electrode pairs 14...vibrating mass 15...detection electrode pairs
16...supports 17...securing sections

[FIGURE 2]

(FIGURE 2)



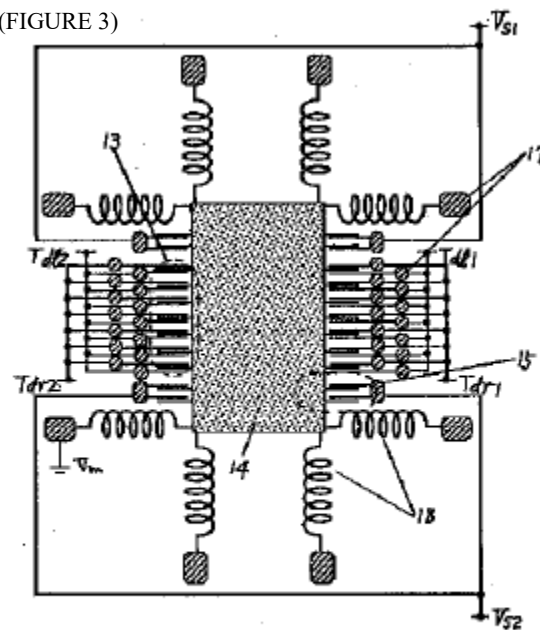
12...silicon substrate

14...vibrating mass

17...securing section

[FIGURE 3]

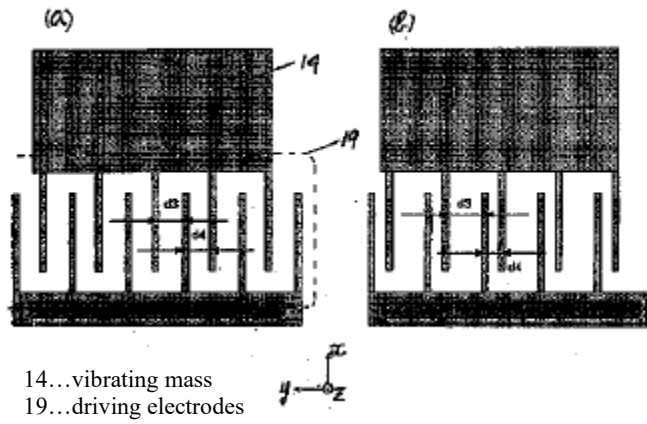
(FIGURE 3)



13...driving electrode pairs 14...vibrating mass 15...detection electrode pairs
 17...securing sections 18...supports

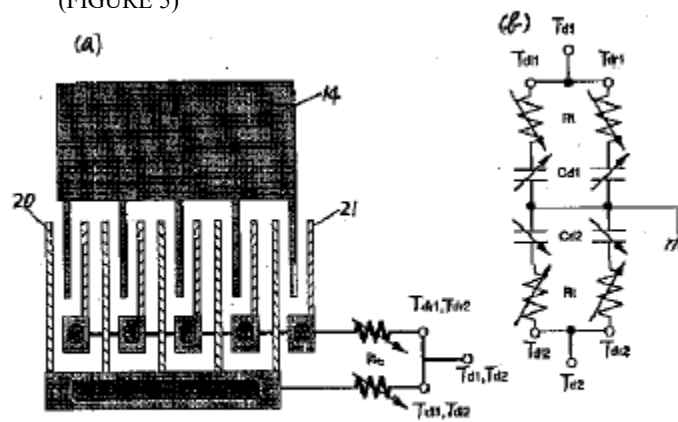
[FIGURE 4]

(FIGURE 4)



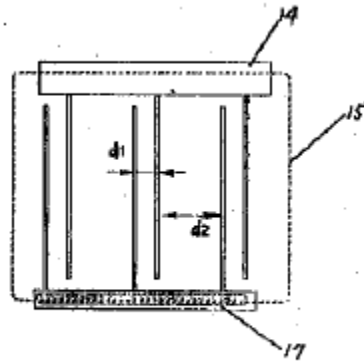
[FIGURE 5]

(FIGURE 5)



[FIGURE 6]

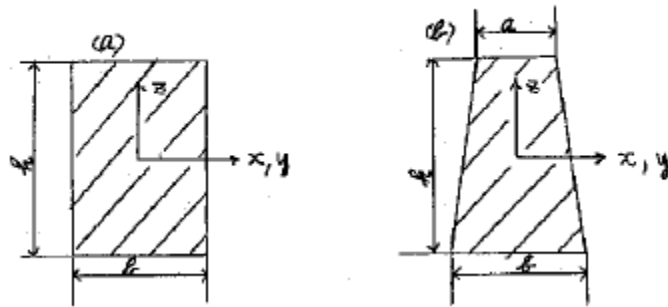
(FIGURE 6)



14...vibrating mass, 15...detection electrode pairs
17...securing section

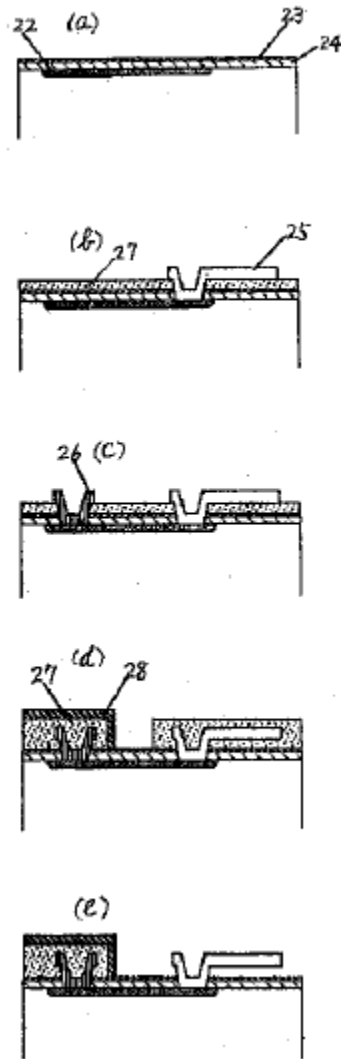
[FIGURE 7]

(FIGURE 7)



[FIGURE 8]

(FIGURE 8)



22...high-concentration diffusion layer

23...silicon nitride film

24...oxidation film

25...polysilicon film

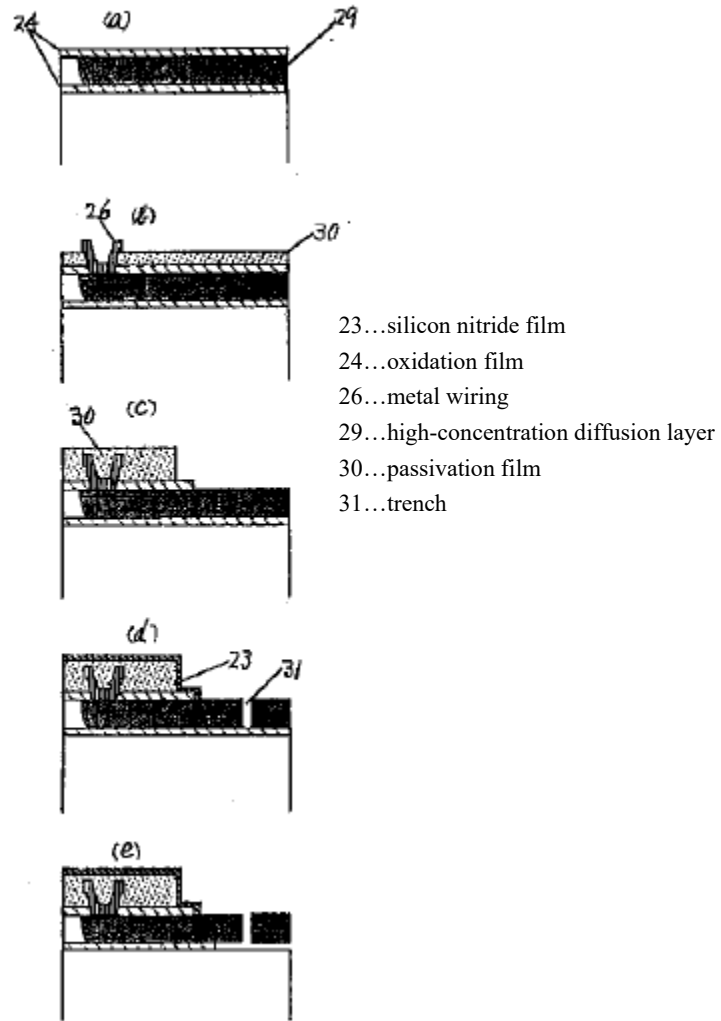
26...metal wiring

27...passivation film

28...silicon nitride film

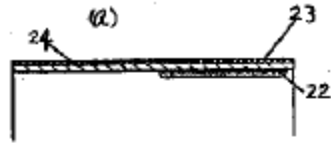
[FIGURE 9]

(FIGURE 9)



[FIGURE 10]

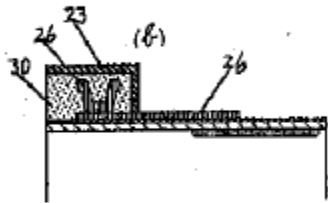
(FIGURE 10)



22...high-concentration diffusion layer

23...silicon nitride film

24...oxidation film

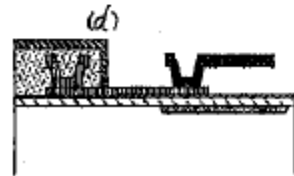
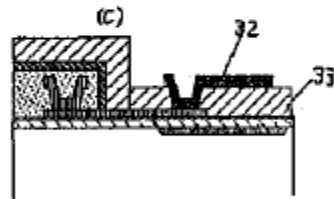


26...metal wiring

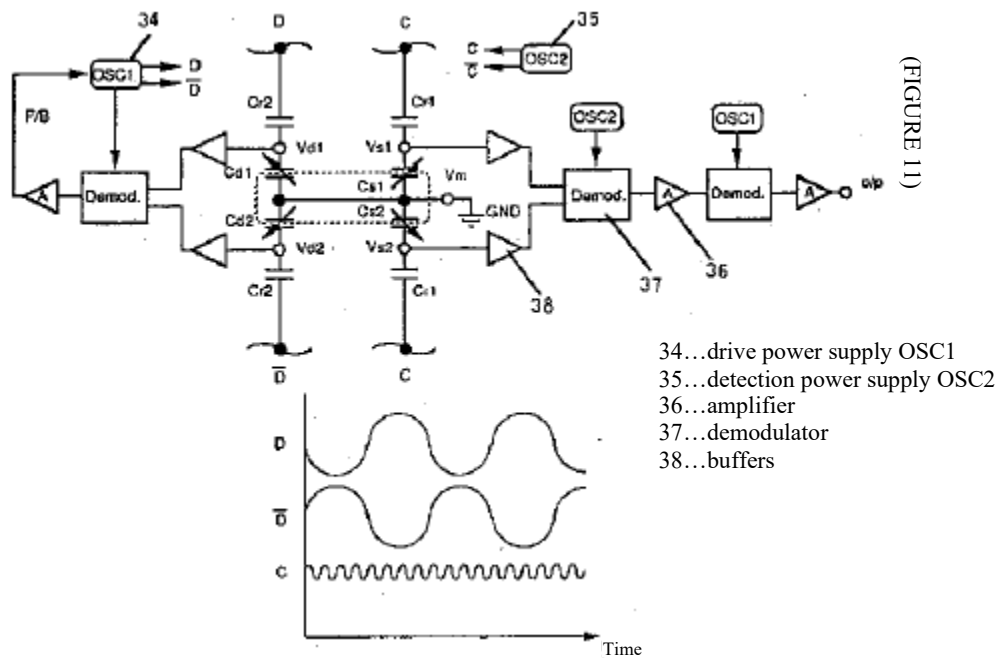
30...passivation film

32...plated metal film

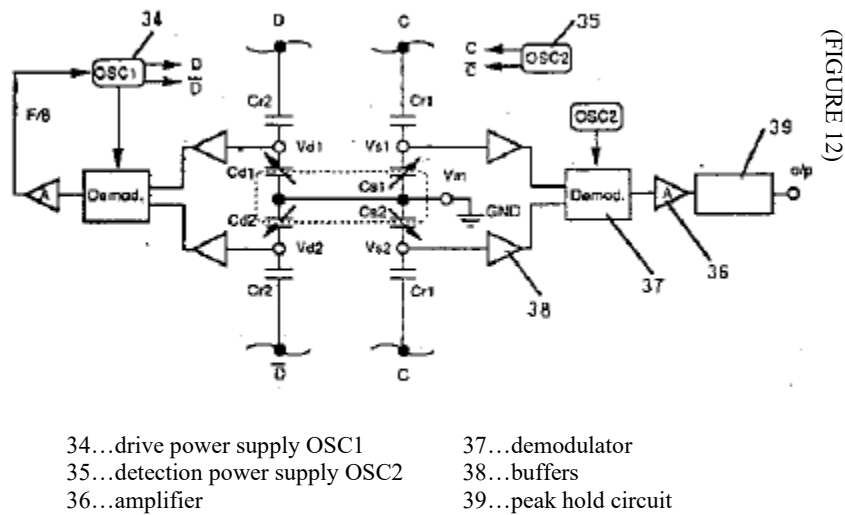
33...sacrificial metal film



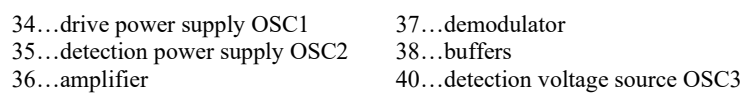
[FIGURE 11]



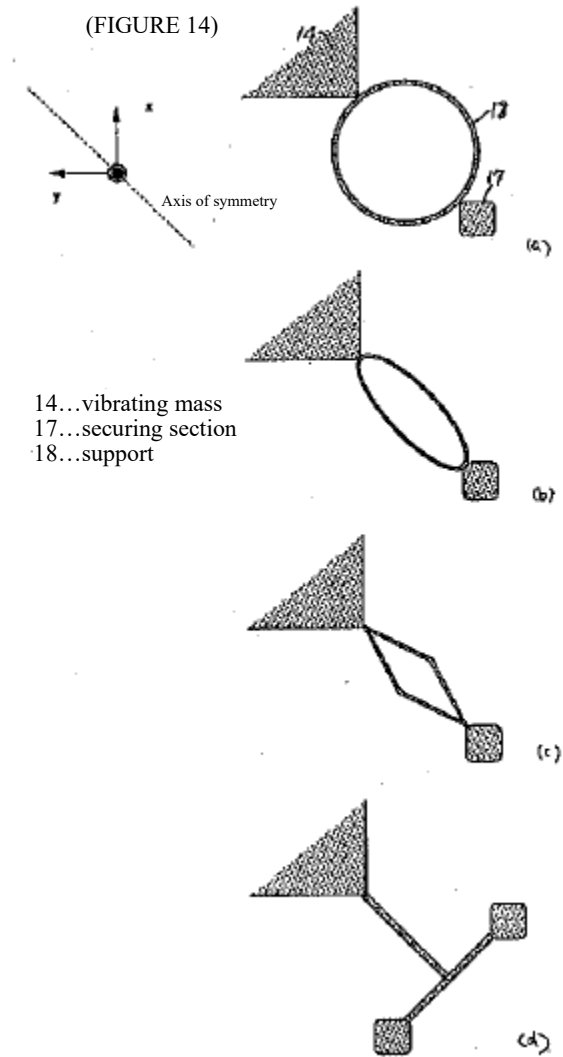
[FIGURE 12]



(FIGURE 13)

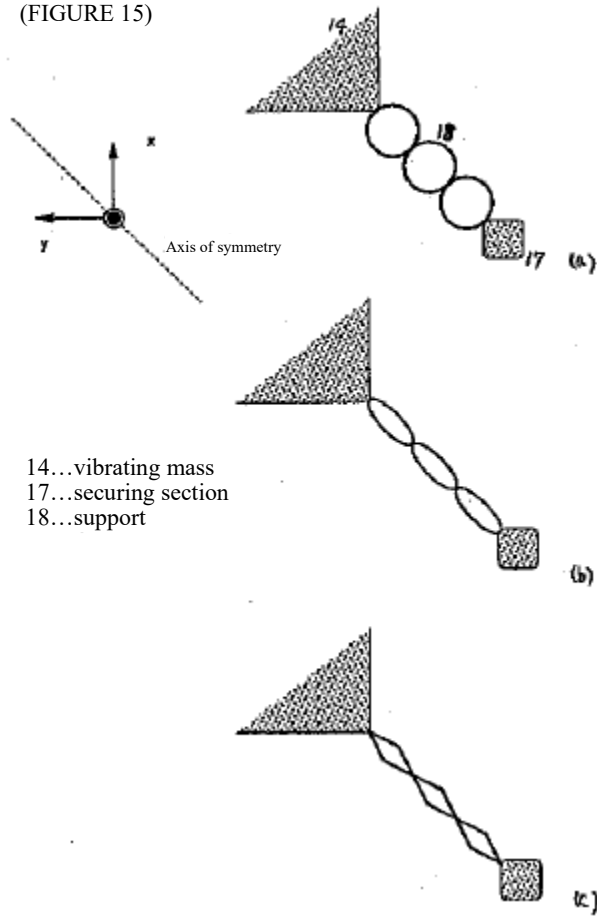


[FIGURE 14]



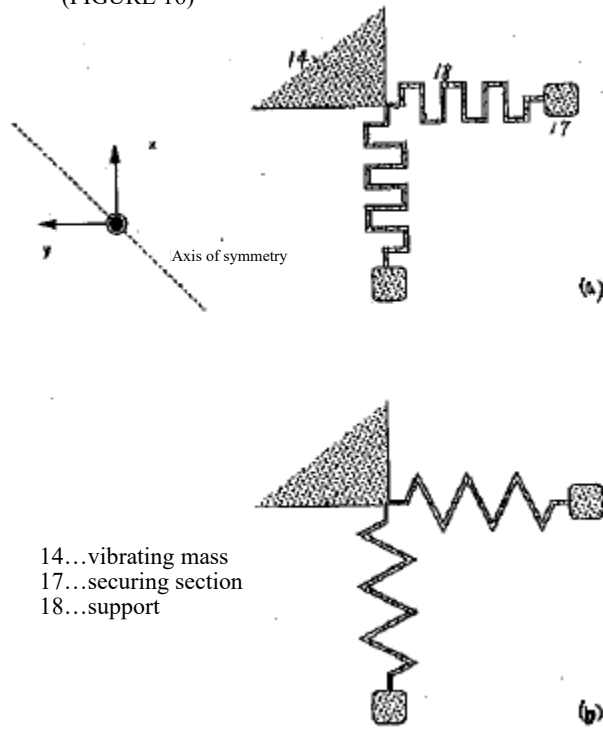
[FIGURE 15]

(FIGURE 15)



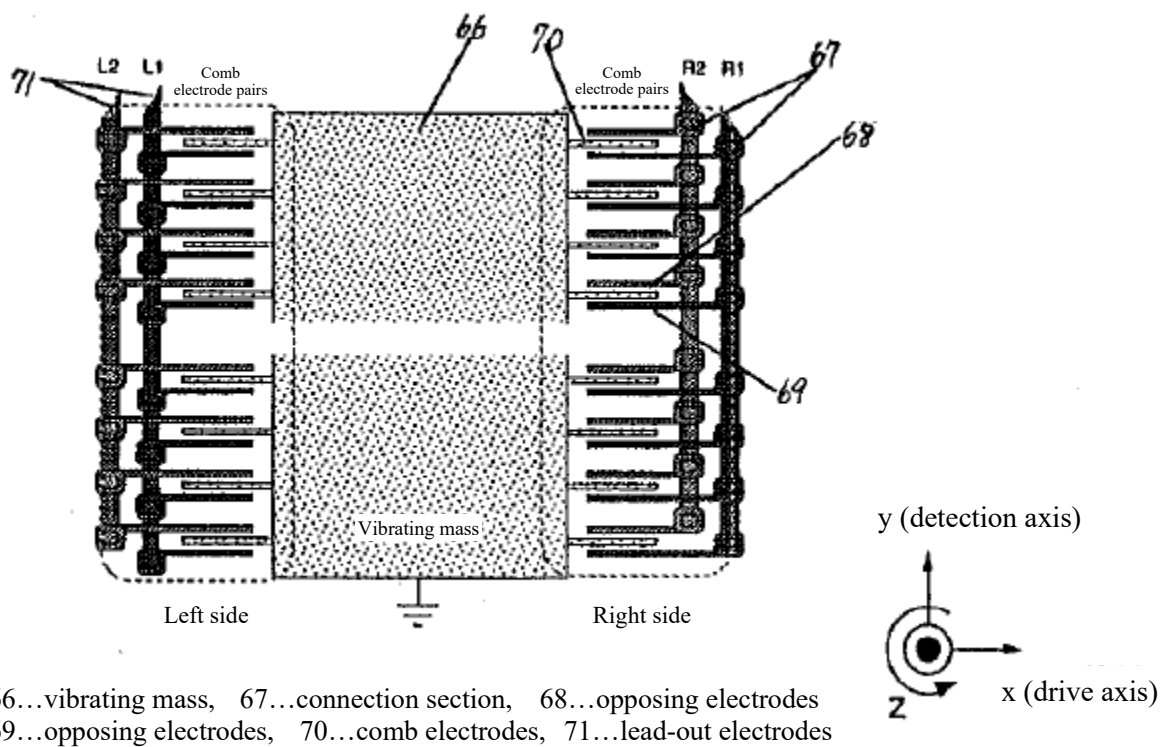
[FIGURE 16]

(FIGURE 16)

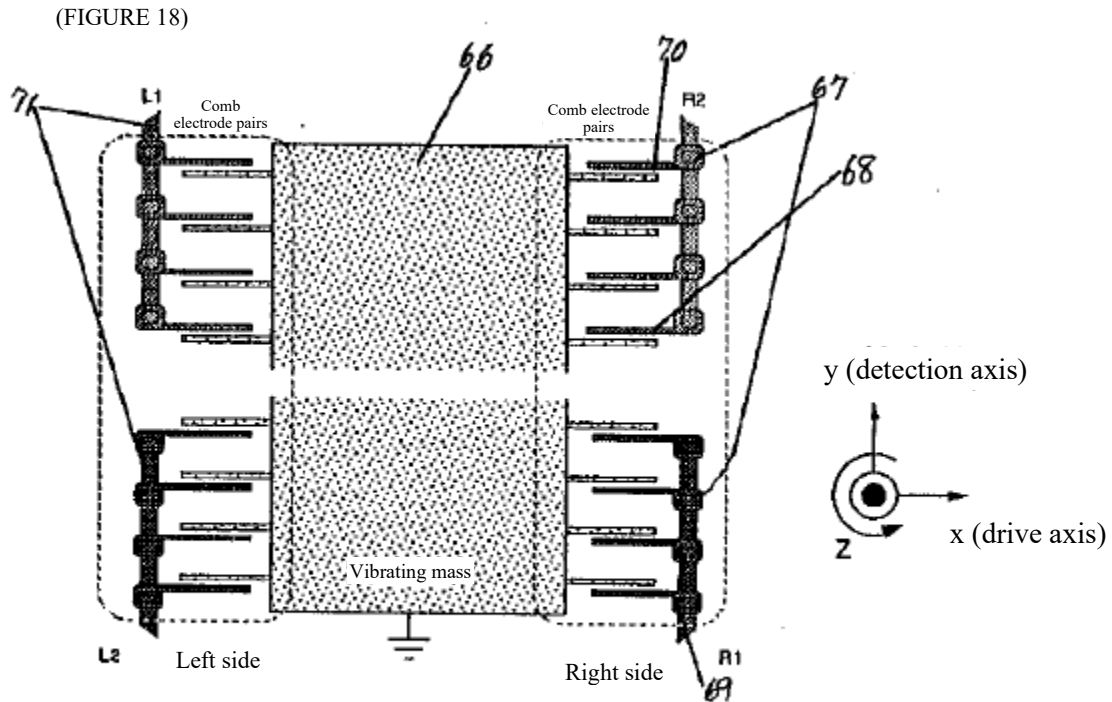


[FIGURE 17]

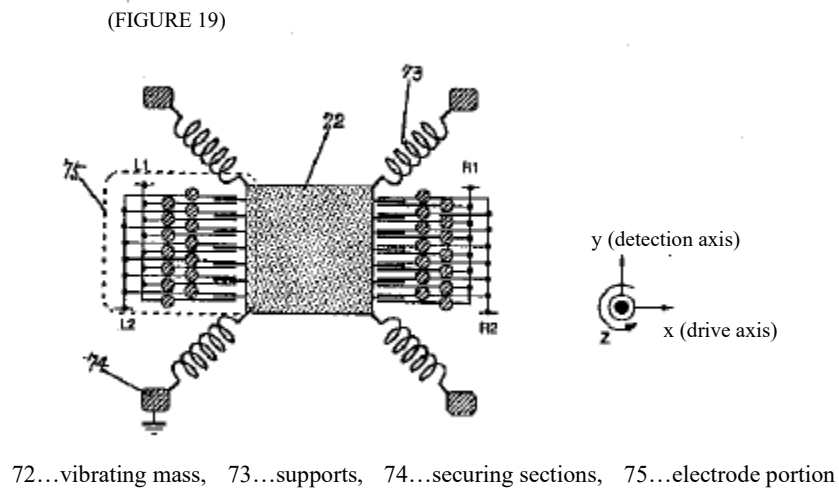
(FIGURE 17)



[FIGURE 18]

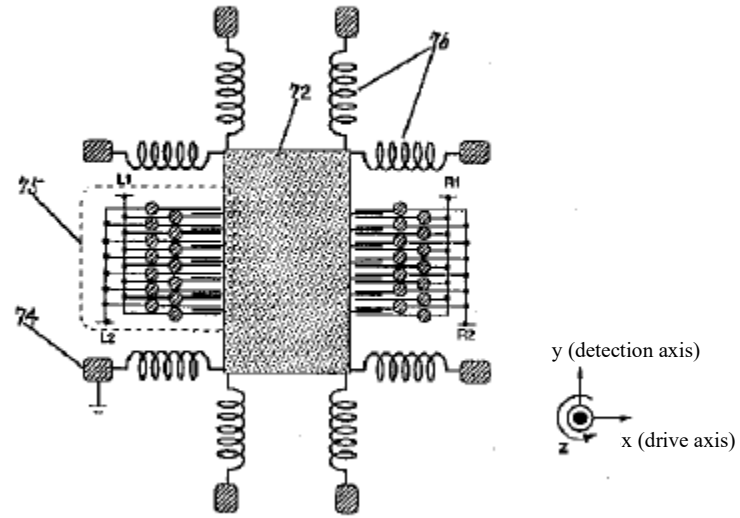


[FIGURE 19]

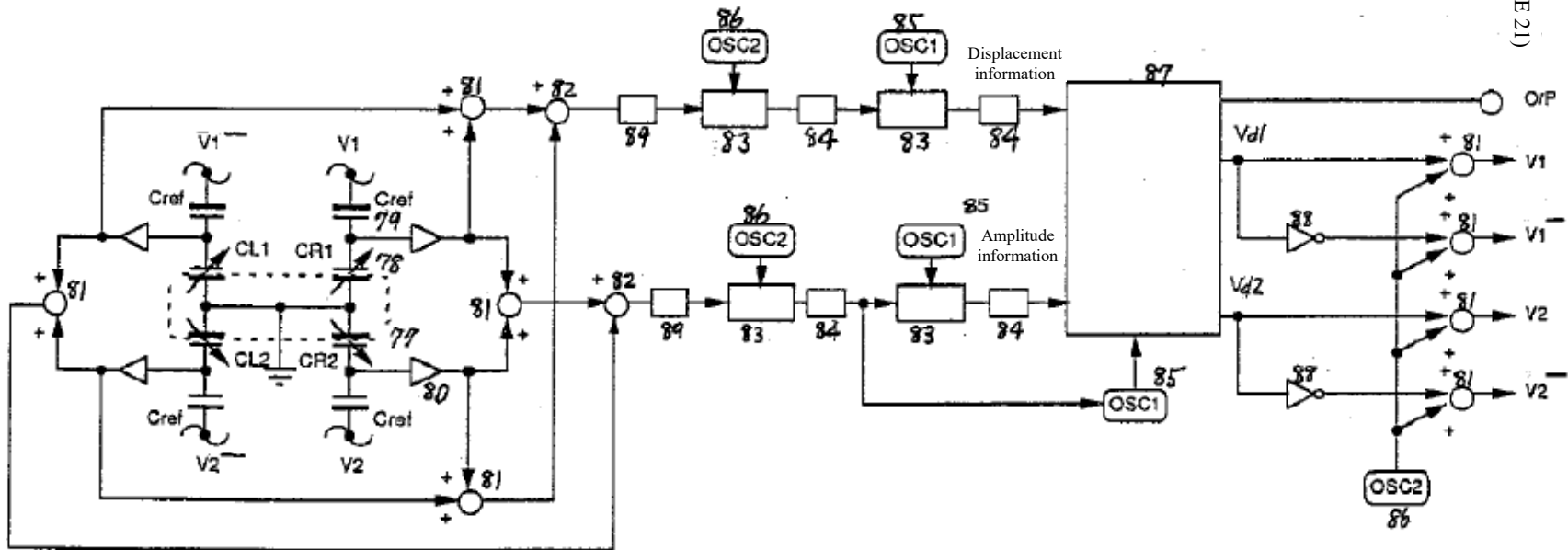


[FIGURE 20]

(FIGURE 20)

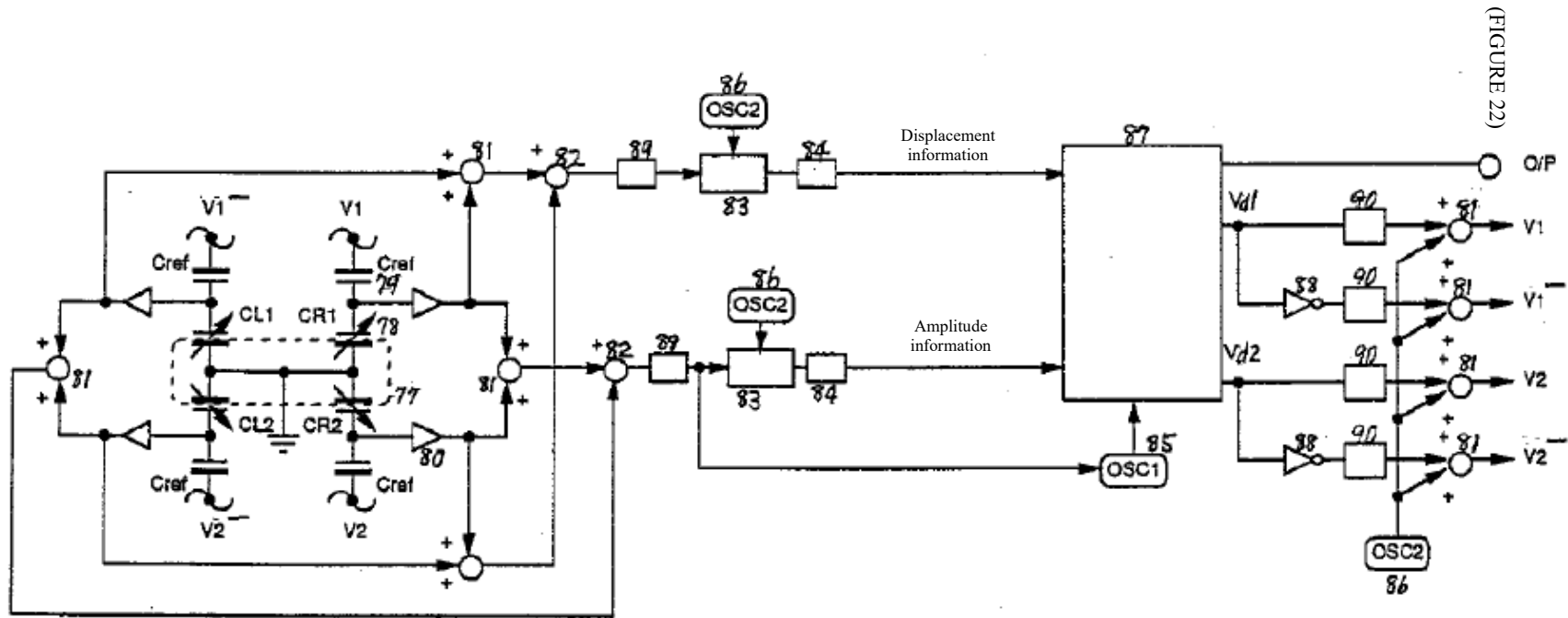


[FIGURE 21]



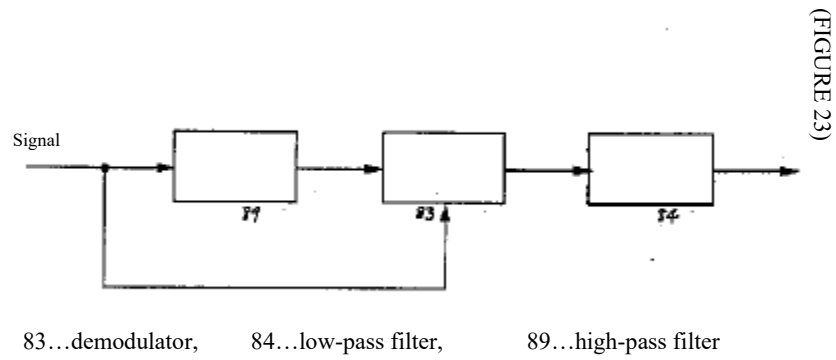
77...vibrating mass, 78...detection capacitance, 79...reference capacitance Cref, 80...buffers, 81...adder
 82...subtractor, 83...demodulator, 84...low-pass filter, 85...oscillator OSC1, 86...oscillator OSC2
 87...control circuit, 88...inverter, 89...high-pass filter

[FIGURE 22]



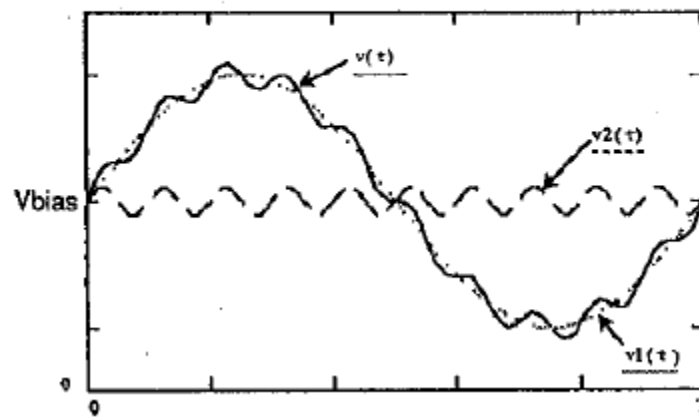
77...vibrating mass, 78...detection capacitance, 79...reference capacitance C_{ref} , 80...buffers, 81...adder
 82...subtractor, 83...demodulator, 84...low-pass filter, 85...oscillator OSC1, 86...oscillator OSC2
 87...control circuit, 88...inverter, 89...high-pass filter, 90...ideal diode circuit

[FIGURE 23]



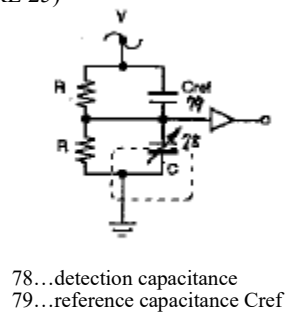
[FIGURE 24]

(FIGURE 24)

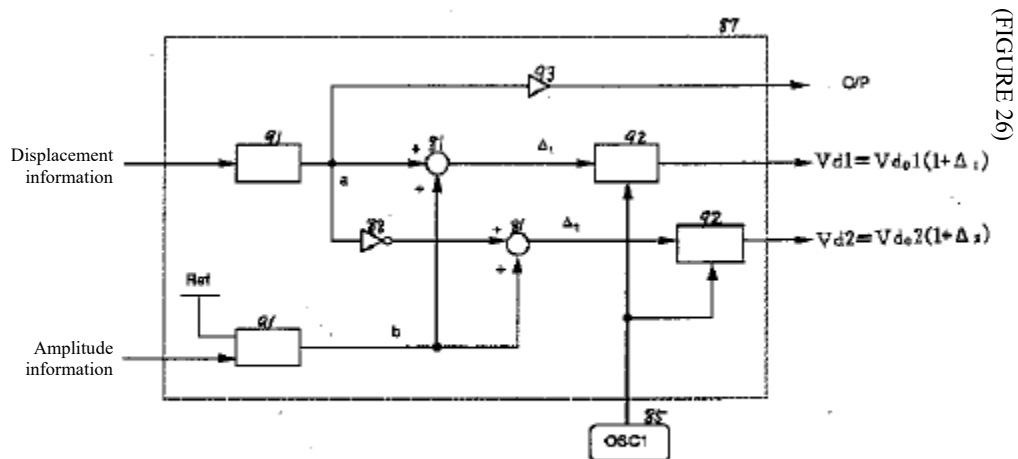


[FIGURE 25]

(FIGURE 25)

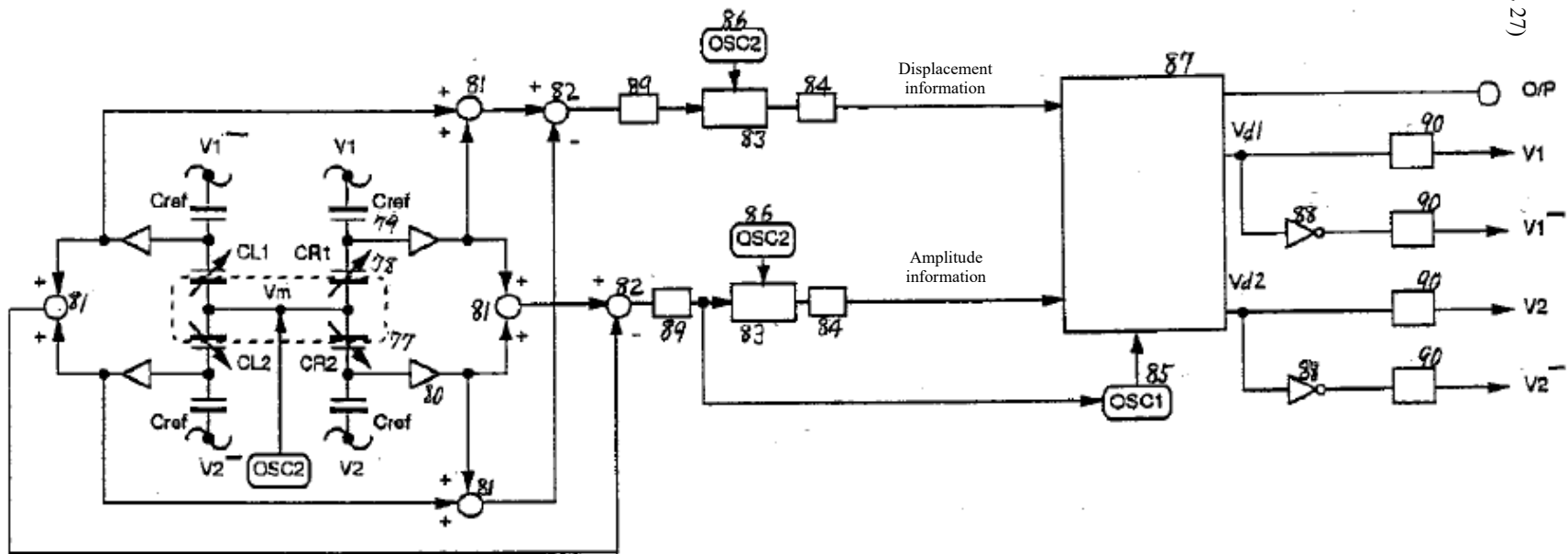


[FIGURE 26]



81...adder addition 85...oscillator OSC1, 87...control circuit, 88...inverter, 91...arithmetic unit
 92...amplitude modulator 93...amplifier

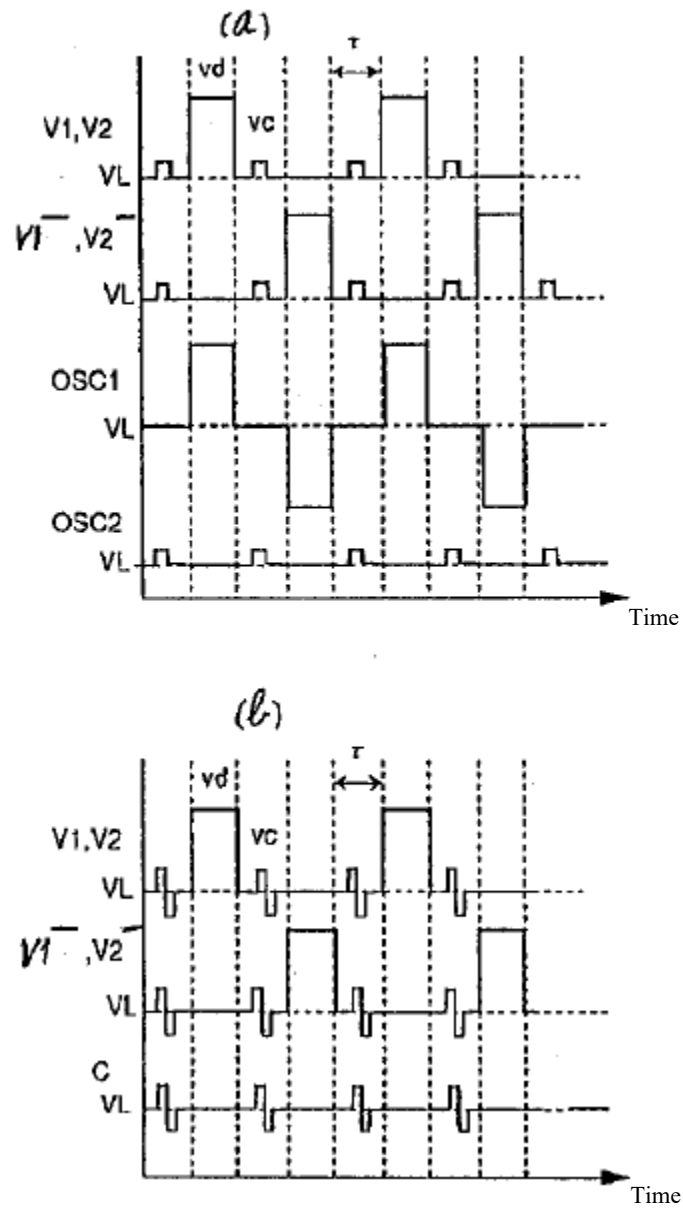
[FIGURE 27]



77...vibrating mass, 78...detection capacitance, 79...reference capacitance C_{ref} , 80...buffers, 81...adder
82...subtractor, 83...demodulator, 84...low-pass filter, 85...oscillator OSC1, 86...oscillator OSC2
87...control circuit, 88...inverter, 89...high-pass filter, 90...ideal diode circuit

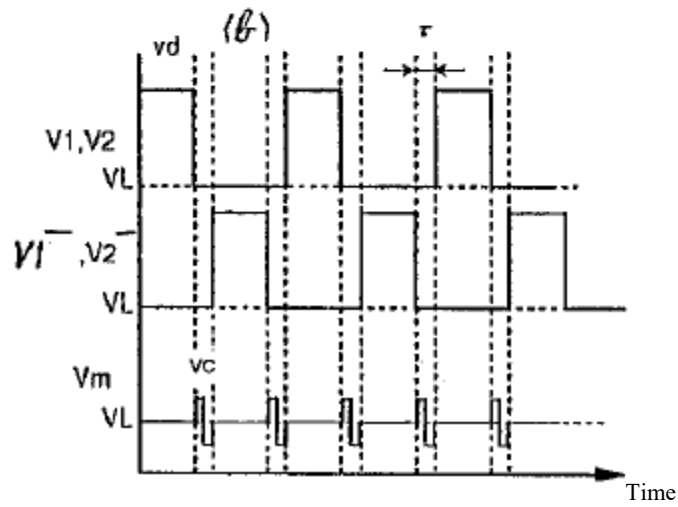
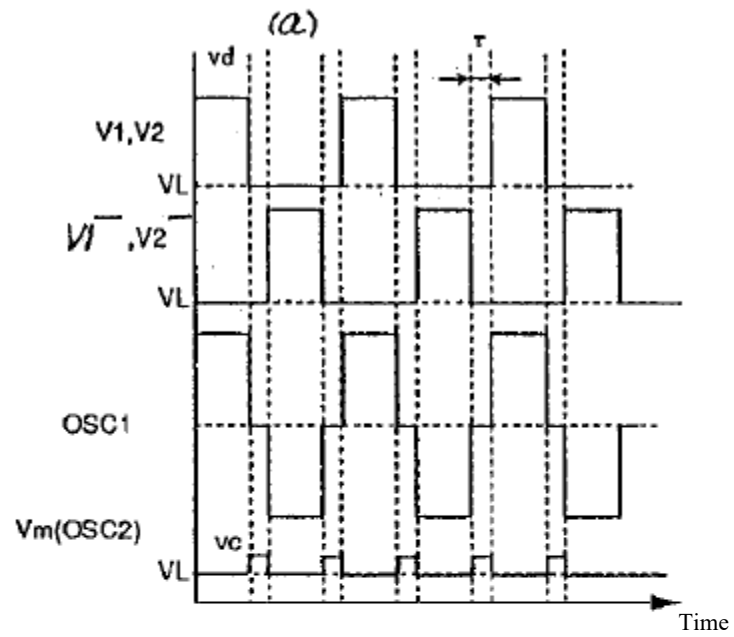
[FIGURE 28]

(FIGURE 28)



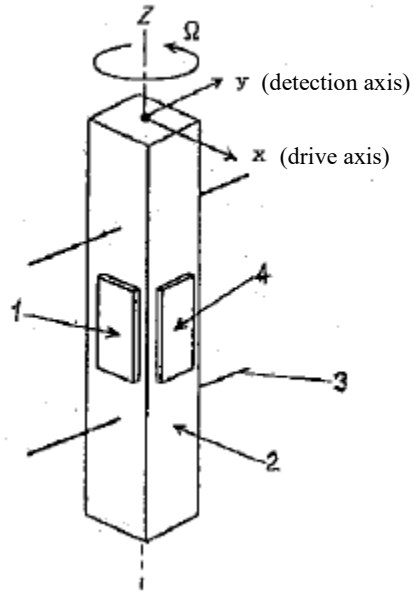
[FIGURE 29]

(FIGURE 29)



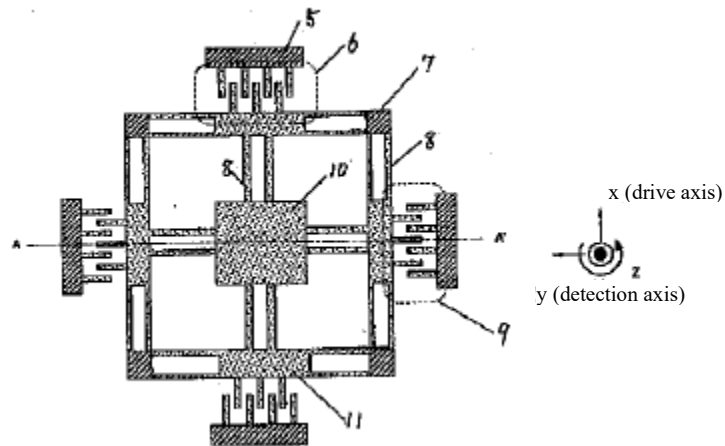
[FIGURE 30]

(FIGURE 30)



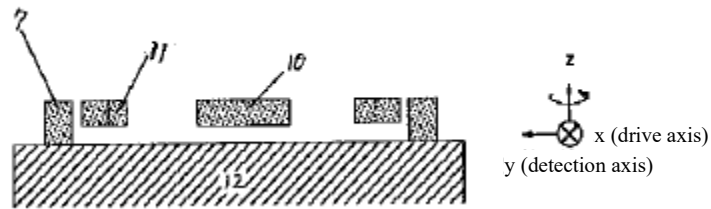
[FIGURE 31]

(FIGURE 31)



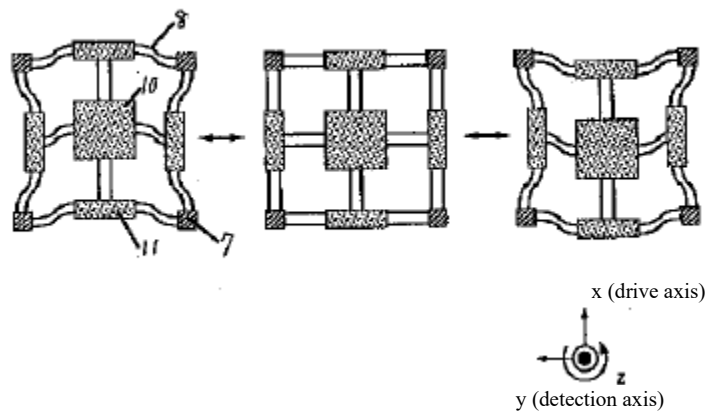
[FIGURE 32]

(FIGURE 32)



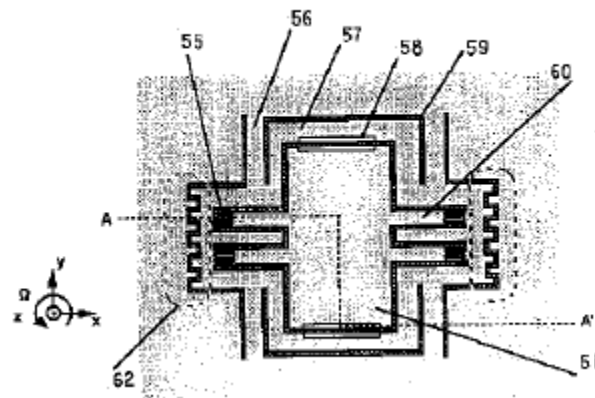
[FIGURE 33]

(FIGURE 33)



[FIGURE 34]

(FIGURE 34)



[FIGURE 35]

(FIGURE 35)

