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[54] **SENSOR WITH SEPARATE ACTUATOR AND SENSE FINGERS**

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Related U.S. Patent Documents

Reissue of:

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Issued: **Oct. 15, 1996**
Appl. No.: **08/347,795**
Filed: **Dec. 1, 1994**

[51] **Int. Cl.**[7] **G01P 15/08**

[52] **U.S. Cl.** **73/514.16**; 73/862.451; 73/763

[58] **Field of Search** ..... 73/514.16, 514.35, 73/517 R, 516 R, 517 AV, 518, 763, 862.392, 862.451

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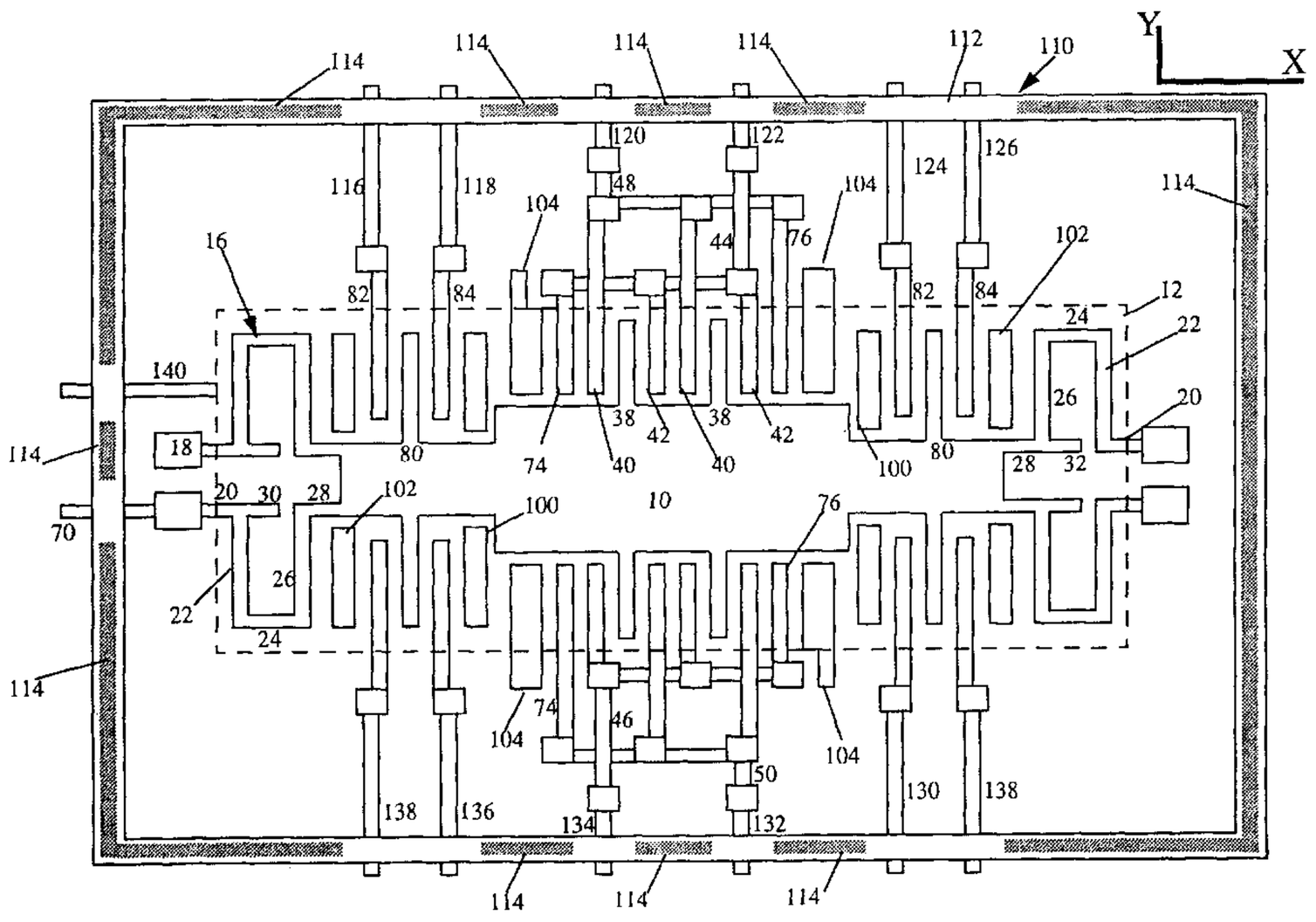
[57] **ABSTRACT**

A micromachined force sensor containing separate sensing and actuator structures. A member is suspended above the substrate so that it is movable along an axis in response to a force. The member includes a set of parallel sense fingers and a separate set of parallel force fingers. The sense fingers are positioned between fingers of two sense plates, to form a first differential capacitor, whose capacitance changes when the member moves in response to a force along the axis. The change in capacitance induces a sense signal on the member, which permits the measurement of the magnitude and duration of the force. The force fingers are positioned between fingers of two actuator plates, to form a second differential capacitor. The sense signal can be used to provide feedback to the second differential capacitor to generate different electrostatic forces between the force fingers and the two actuator plates, to offset the force applied along the preferred axis. Limit stops limit the movement of the member to less than the distance between the electrodes of the differential capacitors, to prevent contact between the electrodes. Additional fingers be positioned around the differential capacitors to minimize parasitic capacitances.

39 Claims, 2 Drawing Sheets



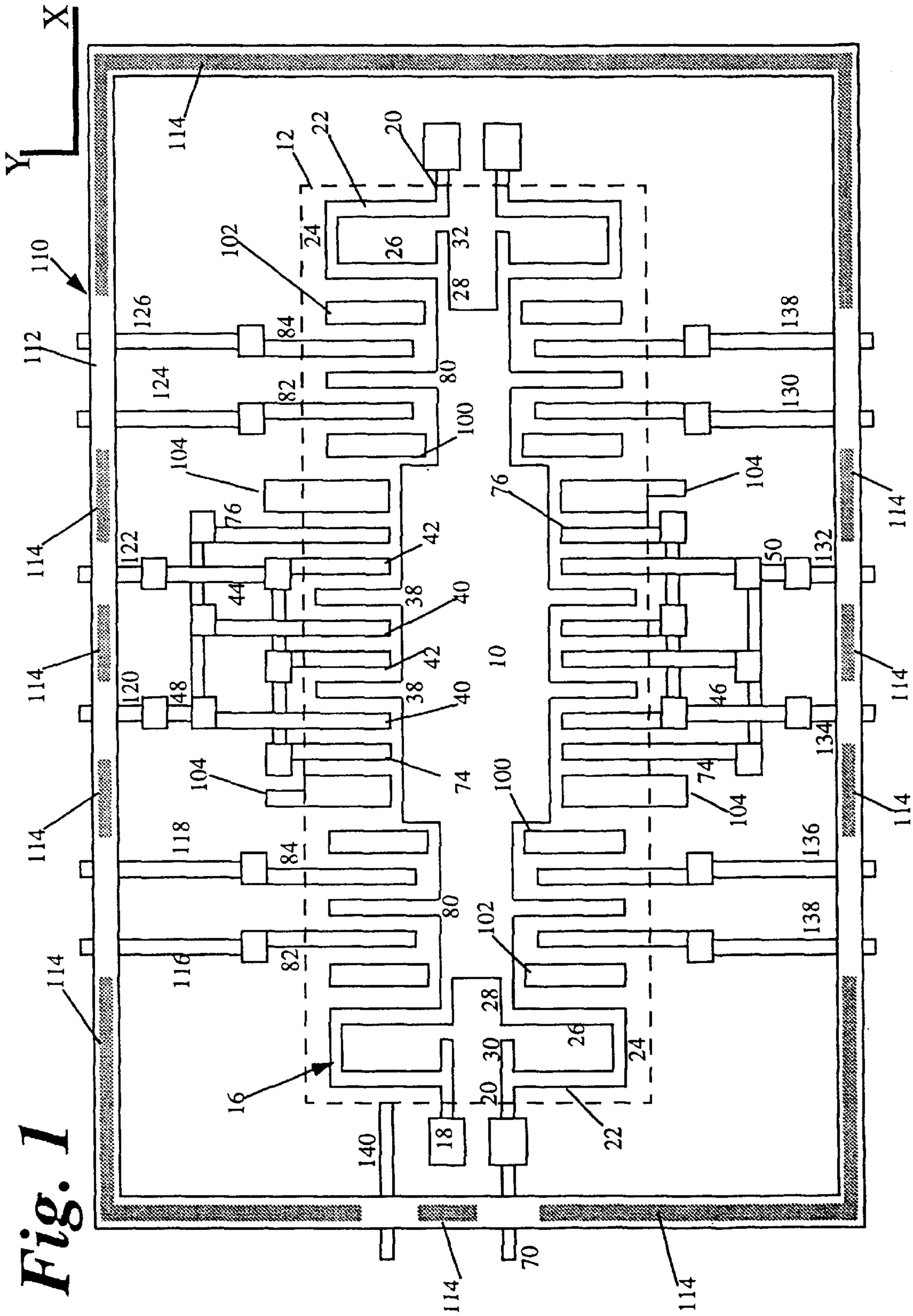

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Fig. 1

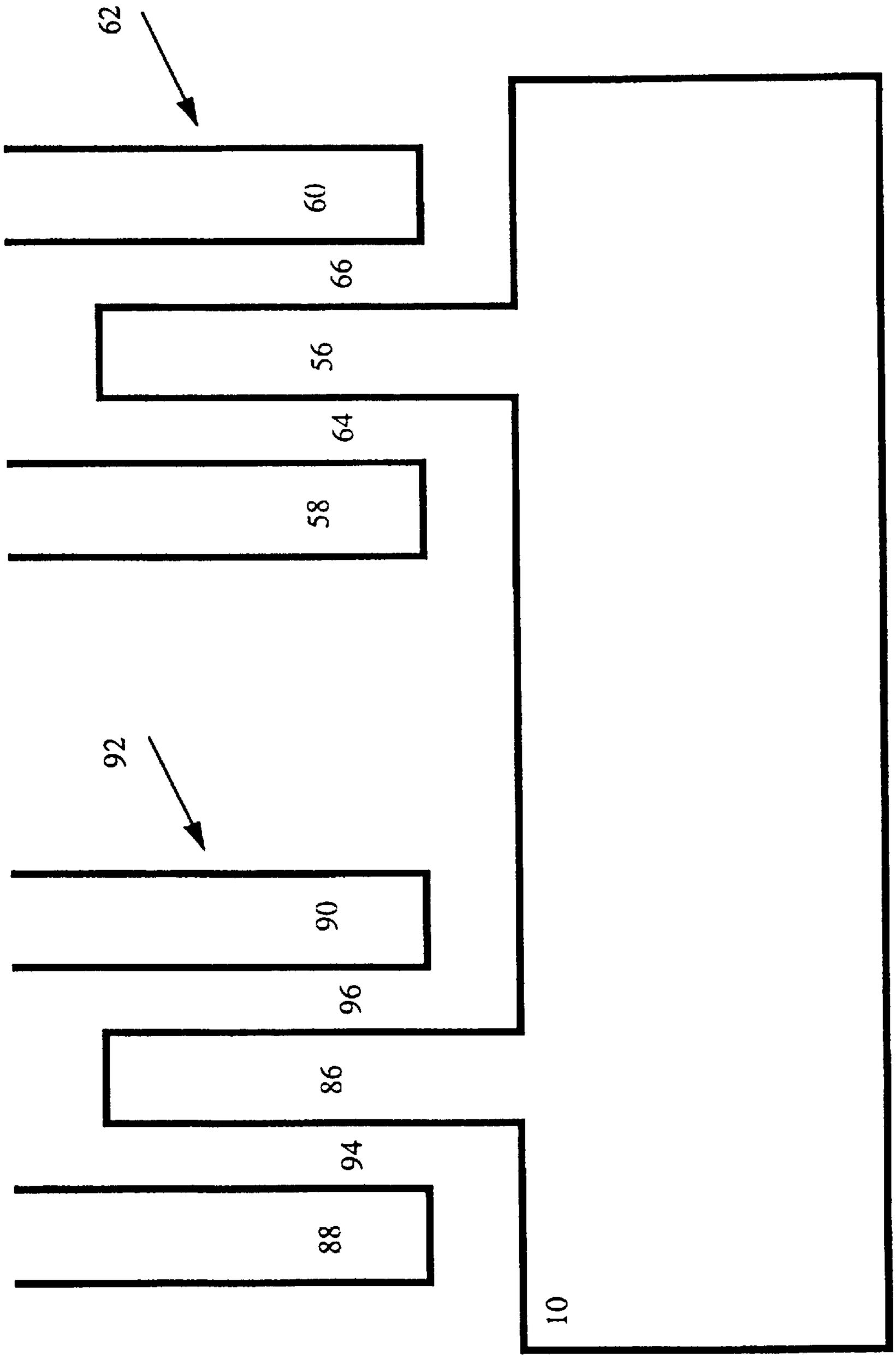

Fig. 2

SENSOR WITH SEPARATE ACTUATOR AND SENSE FINGERS

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

FIELD OF THE INVENTION

This invention relates to the field of force and motion-sensing detectors and, more particularly, to surface-micromachined sensors.

BACKGROUND OF THE INVENTION

Micromachined silicon structures frequently are used as sensors and actuators, and for signal processing. For example, in some existing micromachined sensors, micromachined silicon structures are used to detect and measure acceleration, and sometimes use electrostatic or other forces to restore a movable member to its original position. Acceleration may be measured with piezoresistors or capacitors, typically a differential capacitor.

In a capacitive system, the movable member is positioned midway between two plates so that one capacitor is formed by one plate and the member and a second (and equal) capacitor is formed by the second plate and the member. To maximize the capacitance, the member may contain numerous fingers that are interleaved between fingers from the two plates. Various shapes and arrangements of the capacitor plates have been used.

In one such system, the application of a force along a sensitive axis causes the member to move relative to the plates, causing a change in the capacitances of the two capacitors of the differential capacitor, and a signal appears on the member that reflects the amount of acceleration. This signal may be fed back to the member with a negative feedback loop, to create electrostatic forces that will offset the acceleration and maintain the member centered between the plates. An accelerometer based on this principle and a process for fabricating such an accelerometer are described in commonly assigned U.S. Pat. Nos. 5,345,824, 5,326,726, and 5,314,572.

Although this structure is well-suited to measure large accelerations (on the order of 50 g's), it is inadequate to measure accelerations on the order of 5 's, where greater sensitivity is required. In order to obtain this greater sensitivity, it is important to reduce electrostatic forces and parasitic capacitances in the sensing function. The present invention solves this problem as set forth in the remainder of the specification referring to the drawings.

SUMMARY OF THE INVENTION

The present invention is directed to a sensor that is configured to have the sensing and feedback functions separated, while maximizing the symmetry and sensitivity of the sensing structures. As the sensor is designed to measure small accelerations, the sensor of the present invention has such a compliant suspension that, unless prevented, large accelerations would cause the member fingers to touch the plate fingers. Features are etched into the structure which limit the travel of the sensor and prevent contact, which could result in permanent attachment of the member and plate fingers.

In the sensor of the present invention, a movable member is made by forming a polysilicon beam above a silicon substrate. In a preferred embodiment, between the member and the substrate is an n+ doped emitter diffusion region, which serves as a bootstrap electrode to reduce capacitance between the substrate and the beam. Suspension arms connect the ends of the beam to four anchors. The suspension arms permit the beam to move along a principal axis in response to a force along that axis.

The member has a series of parallel fingers extending transverse to its principal axis, preferably on either side. The two end fingers on either side of the member are separated from the remaining fingers by polysilicon shields anchored to the bootstrap diffusion.

A first set of polysilicon sense plates extend parallel to and to the left of each of the middle member fingers, and a second set of polysilicon sense plates extend parallel to and to the fight of each of the middle member fingers. The sense plates are not connected to the member. All of the first set of polysilicon sense plates are connected, as are all of the second set of polysilicon sense plates. The interleaving of the two sets of sense plates and the middle member fingers forms a differential sense capacitor. The capacitance of the sense differential capacitor will vary in response to a force along the principal axis, which causes the member fingers to move relative to the sense plates.

The sense plates are connected to two high frequency signals of the same amplitude and frequency, but 180 degrees out of phase. When no force component parallel to the sensitive axis is applied to the sensor, the high frequency signals on the member cancel each other. However, when a force is applied parallel to the sensitive axis, the member and its fingers move relative to the sense plates, and the change in capacitances causes the high frequency signal, with its amplitude modulated in proportion to the force, to appear on the member. This permits the measurement of the force.

The feedback function is provided with separate actuator plates. A first set of polysilicon actuator plates extend parallel to and to the left of each of the four end member fingers, and a second set of polysilicon actuator plates extend parallel to and to the fight of each of the four end member fingers. The actuator plates are not connected to the member. All of the first set of actuator plates are connected, as are all of the second set of actuator plates. The interleaving of the two sets of actuator plates and the end member fingers forms a force differential capacitor. As with the sense differential capacitor, a force along the principal axis causes the member fingers to move relative to the actuator plates.

The actuator plates are connected to two different biasing voltages. When no force is applied to the sensor, the member is maintained at a potential midway between the two biasing voltages, which causes no net electrostatic force on the member. When a force is applied, a feedback loop may be used to apply a voltage to the member that will create a net electrostatic force on the member. The different electrostatic forces between the member fingers and the two sets of actuator plates push the member back toward its original position. The electric circuits for the sense circuit and the actuator circuit are described in commonly assigned U.S. patent application No. 08/347,703, entitled Electric Field Attraction Minimization Circuit, and filed Dec. 1, 1994 by Stephen R. Lewis and Yang Zhao, which is incorporated herein by reference.

Polysilicon shield plates electrically isolate the actuator plates from the sense plates and the suspension arms.

To prevent the member fingers from moving into the sense plates or the actuator plates in response to a force along the principal axis, the suspension arms include protrusions to limit the movement of the member.

An object of the present invention to provide an improved sensor.

Another object of the present invention to provide a micromachined sensor that is less sensitive to electrostatic forces and parasitic capacitances.

A further object of the present invention to provide a micromachined sensor in which the sensor electrodes are prevented from contacting each other when the sensor is exposed to large accelerations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top view of a micromachined differential capacitor sensor of the present invention.

FIG. **2** is a representational diagram of the circuit formed by the differential capacitor sensor of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a sensor that has its sense and feedback functions separated, while maximizing the symmetry and sensitivity of the sensing structures.

A top view of the sensor structure is shown in FIG. **1**. Member **10** is a polysilicon structure suspended above bootstrap diffusion layer **12**. In a preferred embodiment, member **10** is approximately 450 micrometers long, the middle portion is approximately 80 micrometers wide, and the end portions are approximately 40 micrometers wide. Bootstrap diffusion layer **12** is formed from an n+ doped emitter diffusion region in the substrate. Member **10** is parallel to the surface of the substrate.

Member **10** is connected to suspension arms **16**, which attach to anchors **18**. Suspension arms **16** and anchors **18** are formed from polysilicon. Anchors **18** are mounted on the substrate outside bootstrap diffusion layer **12**. In a preferred embodiment, anchors **18** are square, with sides approximately 8 micrometers long.

In a preferred embodiment, suspension arms **16** consist of segments **20**, **22**, **24**, **26**, and **28**, all of which are approximately 1.9 micrometers wide. Long segments **22** and **26** are parallel to each other, connected at one end by short segment **24**. Short segments **20** and **28** connect the other (non-connected) ends of long segments **22** and **26** to an anchor **18** and an end of member **10**, respectively. Long segments **22** and **26** are flexible, allowing member **10** to move along the X-axis in response to a force along the X-axis, as the non-connected ends of long segments **22** and **26** move closer together or further apart. In a preferred embodiment, long segments **22** and **26** are approximately 125–130 micrometers long. Alternatively, other shapes can be used for the suspension arms.

To limit the amount of movement along the X-axis, limit stop **30** is attached at the free end of long segment **22** or limit stop **32** is attached at the free end of long segment **26**. In either case, the limit stop points toward the other long segment Preferably, the space between the end of limit stop **30** and long segment **26**, and between the end of limit stop **32** and long segment **22**, is approximately 0.7 micrometers. As member **10** moves to the right along the X-axis, the non-connected ends of long segments **22** and **26** on the left end of member **10** move further apart, and the non-connected ends of long segments **22** and **26** on the fight end of member **10** move closer together. As a result, the limit stops on the right end of member **10** will limit the movement. While the limit stops are shown between the non-connected ends of long segments **22** and **26**, any other

arrangement that would limit the movement of member **10** could be used. Preferably, as shown, the limit stops cause contact between two structures at the same potential. Otherwise, the two structures may become permanently stuck.

Extending from the sides of member **10** along the Y-axis are parallel polysilicon sense fingers **38**. In a preferred embodiment, sense fingers **38** are 4 micrometers wide and approximately 150 micrometers long, and there are 20 sense fingers on each side of member **10**. However, for clarity, fewer are shown in FIG. **1**.

To the left and right (along the X-axis) of each sense finger **38**, and not connected to member **10**, is a left sense plate **40** and a fight sense plate **42**, respectively. Left sense plates **40** and right sense plates **42** are formed from polysilicon. Preferably, left sense plates **40** and fight sense plates **42** are each 4 micrometers wide and there is a 1 micrometer space between each sense plate and its adjoining sense finger **38**. However, the distance between each left sense plate **40** and adjoining sense finger **38** could be different from the distance between each right sense plate **42** and adjoining sense finger **38**. Limit stops **30** and **32** provide a smaller spacing than the spacing between sense fingers **38** and the adjoining sense plates **40** and **42**, and movement of member **10** will not cause sense fingers **38** to touch either sense plate. Preferably, adjoining left and right sense plates **40** and **42** also are spaced approximately 1 micrometer apart.

All of the left sense plates **40** on each side of member **10** are connected together with an emitter diffusion segment, as are all of the right sense plates **42**. Electrical connection to the inner set of sense plates on each side of member **10** is made with polysilicon microbridges **44** and **46**. To maintain the symmetry of the structure and match any parasitic capacitance caused by the microbridges, dummy microbridges **48** and **50** extend from the outer set of sense plates on either side of member **10**. The left sense plates **40** on each side of member **10** are electrically connected, as are the right sense plates **42** on each side of member **10**.

Together, sense fingers **38** (which form a single electric node with the body of mass **10**) form center electrode **56** of differential capacitor **62** (FIG. **2**). Left sense plates **40** form left electrode **58**, and fight sense plates **42** form right electrode **60** of differential capacitor **62**, which consists of left capacitor **64** and fight capacitor **66**. Preferably, left capacitor **64** and right capacitor **66** have the same capacitance. Each set of one sense finger **38**, and its adjoining left sense plate **40** and fight sense plate **42** forms one "cell" of differential capacitor **62**, with all of the cells substantially identical and connected in parallel.

When member **10** moves to the fight relative to sense plates **40** and **42**, the distance between each sense finger **38** and the fight sense plate **42** of the same cell decreases, which increases the capacitance of fight capacitor **66**. At the same time, the distance between each sense finger **38** and the left sense plate **40** of the same cell increases, decreasing the capacitance of left capacitor **64**.

Member **10** is connected to resolving circuitry through emitter diffusion segment **70**, which extends from one of the anchors **18**.

In a preferred embodiment, high frequency signals (approximately 1 MHz) of the same amplitude, but 180 degrees out of phase, are applied to left sense plates **40** and right sense plates **42**. When sense fingers **38** are centered between sense plates **40** and **42**, no part of the high frequency signal is output from member **10** through segment **70**.

When a force is applied to the sensor along the X-axis, member **10** moves relative to sense plates **40** and **42**. The amount of movement is proportional to the force, in accordance with the spring constant of suspension arms **16** and the mass of member **10**. This lateral movement of member **10** changes the capacitances of capacitors **64** and **66**, causing a signal proportional to the magnitude of the force to be output through segment **70**. For the small resulting movement of sense fingers **38**, the capacitance changes almost linearly with respect to the amount of movement (and the magnitude of the force).

To the left of the leftmost left sense plate **40** on each side of member **10** is a dummy right sense plate **74**. Similarly, to the fight of the rightmost right sense plate **42** on each side of member **10** is a dummy left sense plate **76**. These dummy sense plates are connected to their corresponding sense plates (that is, dummy left sense plates **76** are connected to left sense plates **40** and dummy fight sense plates **74** are connected to fight sense plates **42**). This ensures that the end cells of differential capacitor **62** behave the same as the middle cells.

At the ends of member **10** are four polysilicon actuator fingers **80**. In a preferred embodiment, actuator fingers **80** are 4 micrometers wide and 150 micrometers long. Actuator fingers **80** are part of the same electric node as sense fingers **38** and the body of member **10**. To the sides of each actuator finger **80**, and not connected to member **10**, are a left actuator plate **82** and a fight actuator plate **84**. In a preferred embodiment, when no force is applied to member **10**, actuator fingers **80** are midway between actuator plates **82** and **84**. Actuator plates **82** and **84** are anchored to the substrate so as to be mirror images of each other with respect to their adjoining actuator finger **80**. Each left actuator plate **82** is electrically connected, as is each right actuator plate **84**.

Together, actuator fingers **80** form center electrode **86** of differential capacitor **92** (FIG. **2**). Left actuator plates **82** and fight actuator plates **84** form left electrode **88** and fight electrode **90**, respectively, of differential capacitor **92**. Left electrode **88** and center electrode **86** form left capacitor **94**, and fight electrode **90** and center electrode **86** form right capacitor **96** of differential capacitor **92**.

As with differential capacitor **62**, the separation between each actuator finger **80** and its adjoining actuator plates **82** and **84** changes when the sensor is subject to a force along the X-axis. However, while differential capacitor **62** is used to measure the magnitude of the force applied to the sensor, differential capacitor **92** is used to generate electrostatic forces to return member **10** to its neutral position. Biasing voltages of different amplitudes are applied to actuator plates **82** and **84**. When no force is applied to the sensor, member **10** is at a potential midway between the two biasing voltages. Accordingly, there is no net electrostatic force tending to push actuator fingers **80** (and hence member **10**) toward left actuator plates **82** or fight actuator plates **84**. However, when member **10** moves relative to sense plates **40** and **42** (which also is movement relative to actuator plates **82** and **84**), and a signal is output through segment **70**, a feedback loop can be employed (not shown) to impose a biasing signal on member **10** that moves the voltage on actuator fingers **80** closer to the voltage on the closer of actuator plates **82** or **84** and further from the voltage on the further of actuator plates **82** or **84**. This causes a net electrostatic force that tends to push actuator fingers **80** closer to the midway point between actuator plates **82** and **84**, which moves member **10** closer to its original position.

On either side of each actuator cell consisting of an actuator finger **80** and left and right actuator plates **82** and **84** are shield plates **100** and **102**. Further separating the end sense cells from the actuator cells are shield plates **104**. Each shield plate **100**, **102**, and **104** is formed from polysilicon and is anchored to bootstrap diffusion **12**, to provide electrical shielding between the sense and actuator functions and to isolate the actuator cells. The shield plates need not be rectangular, and may be formed in a shape to take advantage of the positions of the adjoining structures. Shield plates **100** and **102** also prevent actuator plates **82** and **84** from applying electrostatic forces to suspension arms **16**. Shield plates **100** and **102** may be made narrower than shield plates **104**.

Although the actuator cells are shown at the ends of member **10**, the actuator cells could be located elsewhere along the sides of member **10** and a different number of actuator cells could be used.

In the above-described embodiment the force causes the distance between the sense capacitor electrodes to change. However, the electrodes could be positioned so that the force causes the electrodes to move parallel to each other, so that the capacitive areas change.

Surrounding the sensor is guard ring **110**. Guard ring **110**, which isolates the sensor, consists of polysilicon strip **112**, anchored to an emitter diffusion layer by anchors **114**. The emitter diffusion layer for guard ring **110** is under anchors **114**. The gaps in the anchors **114** and in the underlying emitter diffusion layer permit the electrical connection of the sense and actuator plates, bootstrap diffusion layer **12**, and member **10**, to resolving circuitry, via emitter diffusion segments **70**, **116**, **118**, **120**, **122**, **124**, **126**, **128**, **130**, **132**, **134**, **136**, **138**, and **140**. Preferably, guard ring **110** is tied to either the same potential as bootstrap diffusion layer **12** or some other fixed potential.

While there have been shown and described examples of the present invention, it will be readily apparent to those skilled in the art that various changes and modifications may be made therein without departing from the scope of the invention as defined by the appended claims. Accordingly, the invention is limited only by the following claims and equivalents thereto.

We claim:

1. A micromachined device comprising:

a member;

a suspension connected to the member and to a substrate, so that the member is movable relative to the substrate in response to a force applied to the device along a predetermined axis;

a sense differential capacitor having a first sense electrode connected to the substrate, a second sense electrode connected to the substrate, and a third sense electrode connected to the member, the sense differential capacitor including a first sense capacitor and a second sense capacitor, wherein the first sense capacitor includes the first sense electrode and the third sense electrode and the second sense capacitor includes the second sense electrode and the third sense electrode, and wherein the capacitances of the first sense capacitor and the second sense capacitor are oppositely variable in response to the force; and

an actuator differential capacitor having a first actuator electrode connected to the substrate, a second actuator electrode connected to the substrate, and a third actuator electrode connected to the member, the actuator differential capacitor including a first actuator capacitor and a second actuator capacitor, wherein the first actuator capacitor includes the first actuator electrode and the third actuator electrode and the second actuator

capacitor includes the second actuator electrode and the third actuator electrode, and wherein the capacitances of the first actuator capacitor and the second actuator capacitor are oppositely variable in response to the force;

wherein the first sense electrode forms a separate electric node from the first actuator electrode, a separate electric node from the second actuator electrode, and a separate electric node from the third actuator electrode.

2. A micromachined device comprising:

a plurality of anchors connected to a substrate;

a member suspended above the substrate:

a plurality of suspension arms suspended above the substrate, with each of the plurality of suspension arms having a first end connected to the member and a second end connected to one of the plurality of anchors, such that the member is movable along an axis parallel to the substrate;

at least one sense capacitor cell, with each sense capacitor cell including a sense finger connected to the member, a first sense plate adjacent to a first side of the sense finger, and a second sense plate adjacent to a second side of the sense finger; and

at least one actuator capacitor cell, with each actuator capacitor cell including an actuator finger connected to the member, a first actuator plate adjacent to the first side of the actuator finger and a second actuator plate adjacent to the second side of the actuator finger,

wherein the at least one sense capacitor cell comprises a first differential capacitor and the at least one actuator capacitor cell comprises a second differential capacitor; and

wherein the first sense plate of each sense capacitor cell forms a separate electric node from the actuator finger of each actuator capacitor cell, a separate electric node from the first actuator plate of each actuator capacitor cell, and a separate electric node from the second actuator plate of each actuator capacitor cell.

3. A micromachined device comprising:

a plurality of anchors connected to a substrate:

a member suspended above the substrate having at least one member finger extending from the member, the member finger having a left side and a right side;

a plurality of suspension arms suspended above the substrate, with each of the plurality of suspension arms having a first end connected to the member and a second end connected to one of the plurality of anchors so that the member is movable along a preferred axis parallel to the substrate;

at least one left finger parallel to the at least one member finger, with one of the at least one left lingers being adjacent to the left side of each member finger, and the at least one left finger forming a first capacitor with the at least one member finger;

at least one right finger parallel to the at least one member finger, with one of the at least one right fingers being adjacent to the right side of each member finger, at the at least one right finger forming a second capacitor with the at least one member finger;

a polysilicon guard ring suspended above the substrate and encircling the member, the plurality of suspension arms, the at least one left finger, and the at least one right finger;

a guard diffusion area diffused into the substrate under a portion of the guard ring; and

a polysilicon guard anchor mechanically and electrically connecting the guard ring to the guard diffusion area.

4. The device according to claim **1**, wherein the distance between the first actuator electrode and the third actuator electrode changes in a first direction in response to the force and the distance between the second actuator electrode and the third actuator electrode changes in a second direction in response to the force, the second direction being opposite the first direction.

5. The device according to claim **4**, further comprising means for coupling the first sense electrode to a first carrier signal and the second sense electrode to a second carrier signal of the same frequency as the first carrier signal, with the first carrier signal being 180 degrees out of phase with the second carrier signal.

6. A device according to claim **5**, further comprising means for coupling the first actuator electrode to a first biasing signal having a first amplitude and the second actuator electrode to a second biasing signal having a second amplitude.

7. The device according to claim **6**, wherein the first sense electrode, the second sense electrode, the third sense electrode, the first actuator electrode, the second actuator electrode, and the third actuator electrode are formed from polysilicon; and

the connecting means includes a plurality of anchors connected to a silicon substrate and a plurality of suspension arms, with each of the plurality of suspension arms having a first end connected to one of the plurality of anchors and a second end connected to the member.

8. The device according to claim **7**, wherein each of the first sense electrode, the second sense electrode, and the third sense electrode includes a plurality of parallel fingers, and with each of the plurality of fingers of the third sense electrode being interleaved between one of the plurality of fingers of the first sense electrode and one of the plurality of fingers of the second sense electrode.

9. A micromachined device comprising:

a plurality of anchors connected to a substrate;

a member suspended above the substrate having at least one sense finger extending from the member, and at least one force finger extending from the member, parallel to the at least one sense finger;

a plurality of suspension arms suspended above the substrate, with each of the plurality of suspension arms having a first end connected to the member and a second end connected to one of the plurality of anchors, so that the member is movable along a preferred axis parallel to the substrate;

at least one first sense plate parallel to the at least one sense finger, with one of the at least one first sense plates being adjacent to a first side of each sense finger, and the at least one first sense plate forming a first sense capacitor with the at least one sense finger;

at least one second sense plate parallel to the at least one sense finger with one of the at least one second sense plates being adjacent to a second side of each sense finger, and the at least one second sense plate forming a second sense capacitor with the at least one sense finger;

at least one first actuator plate parallel to the at least one force finger, with one of the at least one first actuator plates being adjacent to the first side of each force finger, and the at least one first actuator plate forming a first actuator capacitor with the at least one force finger; and

at least one second actuator plate parallel to the at least one force finger, with one of the at least one second actuator plates being adjacent to the second side of each force linger, and the at least one second actuator plate forming a second actuator capacitor with the at least one force finger;

wherein the at least one first sense plate forms a separate electric node from the at least one force finger, a separate electric node from the at least one first actuator plate, and a separate electric node from the at least one second actuator plate.

10. The device according to claim **9**, wherein the at least one sense finger includes a plurality of sense fingers, parallel to each other, the at least one first sense plate includes a plurality of first sense plates, and the at least one second sense plate includes a plurality of second sense plates.

11. The device according to claim **10**, wherein the at least one force finger includes a plurality of force fingers, the at least one first actuator plate includes a plurality of first actuator plates, and the at least one second actuator plate includes a plurality of second actuator plates.

12. The device according to claim **11**, further comprising a conductive bootstrap region diffused onto the substrate, below the member.

13. The device according to claim **12**, further comprising:

a first plurality of shield plates anchored to the bootstrap region and parallel to the plurality of force fingers, with one of the first plurality of shield plates being adjacent to the first side of each of the plurality of first actuator plates; and

a second plurality of shield plates anchored to the bootstrap region and parallel to the plurality of force fingers, with one of the second plurality of shield plates being adjacent to the second side of each of the plurality of second actuator plates.

14. The device according to claim **11**, wherein at least one of the plurality of suspension arms includes a limit stop for limiting movement of the member along the predetermined axis.

15. The device according to claim **11**, wherein each of the plurality of suspension arms includes an anchor segment having a first end connected to one of the plurality of anchors, a first suspension segment approximately perpendicular to the anchor segment and having a first end connected to a second end of the anchor segment, a second suspension segment having a first end connected to a second end of the first anchor segment, a third suspension segment approximately parallel to the first suspension segment and having a first end connected to a second end of the second suspension segment, and a member segment approximately perpendicular to the third suspension segment and having a first end connected to a second end of the third suspension segment and a second end connected to the member.

16. The device according to claim **15**, wherein at least one of the plurality of suspension arms further includes a stop segment connected to the first suspension segment and extending from the first suspension segment toward the third suspension segment.

17. The device according to claim **15**, wherein at least one of the plurality of suspension arms further includes a stop segment connected to the third suspension segment and extending from the third suspension segment toward the first suspension segment.

18. The device according to claim **11**, further comprising:

a polysilicon guard ring encircling the member, the plurality of suspension arms, the plurality of first sense plates, the plurality of second sense plates, the plurality of first actuator plates, and the plurality of second actuator plates;

a guard diffusion area diffused into the substrate under a portion of the guard ring; and

a polysilicon guard anchor connecting the guard ring to the guard diffusion area.

19. The device according to claim **9**, further comprising:

a polysilicon guard ring suspended above the substrate and encircling the at least one sense linger, the at least one first sense plate, and the at least one second sense plate;

a guard diffusion area diffused into the substrate under a portion of the guard ring; and

a polysilicon guard anchor mechanically and electrically connecting the guard ring to the guard diffusion area.

20. The device according to claim **2**, wherein the at least one sense capacitor cell includes a plurality of sense capacitor cells, with all of the first sense plates being connected and all of the second sense plates connected.

21. The device according to claim **20**, wherein the plurality of sense capacitor cells includes a plurality of end cells and at least one middle cell, with each end cell having an end side non-adjacent to another sense capacitor cell and a middle side adjacent to one of the at least one middle cells, and each middle cell being adjacent to two of the plurality of sense capacitor cells;

the device further including a plurality of dummy sense plates, with one of the plurality of dummy sense plates being adjacent to the end side of each of the plurality of end cells.

22. A device according to claim **21**, wherein the plurality of end cells includes at least one first end cell and at least one second end cell, with the end side of each first end cell being on the first side of such first end cell, the end side of each second end cell being on the second side of such second end cell, the plurality of dummy sense plates including at least one dummy first sense plate connected to the plurality of first sense plates and at least one dummy second sense plate connected to the plurality of second sense plates, the dummy sense plate adjacent to each first end cell being a dummy first sense plate, and the dummy sense plate adjacent to each second end cell being a dummy second sense plate.

23. The device according to claim **21**, wherein the at least one middle cell includes a plurality of middle cells.

24. The device according to claim **23**, wherein the at least one actuator capacitor cell includes a plurality of actuator capacitor cells, with all of the first actuator plates being connected and all of the second actuator plates being connected.

25. The device according to claim **12**, further comprising at least one first shield plate anchored to the bootstrap region and parallel to the plurality of force fingers, wherein each of the first shield plates is adjacent to one of the plurality of first actuator plates, on an opposite side of such first actuator plate from a side of such actuator plate adjacent to one of the force fingers.

26. The device according to claim **25**, further comprising at least one second shield plate anchored to the bootstrap region and parallel to the plurality of force fingers, wherein each of the second shield plates is adjacent to one of the plurality of second actuator plates, on an opposite side of such second actuator plate from a side of such actuator plate adjacent to one of the force fingers.

27. The device according to claim **9**, wherein the member, including the at least one sense finger and the at least one force finger, forms a single electric node.

28. The device according to claim **9**, wherein the at least one sense finger and the at least one force finger extend from the member perpendicular to the preferred axis.

29. The device according to claim **1**, wherein the member, the third sense electrode, and the third actuator electrode form a single electric node.

30. The device according to claim **9**, wherein the at least one second sense plate forms a separate electric node from the at least one force finger, a separate electric node from the at least one first actuator plate, and a separate electric node from the at least one second actuator plate.

31. The device according to claim **9**, further comprising at least one first shield plate anchored to the bootstrap region and parallel to the at least one force finger, wherein each of the first shield plates is adjacent to one of the at least one first actuator plates, on an opposite side of such first actuator plate from a side of such actuator plate adjacent to one of the force fingers.

32. The device according to claim **31**, further comprising at least one second shield plate anchored to the bootstrap region and parallel to the at least one force finger, wherein each of the second shield plates is adjacent to one of the at least one second actuator plates, on an opposite side of such second actuator plate from a side of such actuator plate adjacent to one of the force fingers.

33. A micromachined device comprising:

a plurality of anchors connected to a substrate;

a member suspended above the substrate having at least one member finger extending from the member, the member finger having a left side and a right side;

a plurality of suspension arms suspended above the substrate, with each of the plurality of suspension arms having a first end connected to the member and a second end connected to one of the plurality of anchors so that the member is movable along an axis parallel to the substrate;

at least one left finger parallel to the at least one member finger, with one of the at least one left fingers being adjacent to the left side of each member finger, and the at least one left finger forming a first capacitor with the at least one member finger;

at least one right finger parallel to the at least one member finger, with one of the at least one right fingers being adjacent to the right side of each member finger, and the at least one right finger forming a second capacitor with the at least one member finger; and

a conductive guard ring formed above and mechanically connected to the substrate, wherein the guard ring surrounds the member, the plurality of suspension arms, the at least one left finger, and the at least one right finger.

34. The device according to claim 33, wherein the conductive guard ring includes polysilicon.

35. The device according to claim 33, wherein the guard ring is electrically connected to the substrate.

36. A micromachined device comprising:

a plurality of anchors connected to a substrate;

a member suspended above the substrate having at least one member finger extending from the member, the member finger having a left side and a right side;

a plurality of suspension arms suspended above the substrate, with each of the plurality of suspension arms having a first end connected to the member and a second end connected to one of the plurality of anchors so that the member is movable along an axis parallel to the substrate;

at least one left finger parallel to the at least one member finger, with one of the at least one left fingers being adjacent to the left side of each member finger, and the at least one left finger forming a first capacitor with the at least one member finger;

at least one right finger parallel to the at least one member finger, with one of the at least one right fingers being adjacent to the right side of each member finger, and the at least one right finger forming a second capacitor with the at least one member finger; and

a conductive guard ring surrounding the member, the at least one left finger, and the at least one right finger so as to electrically isolate the member, the at least one left finger, and the at least one right finger.

37. The device according to claim 36, wherein the conductive guard ring is suspended above the substrate.

38. A micromachined device comprising:

a plurality of anchors connected to a substrate;

a member suspended above the substrate having at least one member finger extending from the member, the member finger having a left side and a right side;

a plurality of suspension arms suspended above the substrate, with each of the plurality of suspension arms having a first end connected to the member and a second end connected to one of the plurality of anchors so that the member is movable along an axis parallel to the substrate;

at least one left finger parallel to the at least one member finger, with one of the at least one left fingers being adjacent to the left side of each member finger, and the at least one left finger forming a first capacitor with the at least one member finger;

at least one right finger parallel to the at least one member finger, with one of the at least one right fingers being adjacent to the right side of each member finger, and the at least one right finger forming a second capacitor with the at least one member finger; and

a conductive guard ring formed above and mechanically connected to the substrate so as to electrically isolate the member, the at least one left finger, and the at least one right finger.

39. The device according to claim 38, wherein the conductive guard ring includes polysilicon.

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