

A SEMICONDUCTOR ACCELEROMETER

Field of the Invention

5 This invention relates to a semiconductor accelerometer and particularly to a semiconductor accelerometer having a movable gate.

Background of the Invention

10 An accelerometer detects an imposed accelerative or decelerative force and provides an output signal indicating the magnitude of the detected force. A conventional semiconductor accelerometer includes a movable part for detecting the accelerative or decelerative force, and circuitry for converting the movement of the movable part to an output signal which is
15 suitable for use by other circuitry external to the accelerometer.

 A known semiconductor accelerometer consist of a metal oxide semiconductor field effect transistor (MOSFET) having a channel region formed between the source and the drain on a substrate, and having a movable gate mounted on the substrate, positioned parallel to the channel
20 region, and separated from the channel region by a predetermined distance. When an accelerative or decelerative force is imposed on the accelerometer, the movable gate moves in accordance with the force resulting in a variation in the predetermined distance between the gate and the channel region. This variation causes the drain-source current to vary,
25 and the variation of the drain-source current indicates the magnitude of the detected accelerative or decelerative force.

 An advantage of this semiconductor accelerometer is that the output signal can be readily coupled to circuitry external to the accelerometer without the need for additional conversion circuitry. However, a
30 disadvantage of this semiconductor accelerometer is that its detection sensitivity is susceptible to variations caused by changes in ambient temperature, which leads to inaccurate detection.

Brief Summary of the Invention

The present invention therefore seeks to provide an accelerometer which is significantly less sensitive to changes in ambient temperature.

5 Accordingly, in one aspect the invention provides a device comprising: a semiconductor substrate having an area formed thereon between a first and second electrode, wherein the area is sensitive to an electric field; an elongate member having one end mounted on the substrate and forming a third electrode, the elongate member cantilevered over the
10 substrate and shaped to form a first pivot section between a first substantially planar section and the mounted end, and a second pivot section between a second substantially planar section and the first substantially planar section, the second substantially planar section positioned essentially parallel to the area on the substrate, the second substantially planar section for coupling to
15 the area on the substrate through the electric field; and a positioner coupled to the first substantially planar section.

In another aspect, the invention provides a sensor comprising: an active device on a substrate, wherein the active device comprises a first and second electrode having an area formed therebetween, wherein the area is
20 sensitive to an electric field; a gate comprising an elongate electrode, wherein the elongate electrode comprises: a mount for mounting the elongate electrode to the substrate; a first resilient portion formed by the free end of the elongate electrode, the first resilient portion for moving in response to movement of the semiconductor sensor, and the first resilient
25 portion coupled to the area on the substrate through the electric field; and a second resilient portion between the mount and the first resilient portion for positioning the first resilient portion essentially parallel to the area; and a positioner coupled to the second resilient portion for setting the distance between the first resilient portion and the area.

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Brief Description of the Drawings

Embodiments of the invention will now be more fully described, by way of example, with reference to the drawings, of which:

35 FIG. 1 shows a side sectional view of a semiconductor accelerometer in accordance with a first embodiment of the present invention;

FIG. 2 shows the side sectional view of the semiconductor accelerometer in FIG. 1 and the effect of variation in ambient temperature;

FIG. 3 shows a side sectional view of the semiconductor accelerometer in FIG. 1 with an applied compensation voltage;

5 FIG. 4 shows a perspective view of a second embodiment of a semiconductor accelerometer in accordance with the present invention; and

FIG. 5 shows a perspective view of a third embodiment of a semiconductor accelerometer in accordance with the present invention.

10 Detailed Description of the Drawings

FIG. 1 illustrates an accelerometer 1 having a metal oxide semiconductor field effect transistor (MOSFET) 2 formed on a substrate 21. The MOSFET 2 has a channel region 15 located between a drain region 17 and a source region 19. A movable gate 4 is formed by a resilient polysilicon beam structure mounted on the substrate 21 by an anchor 5. The movable gate 4 has a pivot section 7, a support section 9, a pivot section 10, and an end section 13. The support section 9 positions the end section 13 parallel to the channel region 15, and separated by a predetermined distance d_1 perpendicular to the channel region 15. In addition, the support section 9 pivots about the pivot section 7 and the detection end 13 pivots about the pivot section 10. A plate 30 is located on the substrate 21 below the support section 9 and separated by a distance d_2 from the plate 30.

25 An accelerative or decelerative force imposed on the accelerometer 1 causes the end section 13 to swing up and down about the pivot section 10 as shown by the outlines 12 and 14. The variation in the distance between position 12 and 14 of the end section 13 is identified as δ_a .

30 The spring constant of pivot section 7 is much greater than the spring constant of pivot section 10, such that the support section 9 does not move significantly about the pivot section 7 when the accelerative or decelerative force is imposed on the accelerometer 1.

The transfer function of the MOSFET 2 is given by the following equation:

$$I_{DS} = g_m \cdot V_{DS}$$

where I_{DS} is the drain - source current of the MOSFET 2;

g_m is the transconductance of the MOSFET 2;

V_{DS} is the applied drain - source voltage of the MOSFET 2;

and the transconductance g_m of the MOSFET 2 is given by the equation below.

$$g_m = \mu \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{gs} - V_{th})$$

$$= \mu \cdot \frac{\epsilon}{d_1 + \delta l + \delta a} \cdot \frac{W}{L} \cdot (V_{gs} - V_{th}) \text{ ----- [1]}$$

where g_m is the transconductance of the MOSFET 2;

C_{ox} is the gate capacitance of the MOSFET 2;

μ is the carrier mobility of the MOSFET 2;

ϵ is the relative dielectric constant of the MOSFET 2;

d_1 is the distance separating the end section 13
and the channel region 15;

δl is the distance variation of the end section 13
caused by temperature variation;

δa is the distance variation of the end section 13
caused by acceleration or deceleration;

W is the effective width of the end section 13;

L is the effective length of the end section 13;

V_{gs} is the applied gate - source voltage on MOSFET 2; and

V_{th} is the threshold voltage of the MOSFET 2.

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Movement of the end section 13 causes the distance d_1 between the end section 13 and the channel region 15 to vary. When the end section 13 moves downwards to position 14, d_1 reduces. This increases the gate capacitance C_{OX} in the channel region 15 which in turn increases the transconductance g_m of the MOSFET 2. Hence, when the drain-source voltage V_{DS} is constant, the drain-source current I_{DS} of the MOSFET 2 will increase.

Alternatively, when the end section 13 moves upwards to position 12, d_1 increases. This decreases the gate capacitance C_{OX} in the channel

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region 15, which in turn decreases the transconductance g_m of the MOSFET 2, thus reducing the drain-source current I_{DS} of the MOSFET 2.

In FIG. 2, when the ambient temperature changes, the movable gate 4, including the support section 9, the end section 13, and the pivot sections 7 and 10, expand or contract, dependent on whether the ambient temperature rises or falls. The expansion and contraction of the movable gate 4 causes the end section 13 to move between an upper position 24 and a lower position 22. Hence, even without an accelerative or decelerative force being imposed on the accelerometer 1, the distance d_1 will change by a distance δ_i because of variation in ambient temperature.

It should be noted that the variation δ_a in the distance d_1 caused by movement resulting from acceleration or deceleration can have a significantly higher frequency than the variation in the distance d_1 caused by variation in temperature δ_i .

In equation 1, the variables $\mu, \epsilon, d_1, W, L, V_{GS}$ and V_{th} are virtually constant in a particular circuit application. Consequently, it can be seen that the transconductance g_m of the MOSFET 2 will change with variation δ_a in the distance d_1 caused by acceleration or deceleration, and also by variation δ_i caused by changes in temperature. And, when the drain source-voltage V_{DS} is constant, the drain-source current I_{DS} will vary in proportion to the changes of the transconductance g_m of the MOSFET 2. Hence, the variation in drain-source current will not provide an accurate indication of an imposed accelerative or decelerative force because the distance d_1 is not only affected by δ_a but also by δ_i .

The accelerometer in accordance with the described embodiment advantageously enables d_1 to be changed to neutralise the effect of δ_i , thereby providing an I_{DS} that more accurately indicates an imposed accelerative or decelerative force across a range of ambient temperatures.

In FIG. 3 the plate 30 and the movable gate 4 are coupled to opposite polarities of a variable direct current (DC) voltage source 35 which provides a voltage V . The variable DC voltage source 35 produces an electrostatic force between the plate 30 and the support section 9 of the movable gate 4, which is proportional to the applied DC voltage V . The electrostatic force causes the support section 9 to be moved relative to the plate 30, against the opposing force of the spring constant of the pivot section 7. The applied DC voltage V can be varied to move the movable gate between an upper

position 24 and a lower position 22. When the variable direct current (DC) voltage source 35 is set to provide a particular DC voltage, the resulting electrostatic force on the support section 9 causes the movable 4 to move against the spring force of the pivot section 7. The movable gate 4 stops moving when the two forces, the applied electrostatic force and the spring force, are equal i.e. in equilibrium. Hence, by varying the voltage V, the distance d_1 between the detection section 13 and the channel region 15 can be controlled to neutralise the effect of variations δl caused by the changes in temperature.

The spring force in the pivot section 7 can be expressed by the following equation.

$$F_{\text{SPRING}} = -k_2 \cdot \delta v$$

where F_{SPRING} is the force developed in the pivot section 7;

$-k_2$ is the spring constant of the pivot section 7; and

δv is the displacement of the detection end 13 caused by the applied voltage V.

And the electrostatic force exerted on the support section 9 can be expressed by the following equation.

$$F_{\text{ELECTROSTATIC}} = \frac{\epsilon \cdot A \cdot V^2}{2(d_2 - \delta v)}$$

where ϵ is the relative dielectric constant of matter between the support section 9 and the plate 30;

A is the effective area between the support section 9 and the plate 30;

d_2 is the distance between the support section 9 and the plate 30;

V is voltage applied between the support section 9 and the plate 30; and

δv is the displacement of the detection end 13 caused by the applied voltage V.

When the two forces are in equilibrium the following equations can be derived.

$$F_{\text{SPRING}} = F_{\text{ELECTROSTATIC}}$$

$$k_2 \cdot \delta_v = \frac{\epsilon \cdot A \cdot V^2}{2(d_2 - \delta_v)}$$

$$= \frac{\epsilon \cdot A \cdot V^2}{2(d_2 - \delta_v)} \text{ when } d_2 \gg \delta_v$$

$$\delta_v = \frac{\epsilon \cdot A}{2 \cdot d_2 \cdot k_2} \cdot V^2$$

$$\text{hence letting } B = \frac{\epsilon \cdot A}{2 \cdot d_2 \cdot k_2}$$

$$\delta_v = B \cdot V^2 \text{ ----- [2]}$$

Adding the variation caused by δ_v to d_1 in equation 1 for g_m , the following equation results.

$$5 \quad g_m = \mu \cdot \frac{\epsilon}{d_1 + \delta_l + \delta_a + \delta_v} \cdot \frac{W}{L} \cdot (V_{gs} - V_{th}) \text{ ----- [3]}$$

Then from using δ_v from equation 2 and substituting for δ_v in equation 3, the following equation results.

$$10 \quad g_m = \mu \cdot \frac{\epsilon}{d_1 + \delta_l + \delta_a + BV^2} \cdot \frac{W}{L} \cdot (V_{gs} - V_{th}) \text{ ----- [4]}$$

In equation 4, changing the applied voltage V causes BV^2 to change. Thus, BV^2 can be made to have such a magnitude that will neutralise the variations due to temperature δ_l , so that the transconductance g_m will only change in response to the variations due to acceleration or deceleration δ_a .

15 This will enable the accelerometer 1 to provide an output voltage which indicates the variations due to acceleration or deceleration δ_a independent of variations due to temperature changes δ_l . In addition the variations δ_l can be expanded to include variations caused by other sources, such as, variations in manufacturing processes of the accelerometer 1, etc.

20 FIG. 4 illustrates an accelerometer 20 having a movable gate 24 which can be formed using known surface micro-machining processes. The change in drain-source current I_{DS} of a single MOSFET due to a change in gate capacitance C_{OX} is very small, hence, the accelerometer 20 employs four MOSFET devices which increase the total drain-source current I_{DS}

25 significantly. Also, the total cross sectional area of pivot section 10 is made

much smaller relative to the pivot section 7 so that the spring constant of pivot section 10 is substantially less than that of pivot section 7. This ensures that the detection end 13 detects an accelerative or decelerative force, and the support section 9 will not be significantly affected by the accelerative or decelerative force. Further, the surface area of the support section 9 and the plate 30 complement each other such that the required electrostatic force can be imposed between them.

FIG. 5 shows another embodiment in accordance with the present invention having all the elements described in the previous embodiments. It can be seen that this structure is symmetrical and advantageously provides balanced support of the movable gate 4. With this structure the gate 4 is always parallel to the surface of the silicon when it moves in response to a detected accelerative or decelerative force. In addition, this structure allows a greater number of MOSFET devices to be combined to significantly increase the change in drain-source current produced when the movable gate 4 moves in response to a detected accelerative or decelerative force.

The described embodiments advantageously allows the position of the end section of a movable gate semiconductor accelerometer to be controlled, thus enabling the displacement of the end section by factors other than acceleration or deceleration, to be substantially reduced.

Thus, in accordance with the described embodiments of the present invention, a MOSFET having a movable gate with two pivoted sections, one supporting the other, and a plate located adjacent to the movable gate, is provided. A DC bias applied between the supporting section of the gate and the plate advantageously enables the separation of the end section of the gate and the channel region of the MOSFET to be controlled.

Hence, the described semiconductor accelerometer provides an output signal that can be readily coupled to circuitry external to the accelerometer without the need for additional conversion circuitry, and can be configured to be significantly less susceptible to variation in detection sensitivity caused by manufacturing variations, variations in temperature and non-linearity of the accelerometer.



Claims

1. A device comprising:
 - 5 a semiconductor substrate having an area formed thereon between a first and second electrode, wherein the area is sensitive to an electric field;
an elongate member having one end mounted on the substrate and forming a third electrode, the elongate member cantilevered over the substrate and shaped to form a first pivot section between a first substantially
10 planar section and the mounted end, and a second pivot section between a second substantially planar section and the first substantially planar section, the second substantially planar section positioned essentially parallel to the area on the substrate, the second substantially planar section for coupling to the area on the substrate through the electric field; and
15 a positioner coupled to the first substantially planar section.
2. A device in accordance with claim 1, wherein the positioner comprises a plate forming a fourth electrode parallel to the first substantially planar section, wherein the plate and the first substantially planar section
20 are electrostatically coupled.
3. A device in accordance with claim 2 wherein the plate is mounted on the substrate.
- 25 4. A device in accordance with any one of the preceding claims wherein the first pivot section has a first spring constant, and the second pivot section has a second spring constant which is less than the first spring constant.
5. A device in accordance with any one of the preceding claims wherein
30 the first pivot section has a first cross sectional area, and the second pivot section has a second cross sectional area less than the first cross sectional area.
6. A device in accordance with any one of the preceding claims wherein
35 the semiconductor substrate comprises at least one metal oxide semiconductor field effect transistor (MOSFET) formed thereon, wherein the area is the area between a drain and a source of the at least one MOSFET,



and wherein the conductivity of the at least one MOSFET is inversely proportional to the distance separating the second substantially planar section and the area between the drain and the source of the at least one MOSFET.

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7. A semiconductor accelerometer according to any one of the preceding claims wherein the elongate member comprises a polysilicon structure.

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8. A sensor comprising:

an active device on a substrate, wherein the active device comprises a first and second electrode having an area formed therebetween, wherein the area is sensitive to an electric field;

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a gate comprising an elongate electrode, wherein the elongate electrode comprises:

a mount for mounting the elongate electrode to the substrate;

a first resilient portion formed by the free end of the elongate electrode, the first resilient portion for moving in response to movement of the semiconductor sensor, and the first resilient portion coupled to the area on the substrate through the electric field; and

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a second resilient portion between the mount and the first resilient portion for positioning the first resilient portion essentially parallel to the area; and

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a positioner coupled to the second resilient portion for setting the distance between the first resilient portion and the area.

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9. A sensor in accordance with claim 8 wherein the positioner comprises a plate essentially parallel to the second resilient portion for receiving a biasing signal and for imposing an electrostatic force on the second resilient portion in accordance with the biasing signal.

10. A sensor in accordance with claim 9 wherein the plate is mounted on the substrate.



11. A sensor in accordance with any one of claims 8-10 wherein the first resilient portion has a first spring constant, and the second resilient portion has a second spring constant which is greater than the first spring constant.
- 5 12. A sensor in accordance with any one of claims 8-11 wherein the first resilient portion has a first cross sectional area, and the second resilient portion has a second cross sectional area less than the first cross sectional area.
- 10 13. A sensor in accordance with any one of claims 8-12 wherein the active device comprises at least one metal oxide semiconductor field effect transistor (MOSFET) formed thereon, wherein the area is the area between a drain and a source of the at least one MOSFET, and wherein the conductivity of the at least one MOSFET is inversely proportional to the
15 distance between the first resilient portion and the area between the drain and the source of the at least one MOSFET.
14. A sensor according to any one of claims 8-13 wherein the elongate electrode comprises a polysilicon structure.
- 20 15. A device substantially as described herein with reference to and as illustrated by the accompanying drawings.
16. A device substantially as described herein with reference to and
25 as illustrated by the accompanying drawings.
17. A sensor substantially as described herein with reference to and as illustrated by the accompanying drawings.
- 30 18. A sensor substantially as described herein with reference to and as illustrated by the accompanying drawings.

