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(54) **ELECTRICAL CONNECTION TO A MICRO ELECTRO-MECHANICAL SYSTEM**

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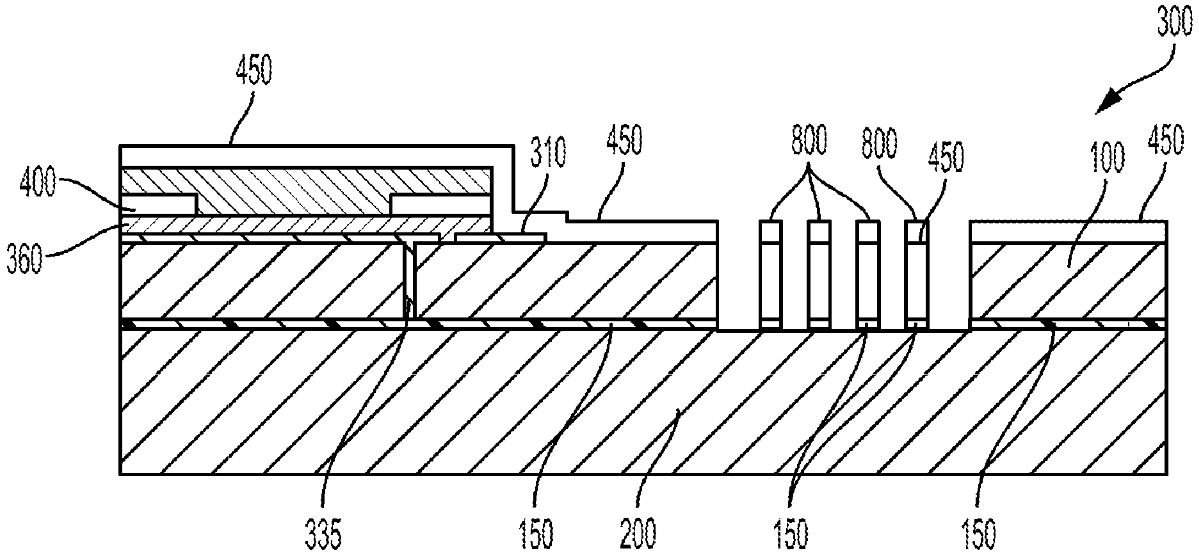
CPC ***B81C 1/00246*** (2013.01); ***B81C 1/00261*** (2013.01); ***B81C 1/00095*** (2013.01); *B81C 2201/013* (2013.01); ***H01L 21/76898*** (2013.01); *B81B 2201/0235* (2013.01); *B81B 2201/0242* (2013.01); ***B81B 7/0032*** (2013.01)

(57) **ABSTRACT**

A MEMS device includes, in part, first and second conductive semiconductor substrates, an insulating material disposed between the semiconductor substrates, a cavity formed in the second semiconductor substrate, and at least first and second drive masses each of which includes a multitude of beams etched from the first semiconductor substrate and is adapted to move in the cavity in response to an applied force. At least a first portion of the first substrate is adapted to move in response to the applied force and causes the at least first and second drive mass to be in electrical communication with the first substrate. The device may further include, in part, a coupling spring disposed between and in electrical communication with the first and second drive masses. The coupling spring is adapted to provide electrical communication between a second portion of the first substrate and the first and second drive masses.



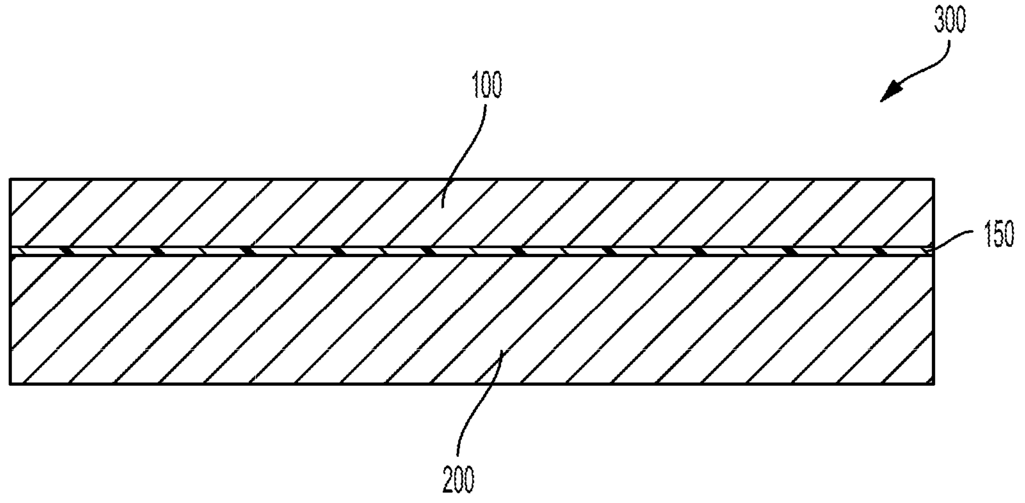


FIG. 1

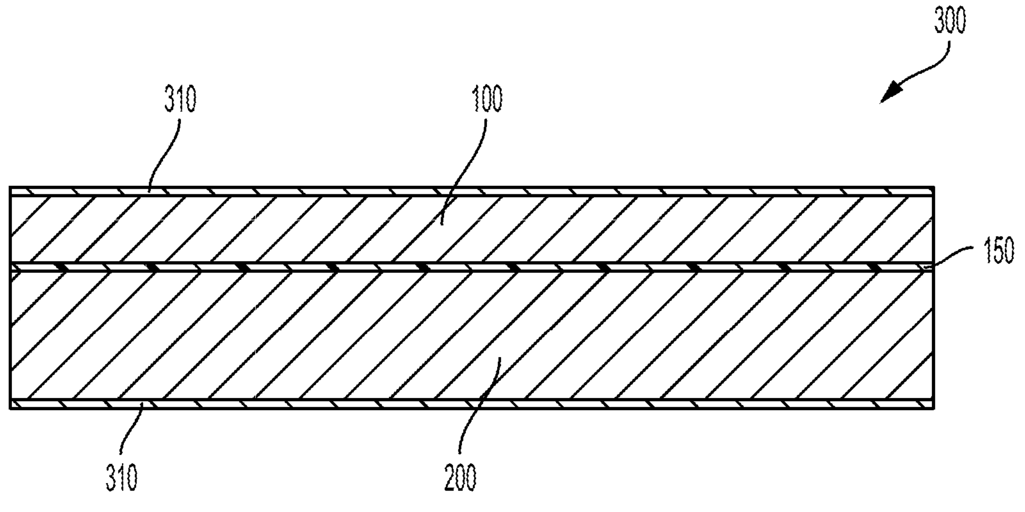


FIG. 2

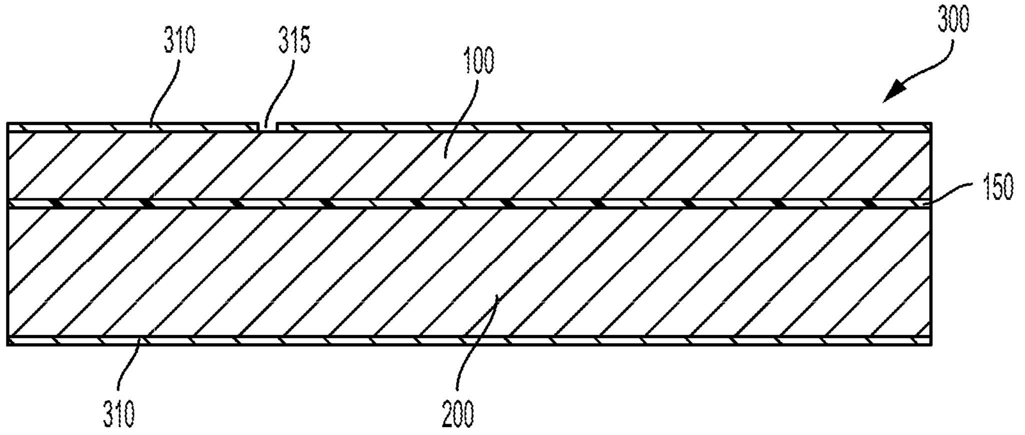


FIG. 3

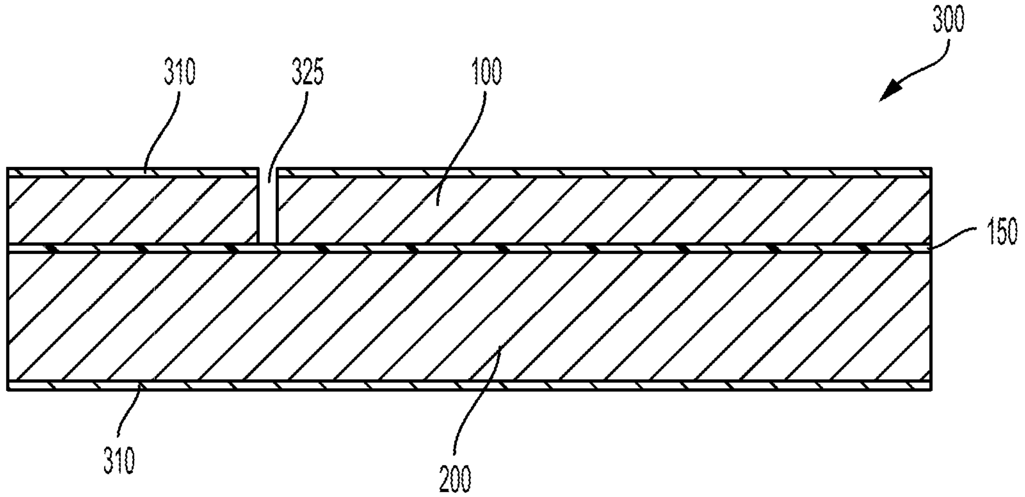


FIG. 4

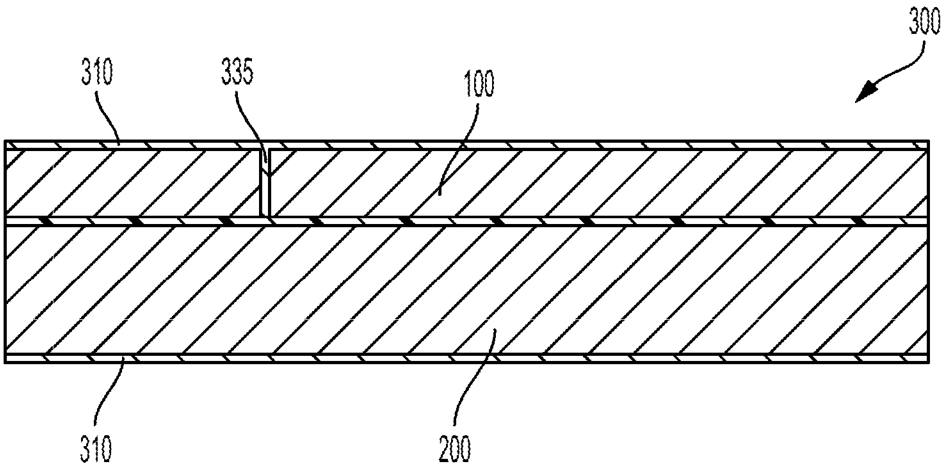


FIG. 5

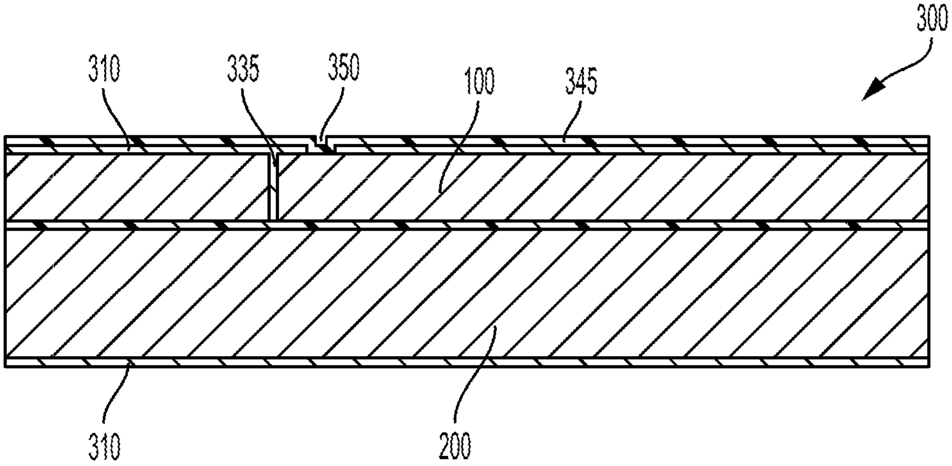


FIG. 6

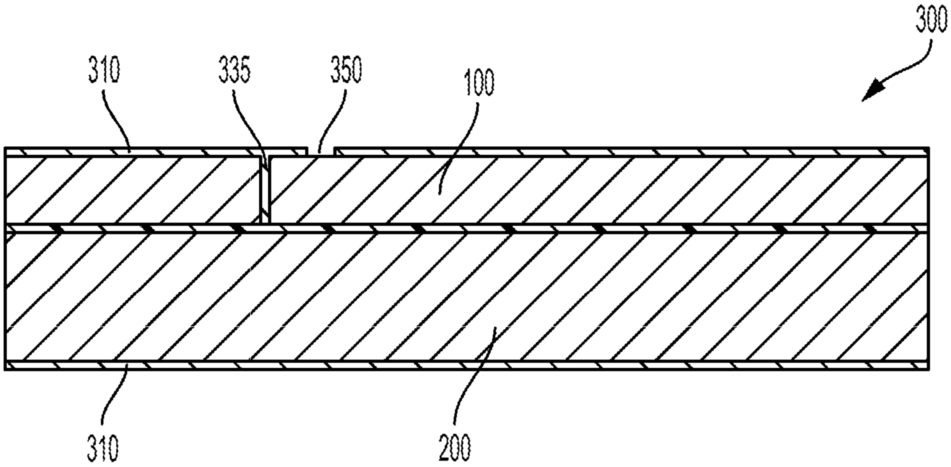


FIG. 7

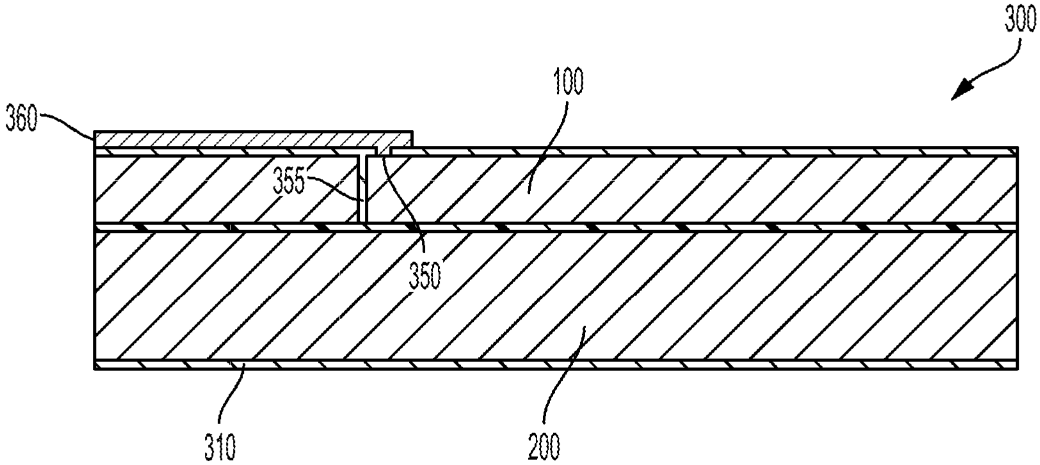


FIG. 8

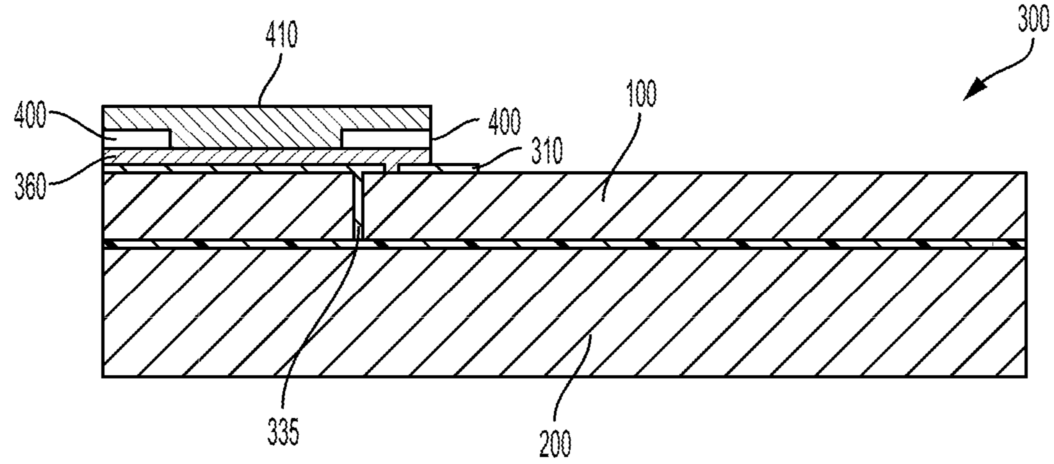


FIG. 9

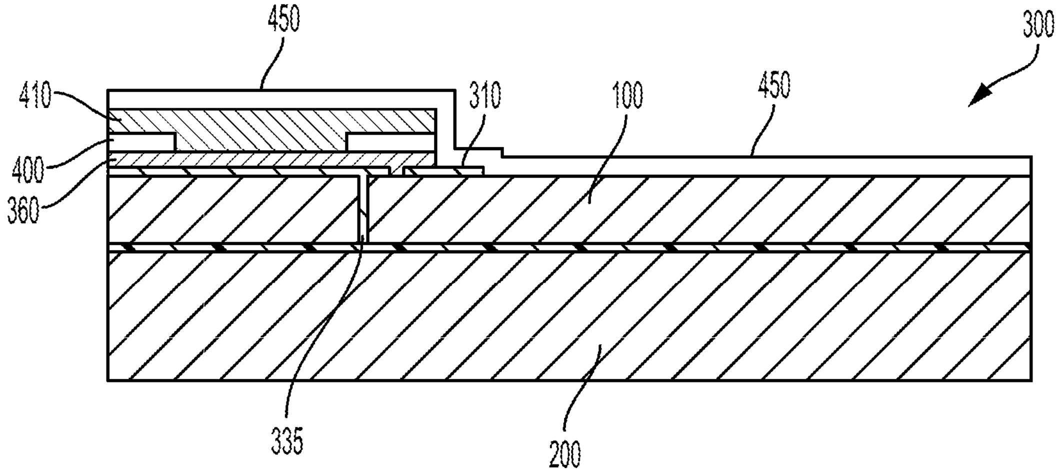


FIG. 10

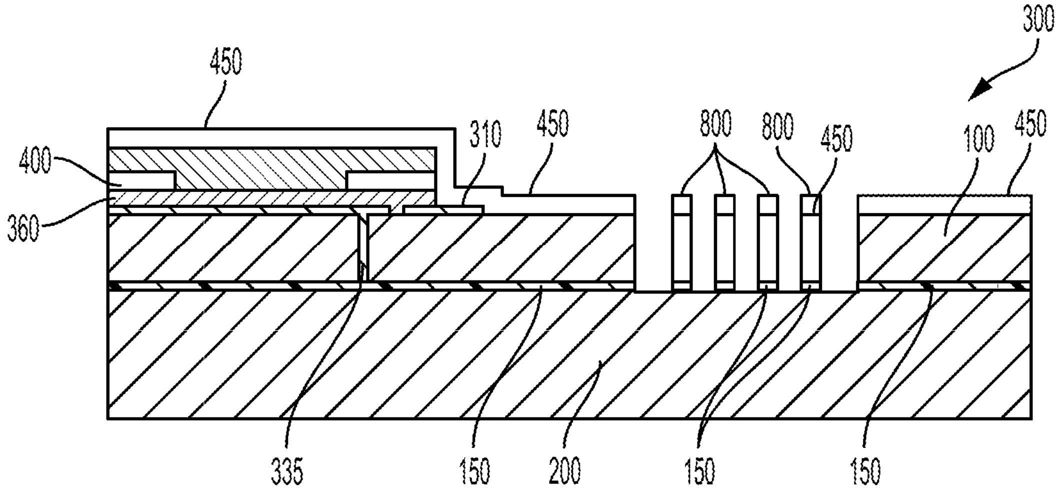


FIG. 11

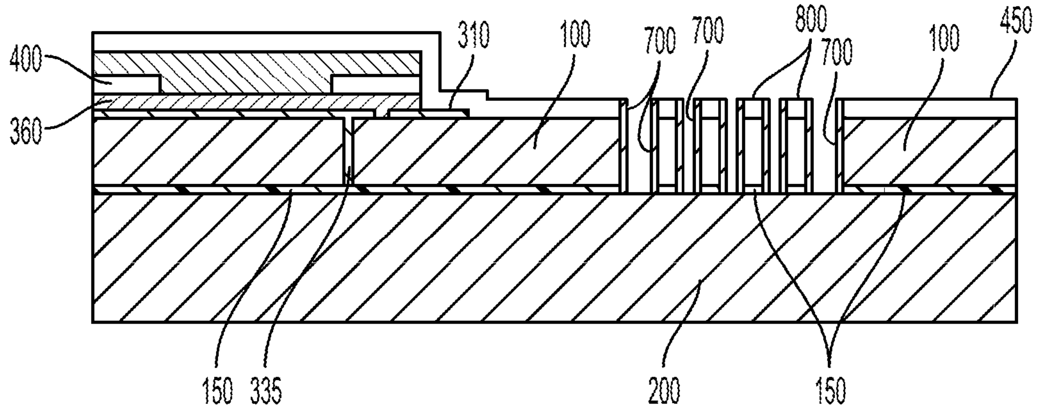


FIG. 12

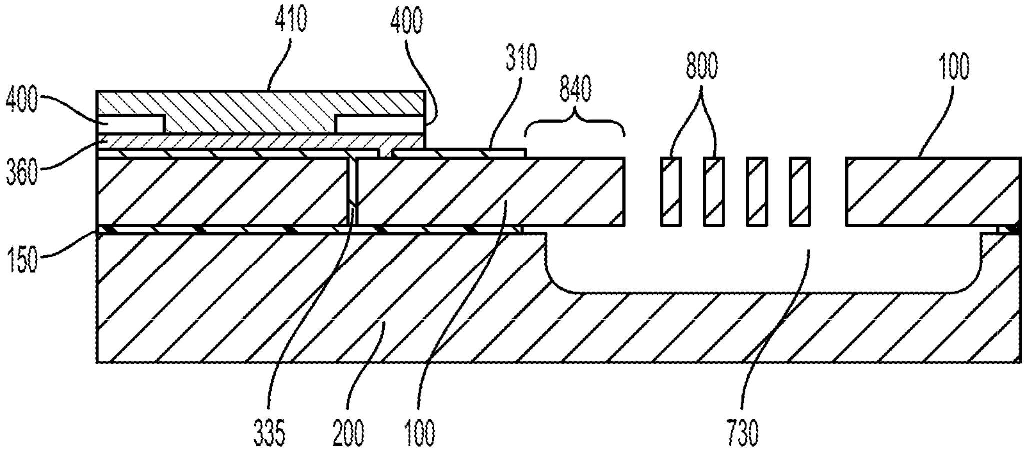


FIG. 13

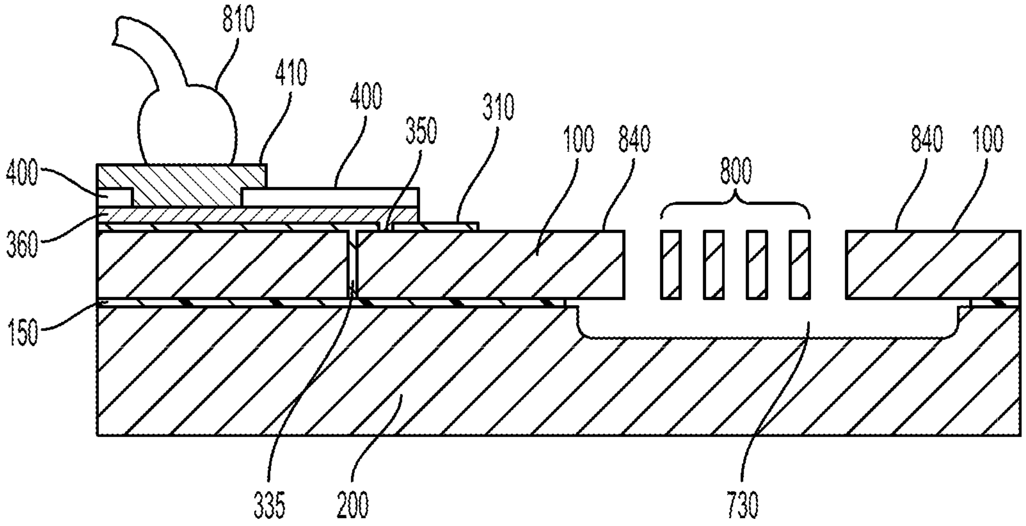


FIG. 14

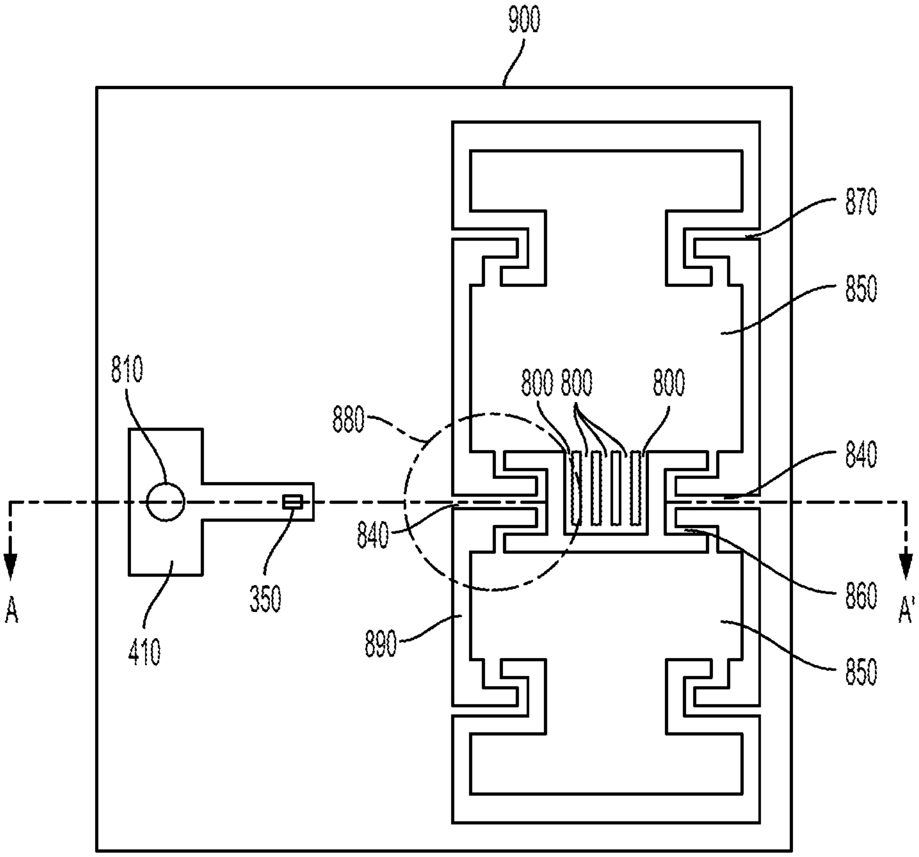


FIG. 15A

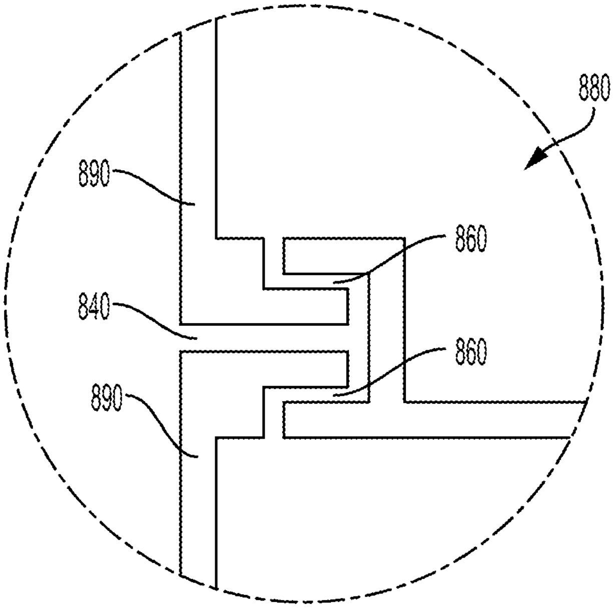


FIG. 15B

ELECTRICAL CONNECTION TO A MICRO ELECTRO-MECHANICAL SYSTEM

FIELD OF THE INVENTION

[0001] The present invention relates to Micro Electro-Mechanical Systems (MEMS), and more particularly to electrical connectivity in MEMS.

BACKGROUND

[0002] MEMS, such as motion sensors, inertial sensors, and movable mirrors, are being widely used. As is well known, a MEMS motion sensor may be, for example, an accelerometer for detecting linear motion, or a gyroscope for detecting rotation and angular velocities. Advanced planar silicon manufacturing processes have become the main manufacturing techniques in MEMS. However, a need continues to exist for improvement in manufacturing MEMS devices.

BRIEF SUMMARY OF THE INVENTION

[0003] A MEMS device, in accordance with one embodiment of the present invention, includes, in part, a first conductive semiconductor substrate, a second conductive semiconductor substrate, an insulating material disposed between the first and second conductive semiconductor substrates, a cavity formed in the second conductive semiconductor substrate, and at least first and second drive masses each of which includes a multitude of beams etched from the first conductive semiconductor substrate and adapted to move in the cavity and in response to an applied force. At least a first portion of the first conductive semiconductor substrate is adapted to move in response to the applied force and causes the at least first and second drive mass to be in electrical communication with the first conductive semiconductor substrate.

[0004] In one embodiment, the MEMS further includes, in part, at least one coupling spring disposed between and in electrical communication with the first and second drive masses. The coupling spring is adapted to provide electrical communication between a second portion of the first conductive substrate and the first and second drive masses. The second portion of the first conductive semiconductor substrate is adapted not to move in response to the applied force

[0005] In one embodiment, the first and second semiconductor substrates are silicon substrates and the first insulating layer is a silicon oxide layer. In one embodiment, the MEMS device further includes, in part, an isolation joint formed in the first conductive semiconductor substrate.

[0006] In one embodiment, the MEMS device further includes, in part at least one spring isolated from at least a portion of each of the first and second drive masses by the isolation joint. In one embodiment, each beam is a silicon beam. In one embodiment, the MEMS device further includes, in part, a metal layer formed on a surface of the first semiconductor substrate, and a wirebond that is in electrical communication with the second portion of the first semi-conductor substrate via the metal layer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a cross-sectional view of a silicon-on-insulator wafer (substrate) in which a MEMS device is formed, in accordance with one embodiment of the present invention.

[0008] FIG. **2** is a cross-sectional view of the substrate of FIG. **1** following a thermal oxidation process, in accordance with one exemplary embodiment of the present invention.

[0009] FIG. **3** is a cross-sectional view of the substrate of FIG. **2** following the formation of an opening in the oxide, in accordance with one exemplary embodiment of the present invention.

[0010] FIG. **4** is a cross-sectional view of the substrate of FIG. **3** following the formation of a trench, in accordance with one exemplary embodiment of the present invention.

[0011] FIG. **5** is a cross-sectional view of the substrate of FIG. **4** following the filling of the trench, in accordance with one exemplary embodiment of the present invention.

[0012] FIG. **6** is a cross-sectional view of the substrate of FIG. **5** following the formation of an opening in the oxide and deposition of a layer of screen oxide, in accordance with one exemplary embodiment of the present invention.

[0013] FIG. **7** is a cross-sectional view of the substrate of FIG. **6** following a dopant implantation step and removal of the screen oxide, in accordance with one exemplary embodiment of the present invention.

[0014] FIG. **8** is a cross-sectional view of the substrate of FIG. **7** following the deposition and patterning of a first metal layer, in accordance with one exemplary embodiment of the present invention.

[0015] FIG. **9** is a cross-sectional view of the substrate of FIG. **8** following a number of deposition and patterning steps, in accordance with one exemplary embodiment of the present invention.

[0016] FIG. **10** is a cross-sectional view of the substrate of FIG. **9** following the deposition of a second passivation layer, in accordance with one exemplary embodiment of the present invention.

[0017] FIG. **11** is a cross-sectional view of the substrate of FIG. **10** following a number of etching steps, in accordance with one exemplary embodiment of the present invention.

[0018] FIG. **12** is a cross-sectional view of the substrate of FIG. **11** following deposition and etching steps, in accordance with one exemplary embodiment of the present invention.

[0019] FIG. **13** is a cross-sectional view of the substrate of FIG. **12** following the formation of cavities in the substrate's handle wafer and a number of etching steps, in accordance with one exemplary embodiment of the present invention.

[0020] FIG. **14** is a cross-sectional view of the substrate of FIG. **13** following the formation of a wirebond, in accordance with one exemplary embodiment of the present invention.

[0021] FIG. **15**A is a simplified high-level top view of a MEMS device of FIG. **14**, in accordance with one exemplary embodiment of the present invention.

[0022] FIG. **15**B is a simplified expanded view of a portion of the MEMS device of FIG. **15**A, in accordance with one embodiment of the present invention,

DETAILED DESCRIPTION OF THE INVENTION

[0023] In accordance with one embodiment of the present invention, a MEMS device includes, in part, an electrical connection to the drive masses that is externally driven. FIG. **1** is a cross-sectional view of a silicon device layer (also referred to herein alternatively as wafer) **100** and a silicon handle wafer **200** with a buried oxide layer **150** disposed therebetween. Device layer **100**, handle wafer **200** and the buried oxide layer **150** collectively form a silicon-on-insulator (SOI) substrate or wafer.

[0024] To form a MEMS, in accordance with one embodiment of the present invention, as shown in FIG. **2**, during a thermal oxidation process, a layer **310** of thermal oxide is grown on the top and back sides of the SOI wafer. Next, using a patterning and reactive ion etching (RIE) steps, an opening **315** is formed in oxide layer **310**, as shown in FIG. **3**.

[0025] Thereafter, using a DRIE process, a trench **325** is formed in device layer **100** at opening **315** which extends to and stops on oxide layer **150**, as shown in FIG. **4**. Trench **325** is then filled with oxide to form isolation joint **335**, as shown in FIG. **5**. Subsequently, oxide layer **310** is planarized. In one embodiment, the thickness of oxide layer **310** following the planarization step is about 1 μm. Although the Figures are shown as including one such isolation joint **335**, it is understood that other embodiments may include more than one isolation joint.

[0026] Next, a contact opening **350** is formed in oxide layer **310** of device layer **100** (using, for example, fluorine based RIE) and a relatively thin layer of screen oxide **345** is grown on the resulting structure, as shown in FIG. **6**. The thickness of screen oxide layer **345** is often less than the thickness of oxide layer **310**. For example, in one embodiment, when oxide layer **310** has a thickness of 1.1 μm, screen oxide layer **345** may have a thickness of 25 nm. It is understood that the various layers and structures shown in the Figures are not drawn to scale. Thereafter, a dopant, such as Boron ions, are implanted through screen oxide layer **345**, thereby ensuring electrical contact between the first metal layer and the region near the top surface of the device layer **100**

[0027] Next, a sacrificial oxide etching step is performed using, for example, buffered oxide etching step (BOE), thereby removing oxide layer **345**, as shown in FIG. **7**. Thereafter, a layer of metal, such as Aluminum, is deposited, using for example physical vapor deposition (PVD), and patterned so as to form metal trace **360** which also forms a contact with the Boron-doped silicon **100** positioned below opening **350**, as shown in FIG. **8**. In one embodiment, metal trace **360** has a thickness ranging from 0.1 um to 0.5 um.

[0028] To form a second metal layer, a second layer of passivation **400**, such as TEOS oxide, is deposited on the device structure shown in FIG. **8** and subsequently patterned. In one embodiment, such a passivation layer may have a thickness of 1.0 μm. Thereafter, a second layer of metal **410** is deposited and patterned, using for example, spray etching. In one embodiment, Aluminum is used as a second layer metal having a thickness of, e.g., 0.7 μm. FIG. **9** shows the resulting device structure after the patterning of the second metal layer. As shown in FIG. **9**, a portion of second metal layer **410** is seen as forming an electrical contact with a portion of first metal layer **360**.

[0029] Next, as shown in FIG. **10**, another passivation layer **450**, such as TEOS oxide, that may have a thickness of e.g. 0.2 μm, is deposited over the device structure of FIG. **9**. A sintering bake process in the temperature range from 375 C to 450 C may be used to enhance electrical connection between the first layer of metal and the top silicon surface in the contact opening area. As is well known, a rapid thermal anneal process (RTA) may also be used to achieve the same effect in forming the metal-silicon contact. Although not shown, additional layers of metal (such as third and fourth metal layer) may be deposited, patterned and passivated in a manner similar to those described above with respect to the first and second metal layers.

[0030] Next, using a standard lithography process, a multitude of beam **800** (four of which are shown in the exemplary embodiment of FIG. **11**) are formed, as described below. To form the beams, in one embodiment, a fluorine based RIE etching process is used to etch the passivation layer. Thereafter, using a DRIE etching process, any silicon exposed in device **100** wafer is etched anistropically. Next, using, for example, a fluorine based RIE etching process, any exposed silicon oxide layer **150** (also referred to herein as buried oxide layer) is also etched. Thereafter, the photoresist is also removed thereby resulting in the formation of a multitude of beams **800** each of which is shown as including a bottom layer formed from oxide **150**, a middle layer formed from silicon **100**, and a top layer formed from passivation layer **450**, as shown in FIG. **11**. Beams **800** are components of the drive masses of the MEMS.

[0031] Next, a layer of TEOS oxide is deposited using, for example, PECVD technique, along sidewalls **700** of beams **800**. The deposited TEOS oxide **700** covers any exposed silicon surfaces that have not already been covered with passivation layers. Any oxide layer covering the top surface of handle wafer **200** is subsequently removed using a fluorine based RIE step, as shown in FIG. **12**. Thereafter, using a DRIE etching process, silicon is etched isotropically from handle wafer **200** to form cavity **730** as shown in FIG. **13**. Cavity **730** enables the free movement of beams **800** of the MEMS drive masses in response to an applied force.

[0032] Next, a vapor HF etch step is performed to remove any exposed oxide and passivation layers on the moving MEMS structures, thereby to from the device structure shown in FIG. **13**. Each beam **800** shown in FIG. **13** thus includes only silicon. Furthermore, a portion of oxide **150** in cavity **730** is also removed. Next, a wirebond **180** is formed on metal layer **410**, as shown in FIG. **14**. Wirebond **810** thus provides an external connection to metal layer **410** and thus to the underlaying device layer **100** which has been implanted/doped with Boron and therefore has a relatively high conductivity.

[0033] In one embodiment, beams **800** of the drive masses form an electrical contact with metal layer **410** through the underlaying device layer **100** and out of the plane of FIG. **14**. Therefore, in such embodiments, electrical connection is made between wirebond **810** and beams **800** of the drive masses via metal layer **410**, metal layer **360** and region **840** of device layer **100**.

[0034] FIG. **15**A is a simplified high-level top view of a MEMS device **900**, in accordance with one exemplary embodiment of the present invention. MEMS device **900** is shown as including, in part, a pair of drive masses **850** that are coupled to one another via a coupling spring **860**. Each drive mass **850**, which includes, in part, a multitude of beams **800** (see, for example, FIG. **14**) is also shown as being coupled to springs **870**. Wirebond **810** is formed on metal trace **410** that is in electrical contact with underlaying device layer **100** though metal trace **360** and via **350**, as described with reference, for example, to FIG. **14**. Also shown in FIG. **15**A are etched regions **890** of device layer **100**.

[0035] Drive masses **850** and coupling spring **860** are both formed from device layer **100** which, as described above, is highly conductive due to the implantation process. Accordingly, drive masses **850** and coupling spring **860** are in electrical communication with one another. Drive masses **850** and coupling spring **860** are in further electrical communication with wirebond **810** through metal traces **410** and **360** via region **840** of device layer **100**, as was also described above. FIG. **15**B is an expanded view of region **880** of FIG. **15**A showing portions of etched regions **890** and coupling spring **860** as well as region **840** of device layer **100**. FIG. **14** is a cross-sectional view of MEMS device **900** when viewed along lines A-A'. It is understood that the connection between region **840** of device layer **100** and beams **800** is made out of the plane of FIG. **14**. Regions **840** of device layer **100**, which move in response to an applied force, are in electrical contact with first layer metal **360** through opening **350** and hence in contact with second layer metal **410** and wirebond **810**.

[0036] Although not shown, in one embodiment, springs **870**, which are also formed in device layer **100**, are electrically isolated from portions or all of the drive masses via one or more isolation joints formed in device layer **100**, such as isolation joint **335** shown in the drawings. Regions **840**, which move in response to an applied force, thus electrically connect the drive masses to the non-moving portions of device layer **100**. Furthermore, although FIGS. **12**-**14** are shown as including two drive masses, it is understood that a MEMS device, in accordance with embodiments of the present invention, may have any number of drive masses, such as 4.

[0037] The above embodiments of the present invention are illustrative and not limitative. Embodiments of the present invention are not limited by the type of MEMS device. Embodiments of the present invention are not limited by the type of deposition, patterning, etching, and other semiconductor processing steps required to form the various layers and structures described herein. Embodiments of the present invention are not limited to any specific thicknesses of the layers described herein. Embodiments of the present invention are not limited to the materials/layers described above. Accordingly, it is understood that other semiconductor materials may be present between the various layers described above. Other additions, subtractions or modifications are obvious in view of the present disclosure and are intended to fall within the scope of the appended claims.

1. A MEMS device comprising:
a first conductive semiconductor substrate;
a second conductive semiconductor substrate;
an insulating material disposed between the first and second conductive semiconductor substrates;
a cavity formed in the second conductive semiconductor substrate; and
at least first and second drive masses each comprising a plurality of beams etched from the first conductive semiconductor substrate and adapted to move in the cavity and in response to an applied force, wherein at least a first portion of the first conductive semiconductor substrate is adapted to move in response to the applied force and causes the at least first and second drive mass to be in electrical communication with the first conductive semiconductor substrate.

2. The MEMS device of claim **1** further comprising:
at least one coupling spring disposed between and in electrical communication with the at least first and second drive masses, said at least one coupling spring adapted to provide electrical communication between a second portion of the first conductive substrate and the first and second drive masses, said second portion of the first conductive semiconductor substrate adapted not to move in response to the applied force.

3. The MEMS device of claim **1** wherein said first and second semiconductor substrates are silicon substrates and the first insulating layer is a silicon oxide layer.

4. The MEMS device of claim **1** further comprising an isolation joint formed in the first conductive semiconductor substrate.

5. The MEMS device of claim **4** further comprising at least one spring isolated from at least a portion of each of the first and second drive masses by the isolation joint.

6. The MEMS device of claim **1** wherein each of the plurality of beams is a silicon beam.

7. The MEMS device of claim **1** further comprising:
a metal layer formed on a surface of the first semiconductor substrate; and
a wirebond in electrical communication with the second portion of the first semiconductor substrate via the metal layer.

* * * * *