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(54) **Title**: MICROELECTROMECHANICAL LOAD SENSOR AND METHODS OF MANUFACTURING THE SAME

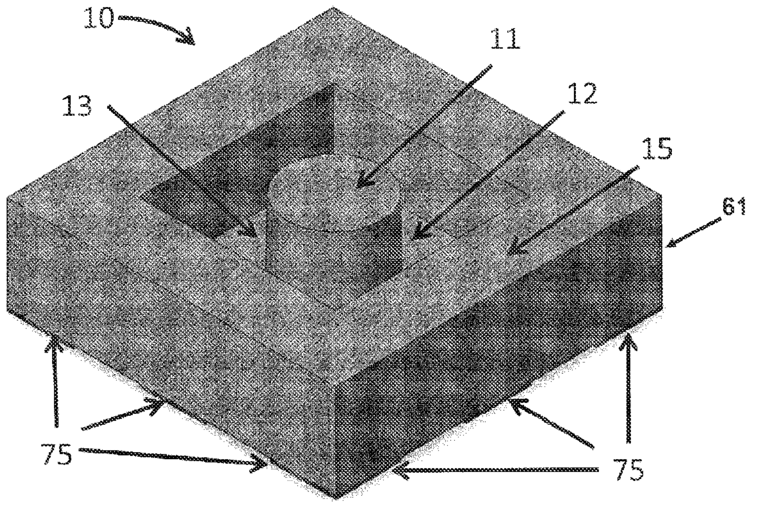

FIGURE 1

(57) **Abstract**: A microelectromechanical ("MEMS") load sensor device (10) for measuring a force applied by a human user is described herein. In one aspect, the load sensor device (10) has a contact surface (11) in communication with a touch surface which communicates forces originating on the touch surface to a deformable membrane (13), on which load sensor elements are arranged, such that the load sensor device produces a signal proportional to forces imparted by a human user along the touch surface. In another aspect, the load sensor device has an overload protection ring to protect the load sensor device from excessive forces. In another aspect, the load sensor device has embedded logic circuitry to allow a microcontroller to individually address load sensor devices organized into an array. In another aspect, the load sensor device has electrical and mechanical connectors such as solder bumps designed to minimize cost of final component manufacturing.

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MICROELECTROMECHANICAL LOAD SENSOR
AND METHODS OF MANUFACTURING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 61/668,135, filed on July 5, 2012, entitled "Microelectromechanical Load Sensor and Methods of Using Same," the disclosure of which is expressly incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0001] This disclosure relates to the technical field of touch interfaces based on microelectromechanical ("MEMS") load sensors that are used as input devices for data processing systems.

BACKGROUND

[0002] A variety of known MEMS devices are designed to measure applied load and produce an output differential voltage signal proportional to the applied load. These known devices, such as conventional piezoresistive, piezoelectric, and capacitive MEMS force sensors, pressure sensors, and strain gauges, utilize the unique electromechanical properties of materials such as silicon and lead zirconate titanate.

[0003] However, there is a need in the pertinent art for an interface device that is capable of receiving and recognizing a range of human user actions. There is also a need in the pertinent art for an interface device that is capable of tolerating a force from a user without being damaged or causing injury to the user.

SUMMARY

[0004] Described herein are MEMS load sensor devices and, more specifically, MEMS load sensor devices designed to measure an applied load and produce an output signal. More specifically, the MEMS load sensor devices described herein are configured to measure forces originating from human user actions such as pressing a button or a touch surface. The MEMS load sensor devices can be configured as a component of a force sensitive touch interface for providing touch input into a data processing system, for example. The MEMS load sensor devices can include a substrate, a deformable membrane, a load sensor element configured to produce a signal when deformed, an overload protection portion, and a means to communicate load sensor signals to an electrical circuit.

[0005] An example MEMS load sensor device can include a substrate defining a deformable membrane, a mesa and an overload protection portion. The mesa can be configured to receive and transfer an applied force to the deformable membrane, and the deformable membrane can be configured to deform in response to the applied force. The MEMS load sensor device can also include at least one load sensor element formed on the deformable membrane. The load sensor element can be configured to change at least one electrical characteristic based on an amount or magnitude of the applied force. Additionally, a height of the mesa can be greater than a height of the overload protection portion.

[0006] Optionally, the mesa defines a contact surface for receiving the applied force. The contact surface can have at least one of a substantially square, rectangular, rounded, circular or elliptical shape.

[0007] Alternatively or additionally, the mesa can optionally be arranged in a central portion of the substrate. Alternatively or additionally, the overload protection portion can optionally be arranged in a peripheral portion of the substrate.

[0008] Optionally, the MEMS load sensor device can further include a touch surface fixed to at least a portion of the mesa. The touch surface can be configured to receive and transfer the applied force to the mesa. Additionally, a gap can be arranged between the touch surface and the overload protection portion when the touch surface is fixed to the mesa. The gap can limit an amount of deflection of the deformable membrane and can prevent the deformable membrane from mechanically failing under an excessive applied force.

[0009] Alternatively or additionally, the MEMS load sensor device can optionally include one or more electromechanical connectors for connecting the MEMS load sensor device to an external circuit.

[0010] Optionally, the deformable membrane, the mesa and the overload protection portion can be formed by removing a portion of the substrate. For example, the substrate can have a first surface and a second surface opposite to the first surface. The deformable membrane, the mesa and the overload protection portion can be formed using a deep reactive ion etching technique on the second surface. Additionally, the MEMS load sensor device can optionally include one or more electromechanical connectors for connecting the MEMS load sensor device to an external circuit formed on the first surface.

[0011] Optionally, the load sensor element can be a piezoresistive element. Additionally, the MEMS load sensor device can include a plurality of piezoresistive elements electrically connected in a Wheatstone bridge circuit. Additionally, the MEMS load sensor device can optionally include an activation circuit for supplying a voltage to the Wheatstone bridge circuit and for communicating a differential output voltage from the Wheatstone bridge circuit. For example, the activation circuit can include one or more output signal traces for communicating the differential output voltage from the Wheatstone bridge circuit to a signal bus and one or more voltage supply traces for connecting the Wheatstone bridge circuit to an external voltage source. The MEMS load sensor device can also include a row trace and a column trace for addressing the MEMS load sensor device and a logical gate having an input and output and one or more switches connected to the output of the logical gate. The input of the logical gate can be connected to the row and column traces, and each switch can be configured to electrically connect an output trace and the signal bus or a voltage supply trace and the external voltage source.

[0012] Also described herein is a method of manufacturing a MEMS load sensor device and optionally electrically and mechanically attaching the MEMS load sensor device to a separate circuit substrate. For example, the method includes the steps to manufacture the MEMS load sensor device and also optionally includes the steps to attach the MEMS load sensor device to the separate circuit substrate. The steps include micromachining the mechanical elements such as the deformable membrane, mesa, and overload protection portion, forming (e.g., by ion implantation) a load sensor element such as a piezoresistive element, metallization steps to form traces to connect the piezoresistive element to other electrical circuit elements on the MEMS load sensor device, steps to embed complementary metal-oxide-semiconductor (“CMOS”) circuitry to activate the MEMS load sensor device and to connect the MEMS load sensor device output to a signal bus of a separate circuit, steps to add electrical and mechanical connectors, and post processing steps to electrically and mechanically attach the MEMS load sensor device to a separate circuit substrate.

[0013] An example method for manufacturing a MEMS load sensor device can include providing a substrate having a first surface and a second surface opposite to the first surface, forming at least one load sensor element on the first surface of the substrate and etching the second surface of the substrate to form a deformable membrane, a mesa and an overload protection portion. The mesa can be configured to receive and transfer an applied force to the deformable membrane, and the deformable membrane can be configured to deform in response to the applied force. Additionally, the load sensor element can be provided on the deformable membrane and can be configured to change at least one electrical characteristic based on an amount or magnitude of the applied force. A height of the mesa can be greater than a height of the overload protection portion.

[0014] Optionally, in the method above, etching the second surface of the substrate to form a deformable membrane, a mesa and an overload protection portion can further include applying a layer of photoresist over the second surface of the substrate, irradiating a portion of the layer of photoresist with ultraviolet light through a mask and removing the irradiated portion of the layer of photoresist to expose a portion of the second surface of the substrate. Thereafter, the method can further include etching the exposed portion of the second surface of the substrate to form the deformable membrane, the mesa and the overload protection portion. For example, the second surface of the substrate can be etched using a deep ion etching technique.

[0015] Alternatively or additionally, in the method above, forming at least one load sensor element on the first surface of the substrate can further include applying a layer of silicon oxide over the first surface of the substrate, applying a layer of photoresist over the layer of silicon oxide, irradiating a portion of the layer of photoresist with ultraviolet light through a mask and removing the irradiated portion of the layer of photoresist to expose a portion of the layer of silicon oxide. Thereafter, the method can further include etching the exposed portion of the layer of silicon oxide to expose a portion of the first layer of the substrate and forming the load sensor element on the exposed portion of the first layer of the substrate.

[0016] Optionally, the load sensor element can be a piezoresistive element formed using a deposition, diffusion, or ion implantation technique.

[0017] Alternatively or additionally, the method can optionally include forming at least one electrical trace on the first surface of the substrate. The electrical trace can be electrically connected to the load sensor element.

[0018] Alternatively or additionally, the method can optionally further include forming one or more electromechanical connectors for connecting the MEMS load sensor device to an external circuit.

[0019] Optionally, the mesa defines a contact surface for receiving the applied force. The contact surface can have at least one of a substantially square, rectangular, rounded, circular or elliptical shape.

[0020] Alternatively or additionally, the mesa can optionally be arranged in a central portion of the substrate. Alternatively or additionally, the overload protection portion can optionally be arranged in a peripheral portion of the substrate.

[0021] Optionally, the method can further include fixing a touch surface to at least a portion of the mesa. The touch surface can be configured to receive and transfer the applied force to the mesa. Additionally, a gap can be arranged between the touch surface and the overload protection portion when the touch surface is fixed to the mesa. The gap can limit an amount of deflection of the deformable membrane and can prevent the deformable membrane from mechanically failing under an excessive applied force.

[0022] Other systems, methods, features and/or advantages will be or may become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features and/or advantages be included within this description and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The components in the drawings are not necessarily to scale relative to each other. Like reference numerals designate corresponding parts throughout the several views.

[0024] Figure 1 is an isometric view of an example load sensor device.

[0025] Figure 2 is a side view of the load sensor device of Fig. 1.

[0026] Figure 3 is a top view of the load sensor device of Fig. 1.

[0027] Figure 4 is a bottom view of the load sensor device of Fig. 1.

[0028] Figure 5 is a cross sectional view of the load sensor device of Fig. 1 along the line L of Fig. 3.

[0029] Figure 6 is a cross sectional view of the load sensor device along the line L of Fig. 3, with a force F applied showing concentration of stresses within the device.

[0030] Figure 7 is a cross sectional view of the load sensor device of Fig. 1 when electrically and mechanically connected to a circuit substrate and a touch surface.

[0031] Figure 8 is an electrical schematic diagram of the electrical circuits embedded within the load sensor device of Fig. 1.

[0032] Figure 9 is an electrical schematic diagram of multiple load sensor devices of Fig. 1 in an independently addressable array.

[0033] Figure 10 illustrates the process steps to manufacture the load sensor device of Fig. 1.

[0034] Figure 11 illustrates the process steps to electrically and mechanically attach the load sensor device of Fig. 1 to a separate circuit.

DETAILED DESCRIPTION

[0035] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art. Methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present disclosure. As used in the specification, and in the appended claims, the singular forms “a,” “an,” “the” include plural referents unless the context clearly dictates otherwise. The term “comprising” and variations thereof as used herein is used synonymously with the term “including” and variations thereof and are open, non-limiting terms. The terms “optional” or “optionally” used herein mean that the subsequently described feature, event or circumstance may or may not occur, and that the description includes instances where said feature, event or circumstance occurs and instances where it does not. While implementations will be described with respect to a MEMS load sensor device and method of manufacturing the same, it will become evident to those skilled in the art that the implementations are not limited thereto.

[0036] Described herein is an example MEMS load sensor device (e.g., load sensor device) for measuring a force applied to a least a portion thereof. In one aspect, as depicted in Figs. 1-6, the load sensor device 10 includes a substrate 61 defining a deformable membrane 13, a mesa 12 and an overload protection portion 15. It should be understood that the overload protection portion as used herein can include a range of structures such as a ring, for example. The substrate 61 can optionally be a silicon substrate. As shown in Figs. 1 and 2, the substrate 61 can have a first surface 61A and a second surface 61B opposite the first surface 61A, and the mesa 12 and the overload protection portion 15 can optionally be arranged in a central portion 61C and a peripheral portion 61D of the substrate 61, respectively. As discussed in more detail below, the deformable membrane 13, the mesa 12 and the overload protection portion 15 can be formed from the substrate 61 using an etching process. Additionally, at least one load sensor element (e.g., piezoresistive elements 14 and 82 discussed below) can be formed on the deformable membrane 13. Optionally the load sensor element can be a piezoresistive, piezoelectric or capacitive element. The load sensor element can be configured to change at least one electrical characteristic (e.g., resistance, charge, capacitance, etc.) based on an amount or magnitude of the applied force. Optionally, the load sensor element can output a signal proportional to the amount or magnitude of the applied force.

[0037] Additionally, the mesa 12 can define a contact surface 11, for example along the top surface of the mesa 12, for receiving an applied force F and transmitting the force F to the deformable membrane 13. It is contemplated that the contact surface 11 can have any shape, such as, for example and without limitation, a substantially square shape, a substantially round, circular or elliptical shape as depicted in Figs. 1-3, a substantially rectangular shape, and the like. Additionally, this disclosure contemplates that the contact surface 11 can have shapes other than those described herein, and therefore, this disclosure should not be limited to the shapes described herein and/or shown in the figures. It is further contemplated, with reference to Fig. 3, that the contact surface 11 can be affixed below a touch surface 71 in order to receive the reaction force F transmitted through the touch surface 71 as depicted in Fig. 7. For example, as discussed below, at least a portion of the contact surface 11 can be bonded to at least a portion of the touch surface 71 using an adhesive. As the deformable membrane 13 deforms, a strain gradient forms within the substrate 61. The concentration of stresses in the load sensor device 10 in response to the applied force F is illustrated in Fig. 6. The strain gradient imparts a localized strain on the piezoresistive elements 14 and 82 (e.g., the load sensor elements). As the piezoresistive elements 14 and 82 experience strain, their resistivities change, such that a Wheatstone bridge circuit, e.g., the Wheatstone bridge circuit 81 of Fig. 8 including two piezoresistive elements 14 and two oppositely arranged piezoresistive elements 82, becomes unbalanced and produces a differential voltage across the positive signal terminal 83 and the negative signal terminal 84. Alternatively, the Wheatstone bridge circuit can include two piezoresistive elements 14 and two oppositely arranged stationary resistors 82, such that the Wheatstone bridge circuit 81 becomes unbalanced and produces a differential voltage as the piezoresistive elements 14 change their respective resistivities as they experience strain.

This differential voltage is directly proportional to the applied force F on the contact surface 11. In addition, the load sensor device 10 can include one or more electromechanical connectors 75 for electrically and mechanically connecting the load sensor device 10 to a separate circuit substrate.

[0038] As discussed above, the load sensor device 10 can include a touch surface (e.g., touch surface 71), for example, fixed to the contact surface 11 of the mesa 12. In an additional aspect, the load sensor device 10 incorporates an upper air gap 73 between the overload protection portion 15 and the touch surface 71. As shown in Fig. 7, the upper air gap 73 exists because the height of the mesa 12 is greater than the height of the overload protection portion 15. The difference in height between the mesa 12 and the overload protection portion 15 can be selected or engineered to be less than the maximum vertical deflection of the deformable membrane 13 before it yields or fails due to an excessive applied force. As the force F is applied to the touch surface 71, the deformable membrane 13 deforms, and when the force F reaches a threshold, the touch surface 71 comes into contact with the overload protection portion 15. At this point, the deformable membrane 13 no longer deforms linearly with applied force F. In this way the upper air gap 73 and the overload protection portion 15 work together to prevent the load sensor device 10 (e.g., the deformable membrane 13) from mechanically failing under excessive applied force F.

[0039] Alternatively or additionally, the load sensor device 10 optionally incorporates a lower air gap 74 between a lower surface 16 of the load sensor device 10 and an upper surface of a separate circuit substrate 72 as shown in FIG. 7. As the force F is applied to the touch surface 71, the deformable membrane 13 deforms, allowing the touch surface 71 to move closer to and, as the force F becomes sufficiently large, come in contact with the overload protection portion 15. Alternatively or additionally, as the force F becomes sufficiently larger and the deformable membrane 13 deforms lower, the lower surface 16 of the load sensor device 10 comes into contact with an upper surface 76 of the separate circuit substrate 72. Once force F reaches an upper threshold and the touch surface 71 is in contact with the overload protection portion 15 and the lower surface 16 of the load sensor device 10 comes into contact with the upper surface 76 of the separate circuit substrate 72, the deformable membrane 13 no longer deforms linearly with applied force F. In this way the upper air gap 73, the lower air gap 74, and the overload protection portion 15 work together to prevent the load sensor device 10 (e.g., the deformable membrane 13) from mechanically failing under excessive applied force F. Electromechanical connectors 75, such as a solder joints or wire bonds, can be provided. The electromechanical connectors 75 are used to electrically and mechanically connect the load sensor device 10 to the separate circuit substrate 72.

[0040] Referring now to Fig. 8, in an additional aspect, the load sensor device 10 includes and/or incorporates electrical circuitry 80 to activate the load sensor device 10 and electrically connect the load sensor device 10 to a separate circuit signal bus, for example, through electromechanical connectors such as electromechanical connectors 75 of Figs. 2, 4, 5 and 7. Optionally, the electromechanical connectors are solder joints or wire bonds. As discussed above, the electrical circuitry 80 can include the Wheatstone bridge circuit 81. In one embodiment, the electrical circuitry 80 includes of an activation circuit 86 including an X row signal trace 90 and a Y column signal trace 91 and a logical gate (e.g., AND gate 89). The row and column signal traces 90 and 91 can be used to individually address the load sensor device 10. For example, when both X and Y signals are logic high, the AND gate 89 is enabled, which closes a plurality of switches 87. The electrical circuitry 80 can also include one or more voltage supply traces for electrically connecting the Wheatstone bridge circuit 81 to an external voltage source 88 and one or more output signal traces for electrically connecting the positive and negative terminals 83 and 84 to the separate circuit signal bus. Each of the switches, respectively, connects the external voltage source 88 to the Wheatstone bridge circuit 81 or connects the positive signal terminal 83 and the negative signal terminal 84, respectively, to the separate circuit signal bus. In this way, an array of load sensor devices 10 can be placed into an independently addressable array 90, wherein the sensor value of each individual load sensor device 10 can be read independently, for example, by a microcontroller. An independently addressable array 90 including a plurality of load sensor device 10 is depicted in Fig. 9.

[0041] Referring now to Fig. 10, a method for manufacturing a MEMS load sensor device such as the load sensor device 10 discussed above is described herein. In the described method, step 110 involves growing or depositing a layer of silicon oxide 151 onto a surface of a bare silicon wafer 150. Optionally, the layer of silicon oxide is grown or deposited on a surface of a silicon wafer on which electrical circuitry (e.g., the electrical circuitry 80 discussed above) for activating the load sensor device is already embedded through a separate CMOS semiconductor fabrication process. It should be understood that the silicon wafer can have an upper surface (or a first surface as used herein) and a lower surface (or a second surface as used herein) opposite to the upper surface. The surface of the silicon wafer on which the layer of silicon oxide is grown or deposited in step 110 can be the upper surface of the silicon wafer. In step 111, a layer of photoresist 152 is applied or deposited onto at least a portion of the upper surface of the silicon wafer, for example, over the layer of silicon oxide. Thereafter, ultraviolet light is cast through a mask to weaken portions of the layer of photoresist. The layer of photoresist is then developed and at least a portion of the layer of silicon oxide 151A is exposed, such that the exposed portion can be removed with an etchant as in step 112. In step 113, one or more piezoresistive elements 153 (e.g., load sensors elements) are formed, for example, by a deposition, diffusion or ion implantation process. The piezoresistive elements 153 can be the piezoresistive elements 14 and 82 discussed above, for example.

[0042] In step 114, the layer of silicon oxide 151 is etched completely. In step 115, the silicon wafer is annealed and an additional layer of silicon oxide 154 is formed, for example, on the upper surface of the silicon wafer over the piezoresistive elements 153. Additionally, a layer of silicon oxide 155 is also formed over on the opposite surface of the silicon wafer. It should be understood that the opposite surface of the silicon wafer as used herein can be the lower surface of the silicon wafer. In step 116, an additional layer of photoresist 156 is applied onto at least a portion of the upper surface of the silicon wafer, for example, over the layer of silicon oxide 154. Thereafter, ultraviolet light is cast through a mask, which weakens portions of the layer of photoresist 156. The layer of photoresist is then developed in order to expose at least a portion of the layer of silicon oxide 154A covering the piezoresistive elements 153. In step 117, the exposed portion of the layer of silicon oxide is etched completely to expose the piezoresistive elements 153, e.g., an upper portion of the piezoresistive elements 153. In step 118, a conductive metal 157 (e.g., an electrical trace), such as aluminum, is sputtered onto the upper surface of the silicon wafer, for example, over the exposed piezoresistive elements, to form electrical connections between the piezoresistive elements 153 and the electromechanical connectors (discussed below). In step 119, an additional layer of photoresist 158 is applied onto at least a portion of the upper surface of the silicon wafer, for example, over the conductive metal. Thereafter, ultraviolet light is cast through a mask, which weakens at least a portion of the layer of photoresist. The layer of photoresist is then developed in order to expose at least a portion of the conductive metal 157A to be removed. In step 120, the exposed portion of the conductive metal is etched completely to leave the remaining conductive metal forming one or more portions of the connecting circuitry (e.g., one or more portions of the electrical circuitry 80 discussed above).

[0043] In step 121, a passivation layer 159 is deposited or applied to protect the piezoresistive elements 153 and conductive metal 157. In step 122, an additional layer of photoresist 160 is applied to the upper surface of the silicon wafer, for example, over the passivation layer. Thereafter, ultraviolet light is cast through a mask to weaken at least a portion of the layer of photoresist. The layer of photoresist is then developed in order to expose at least a portion of the passivation layer 159A to be removed. In step 123, the exposed portion of the passivation layer is etched completely to leave a portion of the conductive metal 157B underneath exposed for electrical contact.

[0044] In step 124, the silicon wafer is inverted to expose the lower surface of the silicon wafer. As discussed above with regard to step 115, the lower surface of the silicon wafer has the layer of silicon oxide 155 formed thereon. In addition, an additional layer of photoresist 161 is applied to the lower surface of the silicon wafer, for example, over a portion of the layer of silicon oxide. Thereafter, ultraviolet light is cast through a mask to weaken at least a portion of the layer of photoresist. The layer of photoresist is then developed in order to expose at least a portion of the layer of silicon oxide 155A formed over the lower surface of the silicon wafer. In step 125, the exposed portion of the layer of silicon oxide is etched completely to expose a portion of the lower surface of the silicon wafer 150A. In step 126, the exposed portion of silicon wafer is etched to form the height offset between a mesa and overload protection portion (e.g., the mesa 12 and overload protection portion 15 discussed above) to provide overload protection. In step 127, an additional layer of photoresist 162 is applied onto at least a portion of the lower surface of the silicon wafer. Thereafter, ultraviolet light is cast through a mask to weaken at least a portion of the layer of photoresist. The layer of photoresist is then developed in order to expose at least a portion of the lower surface of the silicon wafer 150B. In step 128, the silicon on the lower surface of the silicon wafer is etched away using a deep reactive ion etching process to form an integrated mesa, contact surface, deformable membrane and overload protection portion (e.g., the mesa 12, contact surface 11, deformable membrane 13 and overload protection portion 15). In step 129, the layer of silicon oxide on the upper surface of the mesa is etched completely to leave exposed bare silicon. The silicon wafer can then optionally be inverted and electromechanical connectors (e.g., electromechanical connectors 75 discussed above) such as solder bumps, wire bonds, etc. are attached to the load sensor device, e.g., to the same surface of the bare silicon wafer on which the piezoresistive elements were formed. The load sensor device is then ready for a separate manufacturing process to be attached to an electrical circuit.

[0045] Referring now to Fig. 11, the steps to attach a load sensor device (e.g., load sensor device 10 of Figs. 1-7) to a separate circuit substrate (e.g., separate circuit substrate 72 of Fig. 7) and complete a touch solution are illustrated. In this final manufacturing process, the load sensor devices are first bonded to the substrate, such as FR4, of a separate circuit. Then, the electrical and mechanical connections are formed through a process such as reflow soldering or wire bonding. Finally, a touch surface (e.g., touch surface 71 of Fig. 7) is affixed to each load sensor device (e.g., to the contact surface 11 of the mesa 12 of each load sensor 10 of Figs. 1-7) in the finished component using adhesive, and the entire assembly is cured to form a finished touch surface component.

[0046] Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

WHAT IS CLAIMED:

1. A microelectromechanical (MEMS) load sensor device, comprising:

a substrate defining a deformable membrane, a mesa and an overload protection portion, the mesa being configured to receive and transfer an applied force to the deformable membrane, the deformable membrane being configured to deform in response to the applied force; and

at least one load sensor element formed on the deformable membrane, the load sensor element being configured to change at least one electrical characteristic based on an amount or magnitude of the applied force, wherein a height of the mesa is greater than a height of the overload protection portion.

2. The MEMS load sensor device of claim 1, wherein the mesa defines a contact surface for receiving the applied force.

3. The MEMS load sensor device of 2, wherein the contact surface has at least one of a substantially square, rectangular, rounded, circular or elliptical shape.

4. The MEMS load sensor device of any of claims 1-3, wherein the mesa is arranged in a central portion of the substrate.

5. The MEMS load sensor device of any of claims 1-4, wherein the overload protection portion is arranged in a peripheral portion of the substrate.

6. The MEMS load sensor device of any of claims 1-5, further comprising a touch surface fixed to at least a portion of the mesa, wherein the touch surface is configured to receive and transfer the applied force to the mesa.

7. The MEMS load sensor device of claim 6, wherein a gap is arranged between the touch surface and the overload protection portion when the touch surface is fixed to the mesa, the gap limiting an amount of deflection of the deformable membrane and preventing the deformable membrane from mechanically failing under an excessive applied force.

8. The MEMS load sensor device of any of claims 1-7, further comprising one or more electromechanical connectors for connecting the MEMS load sensor device to an external circuit.

9. The MEMS load sensor device of any of claims 1-8, wherein the deformable membrane, the mesa and the overload protection portion are formed by removing a portion of the substrate.

10. The MEMS load sensor device of claim 9, wherein the substrate has a first surface and a second surface opposite to the first surface, and the deformable membrane, the mesa and the overload protection portion are formed using a deep reactive ion etching technique on the second surface.

11. The MEMS load sensor device of claim 10, wherein one or more electromechanical connectors for connecting the MEMS load sensor device to an external circuit are formed on the first surface.

12. The MEMS load sensor device of any of claims 1-11, wherein the load sensor element comprises a piezoresistive element.

13. The MEMS load sensor device of claim 12, further comprising a plurality of piezoresistive elements electrically connected in a Wheatstone bridge circuit.

14. The MEMS load sensor device of claim 13, further comprising an activation circuit for supplying a voltage to the Wheatstone bridge circuit and for communicating a differential output voltage from the Wheatstone bridge circuit.

15. The MEMS load sensor device of claim 14, wherein the activation circuit comprises:

one or more output signal traces for communicating the differential output voltage from the Wheatstone bridge circuit to a signal bus;

one or more voltage supply traces for connecting the Wheatstone bridge circuit to an external voltage source;

a row trace and a column trace for addressing the MEMS load sensor device;

a logical gate having an input and output, the input of the logical gate being connected to the row and column traces; and

one or more switches connected to the output of the logical gate, wherein each switch is configured to electrically connect an output trace and the signal bus or a voltage supply trace and the external voltage source.

16. A method for manufacturing a microelectromechanical (MEMS) load sensor device, comprising:

providing a substrate having a first surface and a second surface opposite to the first surface;

forming at least one load sensor element on the first surface of the substrate; and

etching the second surface of the substrate to form a deformable membrane, a mesa and an overload protection portion, the mesa being configured to receive and transfer an applied force to the deformable membrane, the deformable membrane being configured to deform in response to the applied force, and the load sensor element being provided on the deformable membrane and being configured to change at least one electrical characteristic based on an amount or magnitude of the applied force, wherein a height of the mesa is greater than a height of the overload protection portion.

17. The method of claim 16, wherein etching the second surface of the substrate to form a deformable membrane, a mesa and an overload protection portion further comprises:

applying a layer of photoresist over the second surface of the substrate;

irradiating a portion of the layer of photoresist with ultraviolet light through a mask;

removing the irradiated portion of the layer of photoresist to expose a portion of the second surface of the substrate; and

etching the exposed portion of the second surface of the substrate to form the deformable membrane, the mesa and the overload protection portion.

18. The method of any of claims 16-17, wherein the second surface of the substrate is etched using a deep ion etching technique.

19. The method of any of claims 16-18, wherein forming at least one load sensor element on the first surface of the substrate further comprises:

applying a layer of silicon oxide over the first surface of the substrate;

applying a layer of photoresist over the layer of silicon oxide;

irradiating a portion of the layer of photoresist with ultraviolet light through a mask;

removing the irradiated portion of the layer of photoresist to expose a portion of the layer of silicon oxide;

etching the exposed portion of the layer of silicon oxide to expose a portion of the first layer of the substrate; and

forming the load sensor element on the exposed portion of the first layer of the substrate.

20. The method of claim 19, wherein the load sensor element is a piezoresistive element formed using a deposition, diffusion, or ion implantation technique.

21. The method of any of claims 16-20, further comprising forming at least one electrical trace on the first surface of the substrate, wherein the electrical trace is electrically connected to the load sensor element.

22. The method of any of claims 16-21, further comprising forming one or more electromechanical connectors for connecting the MEMS load sensor device to an external circuit.

23. The method of any of claims 16-22, wherein the mesa defines a contact surface for receiving the applied force.

24. The method of 23, wherein the contact surface has at least one of a substantially square, rectangular, rounded, circular or elliptical shape.

25. The method of any of claims 16-24, wherein the mesa is arranged in a central portion of the substrate.

26. The method of any of claims 16-25, wherein the overload protection portion is arranged in a peripheral portion of the substrate.

27. The method of any of claims 16-26, further comprising fixing a touch surface to at least a portion of the mesa, wherein the touch surface is configured to receive and transfer the applied force to the mesa.

28. The method of claim 27, wherein a gap is arranged between the touch surface and the overload protection portion when the touch surface is fixed to the mesa, the gap limiting an amount of deflection of the deformable membrane and preventing the deformable membrane from mechanically failing under an excessive applied force.

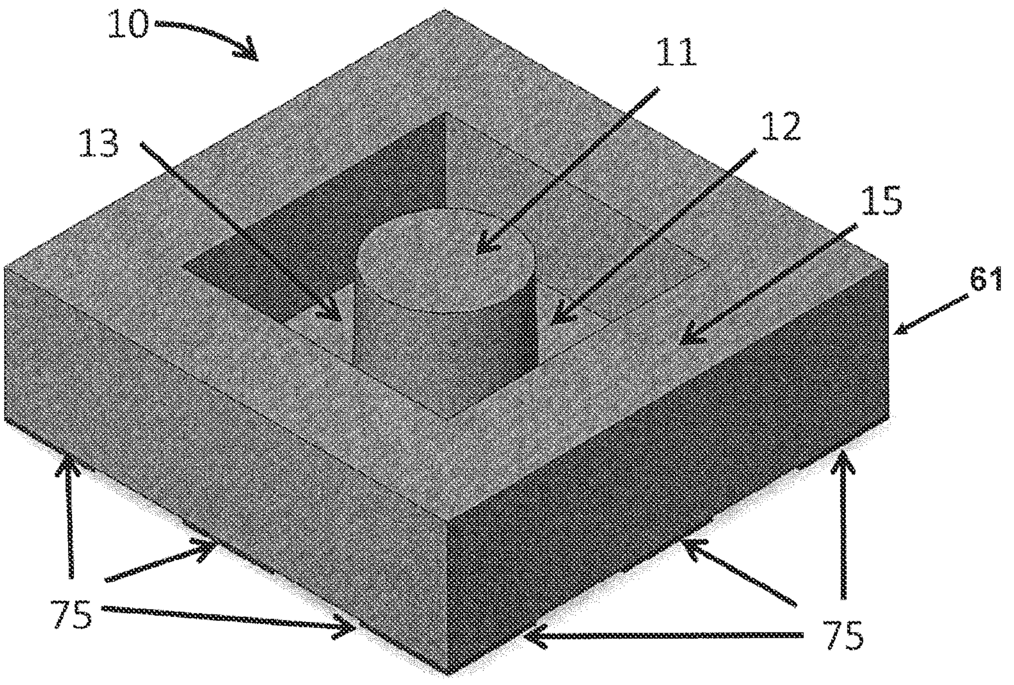


FIGURE 1

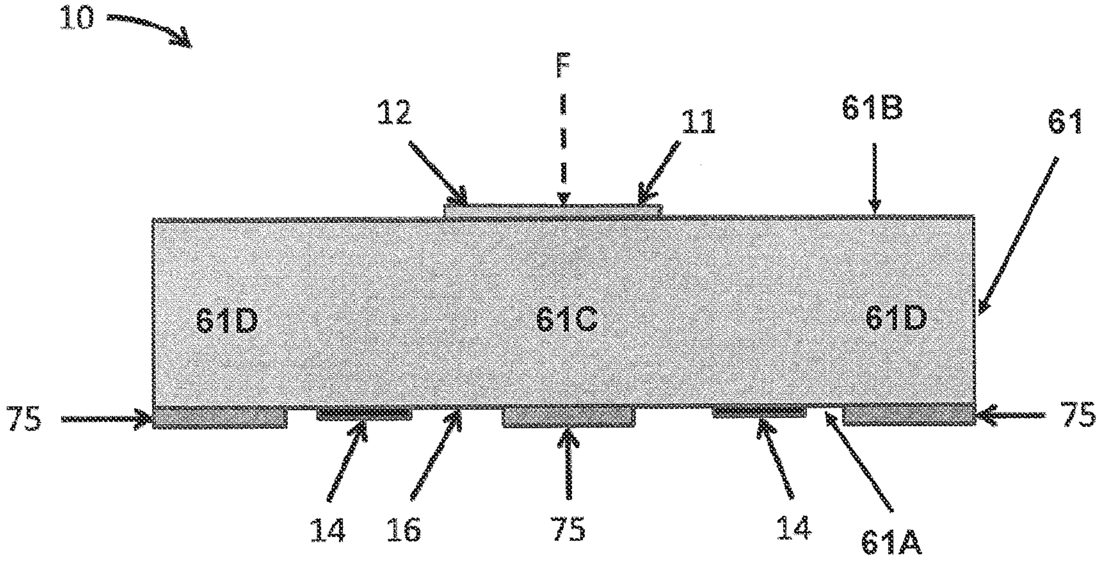


FIGURE 2

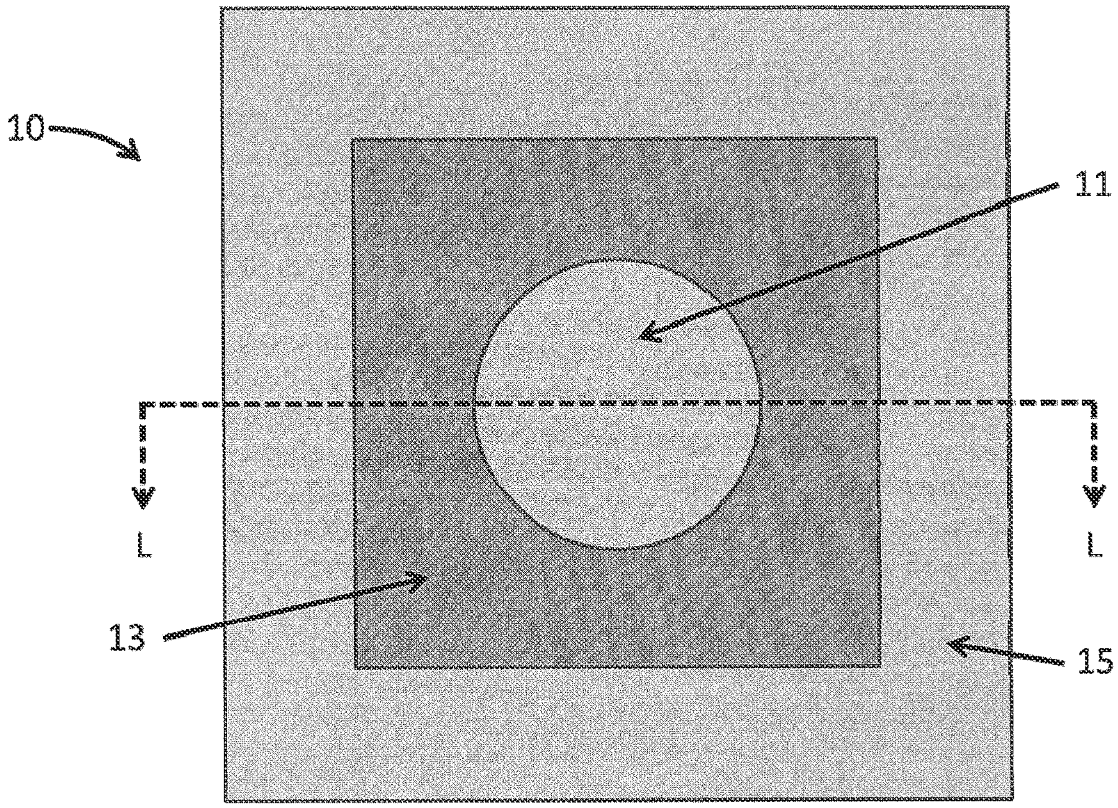


FIGURE 3

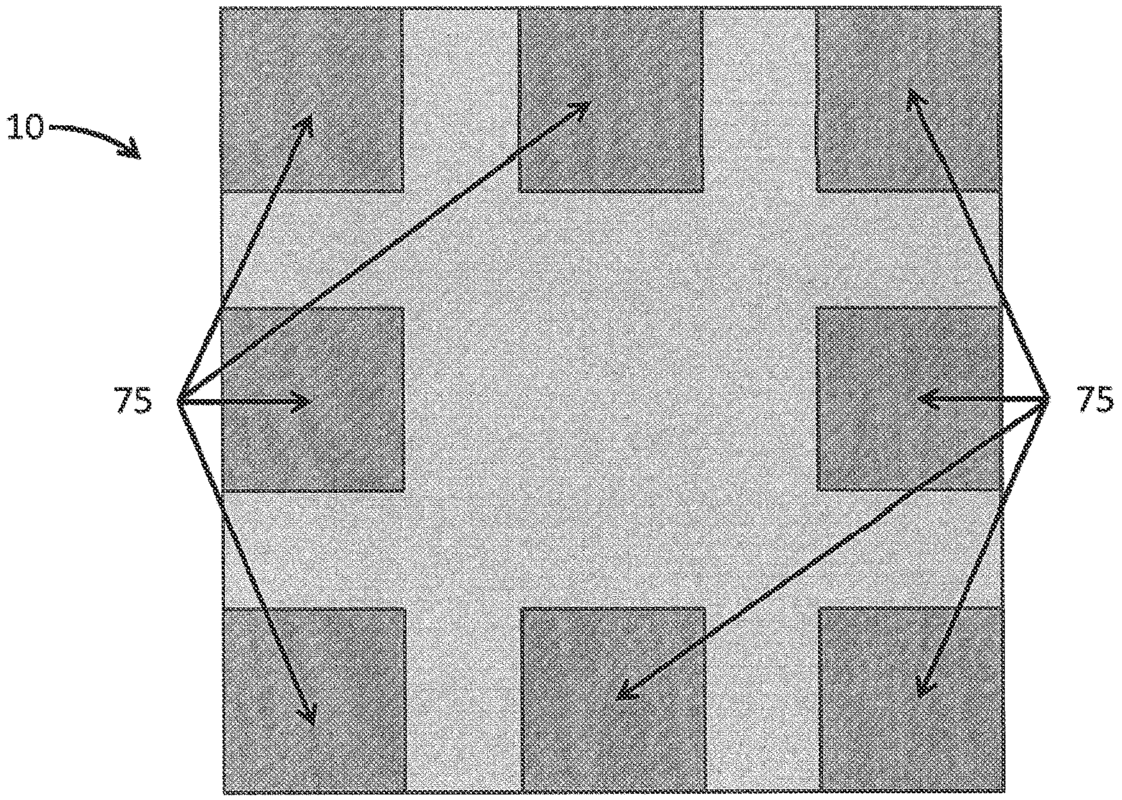


FIGURE 4

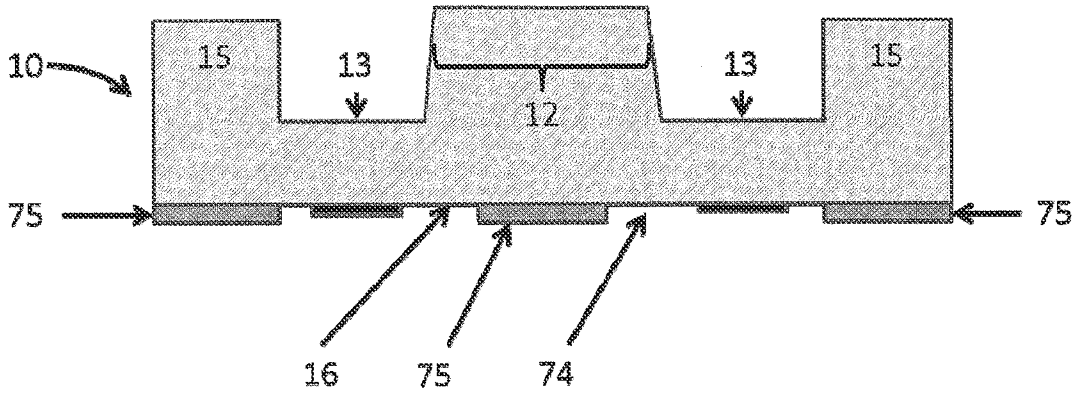
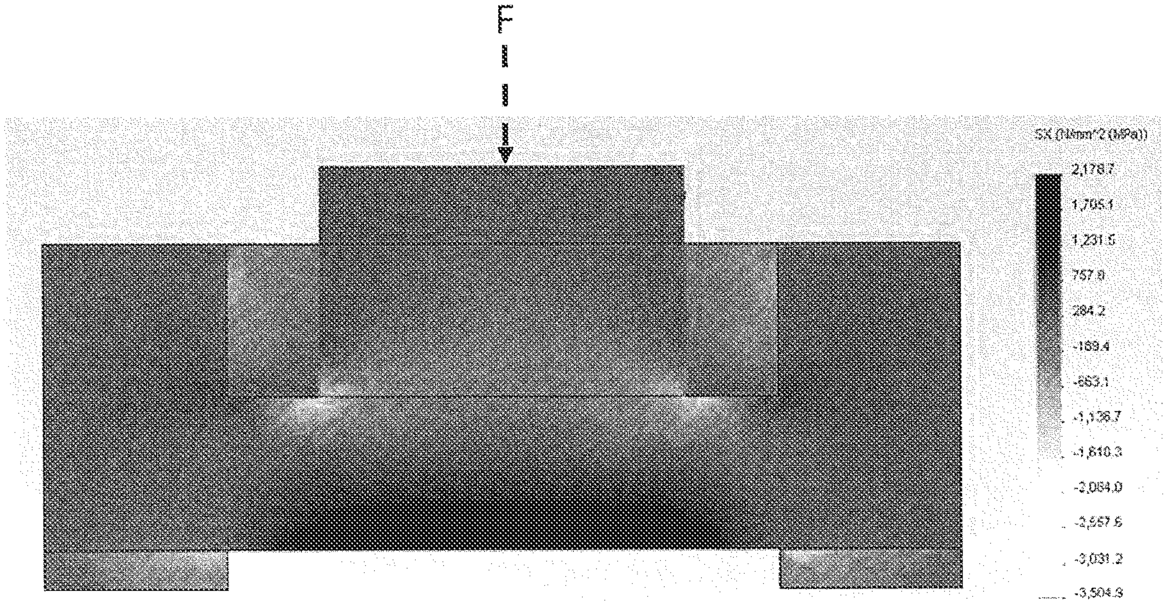


FIGURE 5



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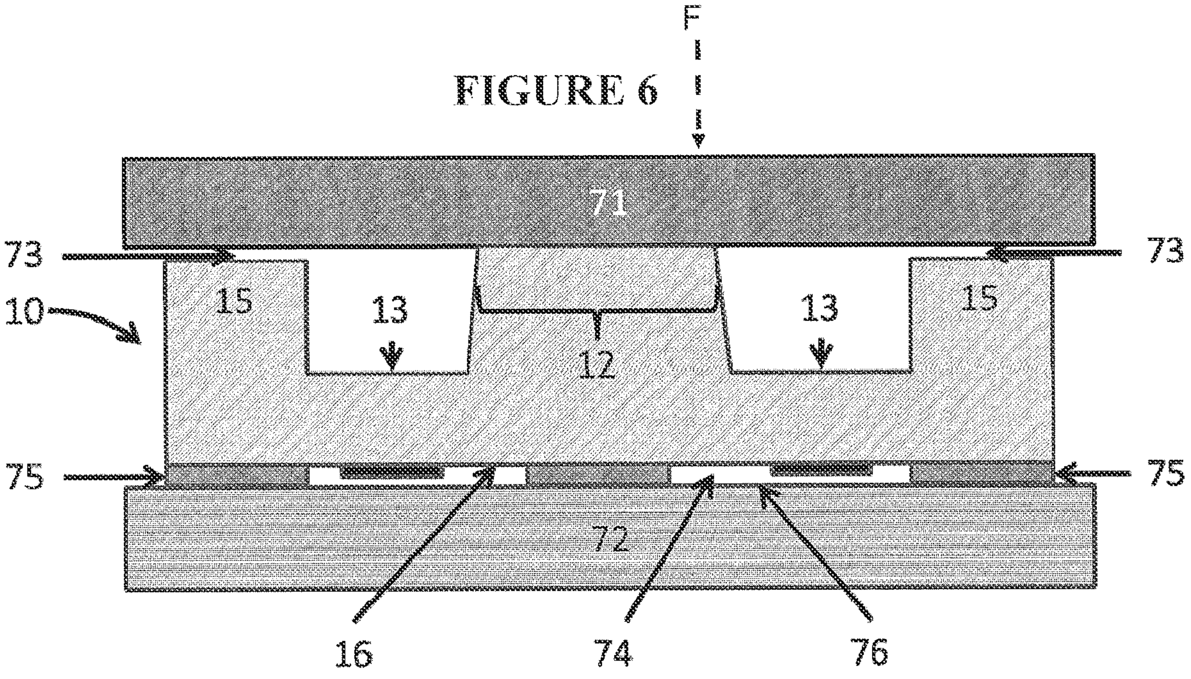

FIGURE 7

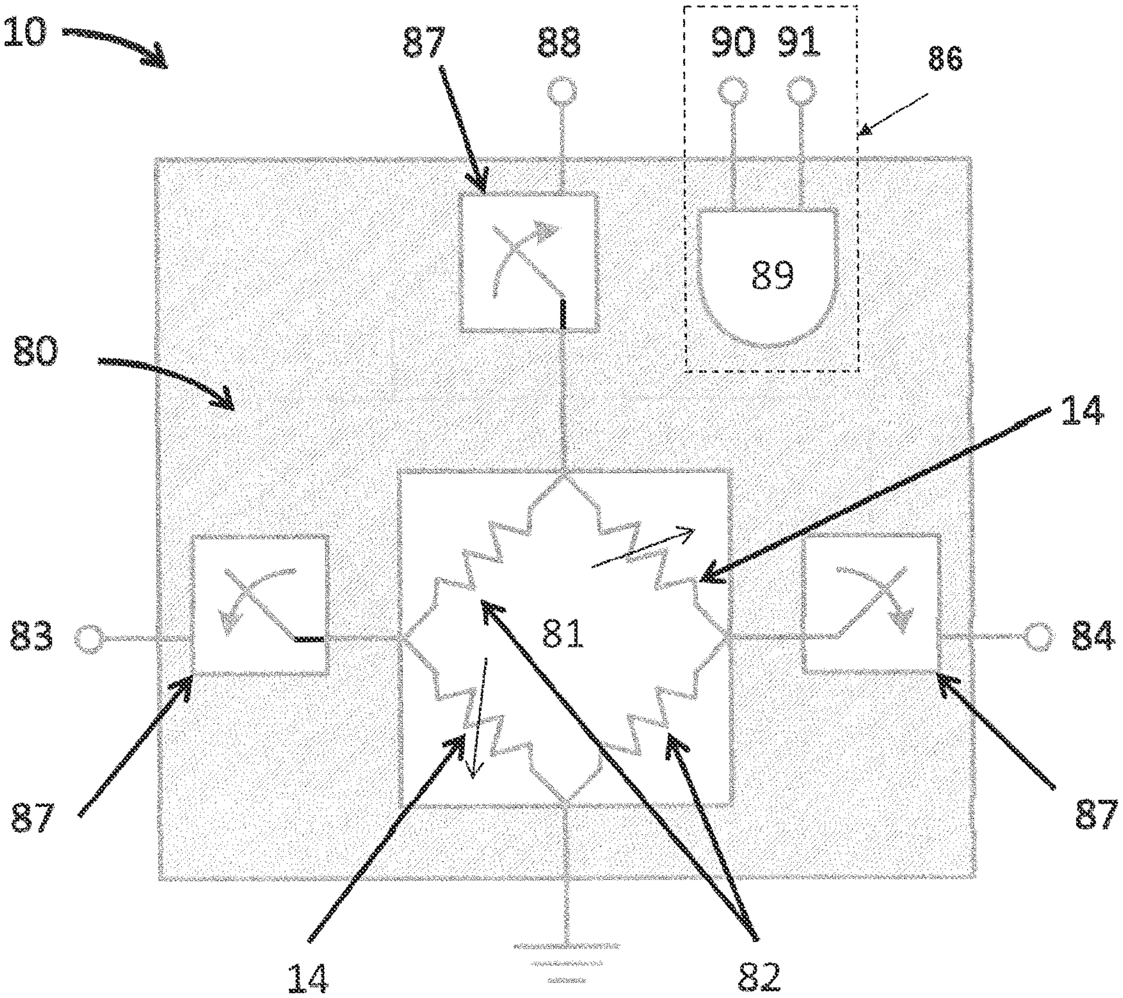

FIGURE 8

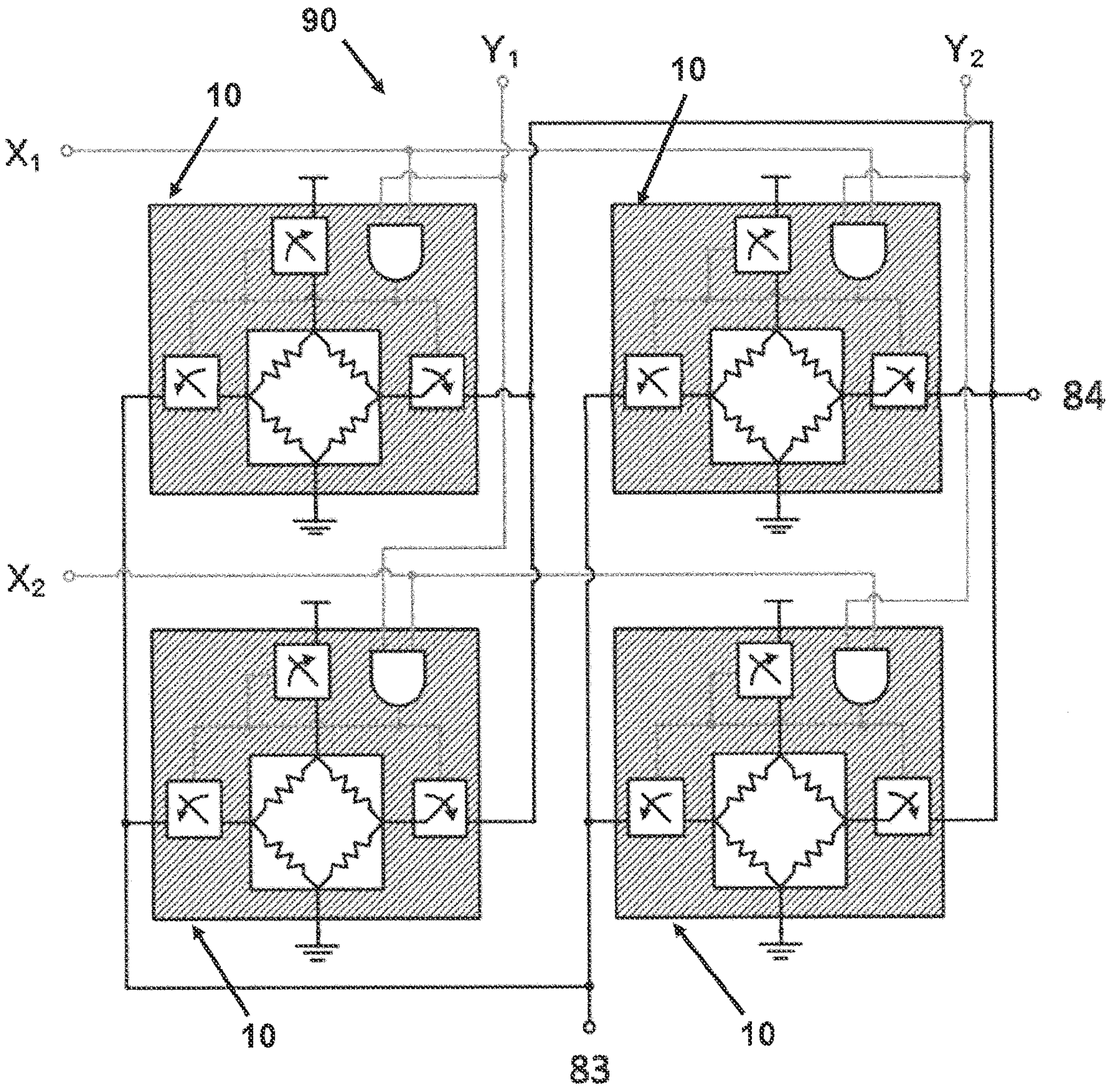

FIGURE 9

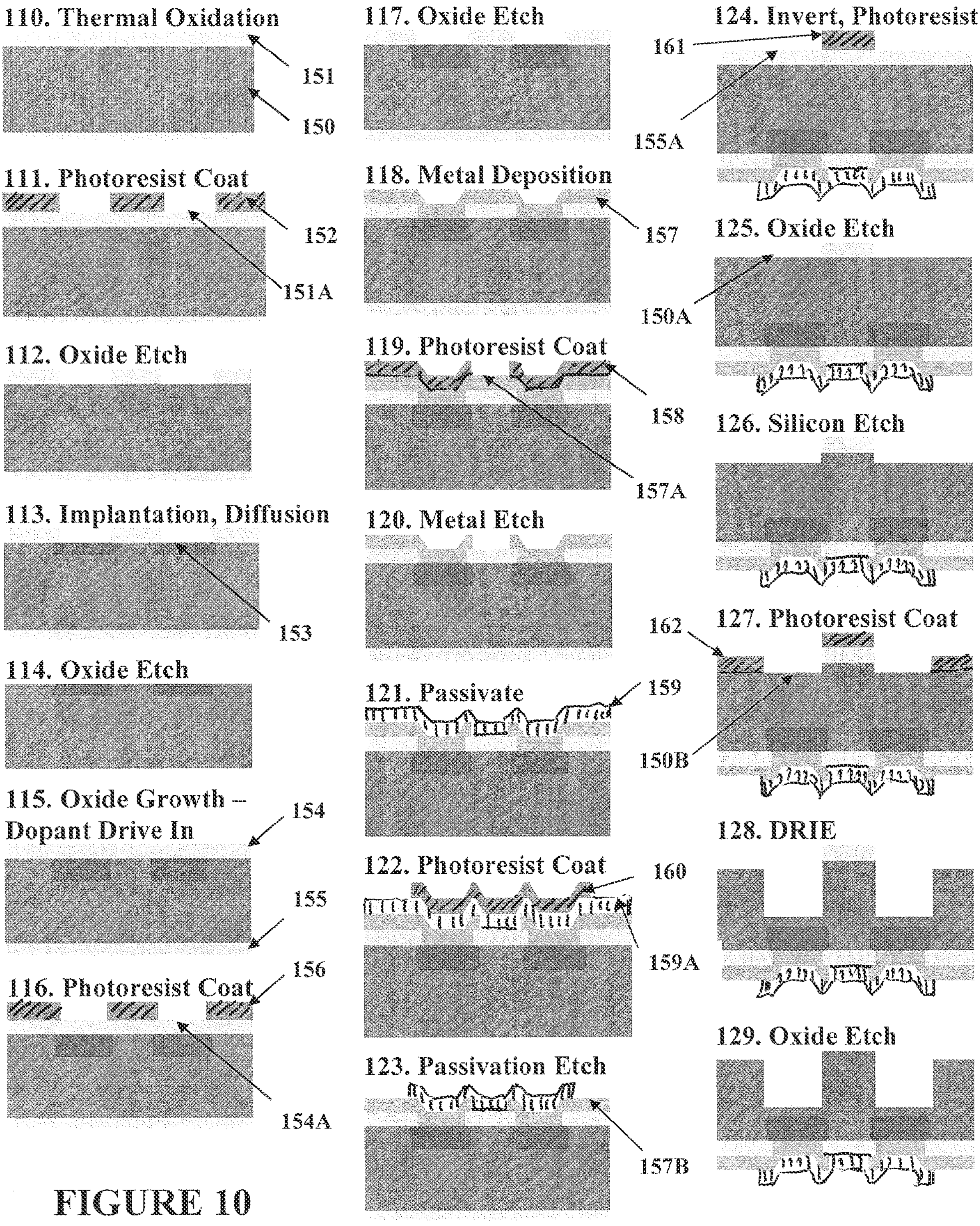
110. Thermal Oxidation
151
150
111. Photoresist Coat
152
151A
112. Oxide Etch
113. Implantation, Diffusion
153
114. Oxide Etch
115. Oxide Growth – Dopant Drive In
154
155
116. Photoresist Coat
156
154A
117. Oxide Etch
118. Metal Deposition
157
119. Photoresist Coat
158
157A
120. Metal Etch
121. Passivate
159
122. Photoresist Coat
160
159A
123. Passivation Etch
157B
124. Invert, Photoresist
161
155A
125. Oxide Etch
150A
126. Silicon Etch
127. Photoresist Coat
162
150B
128. DRIE
129. Oxide Etch

FIGURE 10

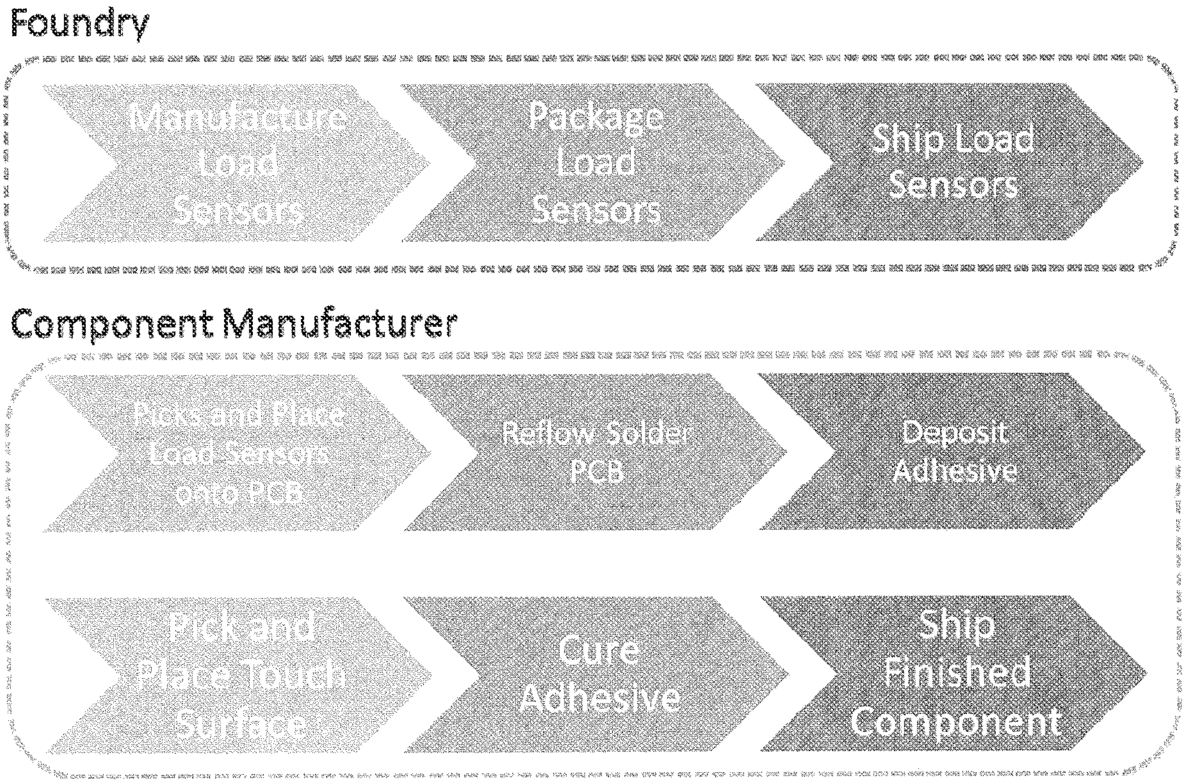
Foundry
Manufacture Load Sensors
Package Load Sensors
Ship Load Sensors
Component Manufacturer
Picks and Place Load Sensors onto PCB
Reflow Solder PCB
Deposit Adhesive
Pick and Place Touch Surface
Cure Adhesive
Ship Finished Component

FIGURE 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/049288

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L1/14 G01L1/26 G01L5/16
ADD. G01L1/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01L G01G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/139695 A2 (VAGANOV VLADIMIR [US]; BELOV NICKOLAI [US]) 6 December 2007 (2007-12-06) the whole document -----	1-28
X	US 2005/190152 A1 (VAGANOV VLADIMIR [US]) 1 September 2005 (2005-09-01) the whole document -----	1-28
X	JP 2004 156937 A (TANITA SEISAKUSHO KK) 3 June 2004 (2004-06-03) abstract; figures -----	1-9, 11-16, 19-28
	-/--	

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 7 November 2013	Date of mailing of the international search report 14/11/2013
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Stavroulis, Stefanos

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	TAO MEI ET AL: "Design and fabrication of an integrated three-dimensional tactile sensor for space robotic applications", MICRO ELECTRO MECHANICAL SYSTEMS, 1999. MEMS '99. TWELFTH IEEE INTERNA TIONAL CONFERENCE ON ORLANDO, FL, USA 17-21 JAN. 1999, PISCATAWAY, NJ, USA,IEEE, US, 21 January 1999 (1999-01-21), pages 112-117, XP032387211, DOI: 10.1109/MEMSYS.1999.746781 ISBN: 978-0-7803-5194-3 the whole document -----	1-9, 11-16, 19-28

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/049288

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2007139695 A2	06-12-2007	US 2008083962 A1	10-04-2008
		US 2010323467 A1	23-12-2010
		WO 2007139695 A2	06-12-2007
US 2005190152 A1	01-09-2005	US 2005190152 A1	01-09-2005
		US 2009237275 A1	24-09-2009
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		JP 2004156937 A	03-06-2004