



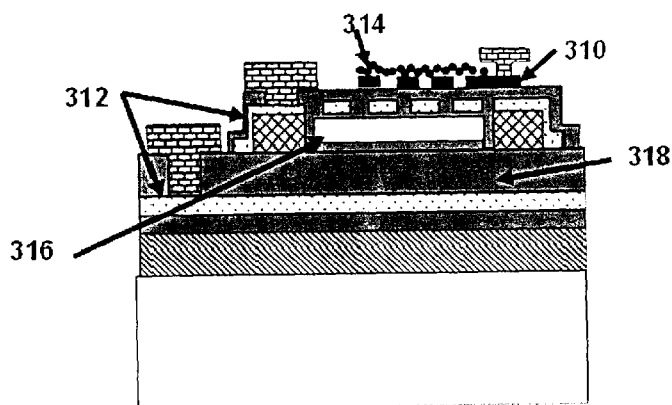
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Declarations under Rule 4.17:

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[Continued on next page]

(54) Title: A SELF-CALIBRATED MINIATURIZED PRESSURE SENSOR



(57) Abstract: The present invention relates to pressure sensor and more particularly self-calibrated miniaturized pressure sensor designed for monitoring applications in automotive, industrial, medical and consumer products. One of the advantages of the present invention is able to detect self-calibration of the pressure sensor at both the initial state of the device or during operation. Another advantage of the present invention is that the self-calibrated miniaturized pressure sensor of the present invention enables the user to know the exact condition of the deformed diaphragm structure to ensure that the measured results are representative of the actual applied external pressure instead of the internal mechanical failure of the diaphragm structure. The present invention further provides a considerable reduction of materials with even greater efficiency and economically during operation.

Figure 3

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A SELF-CALIBRATED MINIATURIZED PRESSURE SENSOR**FIELD OF THE INVENTION**

- 5 The present invention relates to pressure sensor and more particularly self-calibrated miniaturized pressure sensor designed for monitoring applications in automotive, industrial, medical and consumer products.

BACKGROUND OF THE INVENTION

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MEMS/NEMS-based pressure sensor has been developed and commonly deployed for applications in automotive, industrial, medical and consumer products at recent time. The advantages of these miniaturised pressure sensors can be highlighted through their higher sensitivity, fast response time, robustness, reliability and size. There are various designs of pressure sensor which have been developed through micromachining but the most common type is the diaphragm-based pressure sensor in which a diaphragm, where the shape is arbitrary but generally takes the form of a square or circle, is the mechanical structure which will deform upon detection or application of pressure.

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- 20 In most application, the pressure sensors are embedded or fixed on the area of interest after installation for continuous monitoring of the pressure sensing. In other areas of applications, the requirement of the pressure sensing results are based on on-demand response such as in wearable or portable applications whereas only the miniaturised pressure sensing system will be carried externally by human which in turn, required the pressure sensor to deliver prompt and immediate response of pressure sensing.

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However, the conventional pressure sensor has limitation of not possible for calibration to be performed in situ resulting in the sensors being replaced or recalibrated for applications which require operation of longer than five days due to possible drift problems. In view of that, one of main challenges is to ensure that the developed pressure sensor is able to provide reliable and accurate results at an instance whereby the pressure sensors must have the capability for self-testing and self-calibration, and thereby improving long-term reliability and stability.

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Micromachined pressure sensor as shown in **Figure 1** has been popularly developed and researched to be used in many applications in automotive, aerospace, industrial process control and telecommunication system. In recent time there have been great efforts to enhance the performance of the micromachined pressure sensor to overcome the limitation posed by the calibration issues such as to introduce calibration via artificial intelligence such as artificial neural network or circuitry compensation. In normal operation, the main concern on the accuracy and reliability issues for pressure sensor lies on the condition of the mechanical deforming structure (diaphragm structure) itself. This is because the diaphragm structure, expected to be in elastic state during working condition, might be subjected to mechanical or material failures due to excessive usage where deformed occurred although no external pressure is being applied on it. Consequently, false measurement of the pressure will be obtained. In addition, micromachining of the pressure sensor generally creates diaphragm structures which are not perfectly flat and will curl up or down due to residual stress as illustrated in **Figure 2**.

Hence, there exists a need to produce self-calibrated miniaturized pressure sensor during pressure sensing. The self-calibrated miniaturized pressure sensor of the present invention will enable the user to know the exact condition of the deformed diaphragm structure to ensure that the measured results are representative of the actual applied external pressure instead of the internal mechanical failure of the diaphragm structure. The present invention further provides a considerable reduction of materials with even greater efficiency and economically during operation.

SUMMARY OF THE INVENTION

The present invention provides a self-calibrated miniaturized pressure sensor for measuring pressure comprising a diaphragm for allowing deformation when an external force applied, a pressure chamber is provided as a reference pressure; characterised in that a resistor for measuring a change of an electrical resistant due to the diaphragm deformation; and a capacitor sandwiched a pressure chamber for measuring a change of capacitance of an air gap therein between of the pressure chamber.

In one of the embodiment of the present invention, an insulation layer is provided to the capacitor to avoid electrical shortage.

In yet another embodiment of the present invention, wherein the capacitor comprising a pair of electrodes in parallel to each other.

5 In yet another embodiment of the present invention, wherein a capacitance value is measured based on a gap reduction between the electrodes.

In another embodiment of the present invention, when no external force exerted with the change of capacitance is detected, the electrical resistant is calibrated for subsequent measurement.

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A method of calibrating a self-calibrated miniaturized pressure sensor after fabrication comprising measuring an initial reference value by a resistor and an initial capacitance value by a capacitor, if the resistance value is zero, calibration is not required, if the resistance value is not zero, storing the measured initial capacitance value as a stored-indication of
15 initial deformation of the diaphragm and re-calibrating the value of resistance to zero as no external pressure applied.

A method of calibrating a self-calibrated miniaturized pressure sensor during a measurement without an external pressure comprising measuring a capacitance value and comparing the
20 measured value with an initial capacitance value; if the measured capacitance value is equivalent to the initial capacitance value, calibration is not required; if the measured capacitance value is not equivalent to the initial capacitance value, storing the measured capacitance value; and re-calibrating a value of resistance to zero for non-applied external pressure.

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A method of calibrating a self-calibrated miniaturized pressure sensor during a measurement with external pressure comprising measuring a capacitance value and a resistance value of the external pressure, comparing whether measured capacitance value is equivalent to the measured resistance value, if the measured capacitance value is equivalent to the
30 measured resistance value, the diaphragm is determined to be elastic and re-calibration is not required; if the measured capacitance value is not equivalent to the measured resistance value, the diaphragm is determined to be unstable; and replacing the self-calibrated miniaturized pressure sensor.

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BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

Figure 1 illustrates a prior art micromachined pressure sensor (a) Capacitive (b) Resistive.

Figure 2 illustrates a prior art of false measurement of pressure sensing due to: (a) Initial deformation due to residual stress (fabrication processing) and (b) Mechanical/Material failures on diaphragm structure (loss of elasticity).

Figure 3 illustrates a configuration for the surface micromachined self-calibrated pressure sensor platform in accordance of the present invention.

Figure 4 illustrates a flowchart of an initial calibration of the self-calibration pressure sensor after fabrication in accordance of the present invention.

Figure 5 illustrates a flowchart of self-calibration pressure sensor during operation in accordance of the present invention.

Figure 6 illustrates a flowchart of failure indication of the pressure sensor during operation in accordance of the present invention.

Figure 7 illustrates an encapsulation of etch-release holes with LPCVD 1500Å Si_3N_4 of the pressure sensor during operation in accordance of the present invention.

Figure 8 illustrates an encapsulation of etch-release holes with LPCVD 3000Å Si_3N_4 of the pressure sensor during operation in accordance of the present invention.

Figure 9 illustrates an encapsulation of etch-release holes with LPCVD 9000Å Si_3N_4 of the pressure sensor during operation in accordance of the present invention.

Figure 10 illustrates (a) cross-section and (b) tilt view image of the completed capacitance gap area of the pressure sensor during operation in accordance of the present invention.

DETAILED DESCRIPTIONS OF THE INVENTION

The present invention will now be described in detail in connection with specific embodiments with reference to the accompanying drawings.

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The present invention describes pressure sensor and more particularly self-calibrated miniaturized pressure sensor designed for monitoring applications in automotive, industrial, medical and consumer products. **Figure 3** illustrates a configuration for the surface micromachined self-calibrated pressure sensor platform in accordance of the present invention. A basic configuration of the present invention is shown in **Figure 3** where there exists a mechanical deforming structure in the form of the diaphragm (**310**) which deforms upon application on external pressure. At least a pair of electrodes acting as a capacitor (**312**) and an electrode located on top of the diaphragm (**310**) acts as a resistor (**314**) for measurement of the pressure sensing and for calibration purposes. The capacitor comprises a pair of electrodes in parallel to each other. The resistor sits on top of the diaphragm structure and can be any shape of, but not limited to line, serpentine, interdigitated or spiral. The electrodes for the capacitor (**312**) sandwich a pressure chamber (**316**) which acts as the reference pressure during pressure measurement. Insulation layer (**318**) separates the electrodes to avoid electrical shortage. The insulation layer is electrical insulating materials and can be made of, but not limited to materials such as silicon oxide, silicon nitride or polymers. In one of the preferred embodiment, electrode is a conducting material and can be made of, but not limited to materials such as doped polysilicon, metals, conductive polymers, nanowires, nanotubes, nanoparticles or magnetic alloy. The substrate is a base for the overall self-calibrated pressure sensor formation.

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For initial calibration of the pressure sensor after fabrication, a working principle is shown in **Figure 4**. At initial state of the device after fabrication, the diaphragm structure is typically not flat and there exists slight curl of the diaphragm structure due to the residual stress inherited from a microfabrication process condition. Due to this, there exists a resistance change of the resistor although no external pressure has been applied on the top of the diaphragm. At initial state of the pressure sensing (zero applied pressure), the measured resistance value of the resistor is calibrated to zero for compensation purposes so that subsequent measurement on the resistance change of the resistor are based on the actual applied pressure. Nevertheless, the corresponding capacitance value which exists due to a reduced gap between the electrodes is measured at the same time by the pair of electrodes

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acting as the capacitor. This indicates that the diaphragm has been deformed at the initial state and the measured initial deformation of the diaphragm at zero applied pressure is stored for reference.

- 5 For self-calibration of the pressure sensor during operation as shown in **Figure 5**, at zero applied pressure, the measured capacitance value which differs from the initial capacitance value (after fabrication) indicates that a new deformed state of the diaphragm has occurred. At this state, the resistance change as measured by the resistor is recalibrated to zero for subsequent measurement. Hence, the pressure sensor is calibrated from time to time by
- 10 associating the measured capacitance value and the corresponding resistance value with the reference capacitance. In addition, the present invention also provides an indication on the possible failures for the pressure sensor as shown in **Figure 6**. This is because based on the resistance change as measured by the resistor, the applied pressure obtained is used to cross-referenced back with the capacitance value measured by the capacitor since the
- 15 predicted applied pressure generates the expected deformation of the diaphragm structure. If the deformation of the diaphragm structure is above the elastic range of the diaphragm, plastic deformation of the diaphragm structure occurs. The pressure sensor by now is not operational anymore as it does not behave elastically anymore and false measurement is occurred.

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Example

- A low-pressure chemical-vapor-deposition (LPCVD) silicon nitride deposition utilised in this work have the optimised deposition rate of 30Å/min. **Table 1** summarised the process recipe for the corresponding deposition techniques while results for the silicon nitride deposition for
- 25 encapsulation of the etch-release holes with critical dimension of 1µm are presented in **Figure 7** through **Figure 9**.

Table 1: Process recipe for LPCVD silicon nitride deposition

Parameter	Value
Temperature	700°C
Pressure	60Pa
Ammonia (NH ₃) flow rate	50sccm
Dichlorosilane (SiH ₂ Cl ₂) flow rate	150sccm

For deposition of silicon nitride using LPCVD technique as displayed in **Figures 7-9**, it was seen that almost equal thicknesses of silicon nitride are deposited in both the vertical and lateral direction within the pumping chamber. In addition it was observed that for Si_3N_4 deposition of 9000Å, the etch-release holes with critical dimension of 1µm had been completely sealed. This was due to the nature of the LPCVD silicon nitride growth mechanism which created completion in the sealing of the etch-release holes after deposition of approximately 5000Å-thick of Si_3N_4 (or half the critical dimension of the etch release holes). At this instance, any additional deposition of Si_3N_4 increased the thickness at the top layer of the structure exposed to the deposition system, elucidating the fact that higher thickness of Si_3N_4 was visible on the top of the diaphragm structure as opposed to within the capacitance gap area as shown in **Figure 9**. **Table 2** shows the parameters of the capacitance gap area while **Figure 10** shows the fabricated capacitance gap area.

Table 2: Geometrical parameters of the capacitance gap area

Parameters	Value
Dielectric (Silicon nitride) thickness, t_d (µm)	0.5
Electrode (Polysilicon) thickness, t_e (µm)	0.15
Capacitance gap, g (µm)	1.5

One of the advantages of the present invention is able to detect self-calibration of the pressure sensor at both the initial state of the device or during operation. Another advantage of the present invention is that the self-calibrated miniaturized pressure sensor of the present invention enables the user to know the exact condition of the deformed diaphragm structure to ensure that the measured results are representative of the actual applied external pressure instead of the internal mechanical failure of the diaphragm structure. The self-calibrated miniaturized pressure sensor of the present invention can be used to fulfil applications requiring critical and accurate measurement of the pressure such as blood pressure sensing in healthcare industry. The present invention further provides a considerable reduction of materials with even greater efficiency and economically during operation.

The foregoing embodiment and advantages are merely exemplary and are not to be construed as limiting the present invention. The description of the embodiments of the present invention is intended to be illustrative and not to limit the scope of the claims and many alternatives, modifications and variations will be apparent to those skilled in the art.

CLAIMS

1. A self-calibrated miniaturized pressure sensor for measuring pressure comprising
 - 5 a diaphragm for allowing deformation when an external force applied;
 - a pressure chamber is provided as a reference pressure; **characterised in that**
 - a resistor for measuring a change of an electrical resistant due to the diaphragm deformation; and
 - 10 a capacitor sandwiched a pressure chamber for measuring a change of capacitance of an air gap therein between of the pressure chamber.
2. The pressure sensor as claimed in Claim 1 wherein an insulation layer is provided to the capacitor to avoid electrical shortage.
3. The pressure sensor as claimed in Claim 1 wherein the capacitor comprising a pair of
15 electrodes in parallel to each other.
4. The pressure sensor as claimed in Claim 3 wherein a capacitance value is measured based on a gap reduction between the electrodes.
- 20 5. The pressure sensor as claimed in Claim 1 wherein when no external force exerted with the change of capacitance is detected, the electrical resistant is calibrated for subsequent measurement.
6. A method of calibrating a self-calibrated miniaturized pressure sensor after fabrication
25 comprising
 - measuring an initial reference value by a resistor and an initial capacitance value by a capacitor;
 - if the resistance value is zero, calibration is not required;
 - if the resistance value is not zero,
 - 30 storing the measured initial capacitance value as a stored-indication of initial deformation of the diaphragm;
 - re-calibrating the value of resistance to zero as no external pressure applied.

7. A method of calibrating a self-calibrated miniaturized pressure sensor during a measurement without an external pressure comprising

measuring a capacitance value and comparing the measured value with an initial capacitance value;

- 5 if the measured capacitance value is equivalent to the initial capacitance value, calibration is not required;

if the measured capacitance value is not equivalent to the initial capacitance value, storing the measured capacitance value;and

re-calibrating a value of resistance to zero for non-applied external pressure.

- 10 8. A method of calibrating a self-calibrated miniaturized pressure sensor during a measurement with external pressure comprising

measuring a capacitance value and a resistance value of the external pressure;

comparing whether measured capacitance value is equivalent to the measured resistance value,

- 15 if the measured capacitance value is equivalent to the measured resistance value, the diaphragm is determined to be elastic and re-calibration is not required;

if the measured capacitance value is not equivalent to the measured resistance value, the diaphragm is determined to be unstable;and

replacing the self-calibrated miniaturized pressure sensor.

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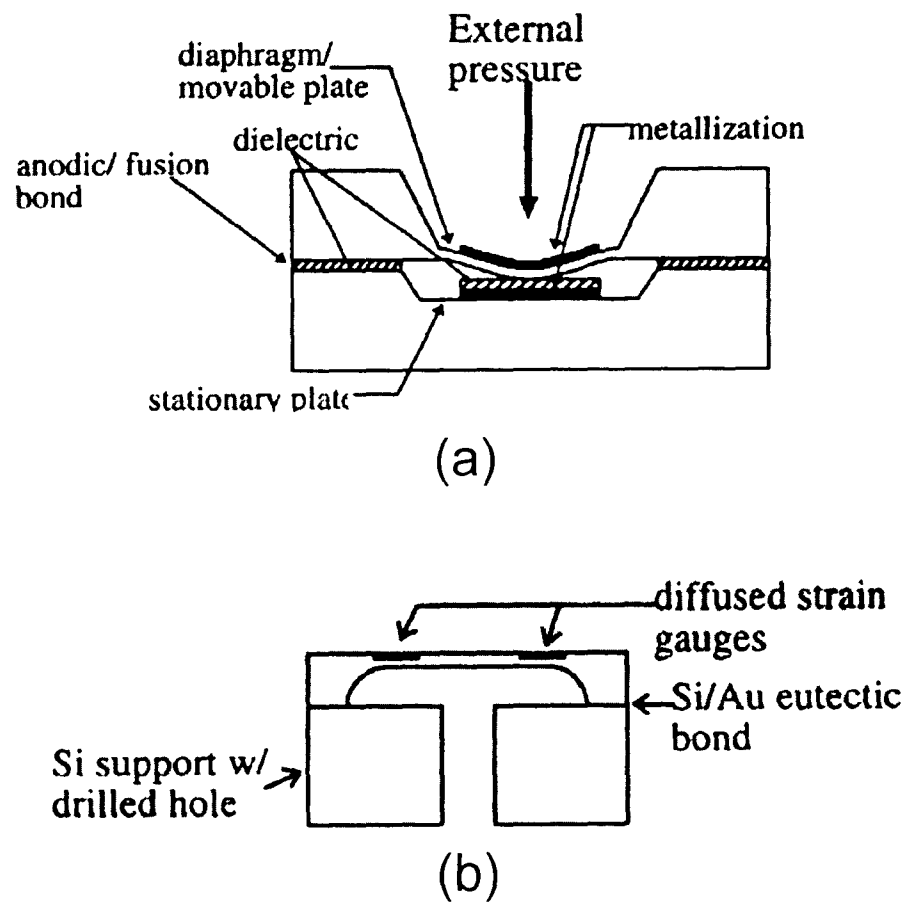


Figure 1(PRIOR ART)

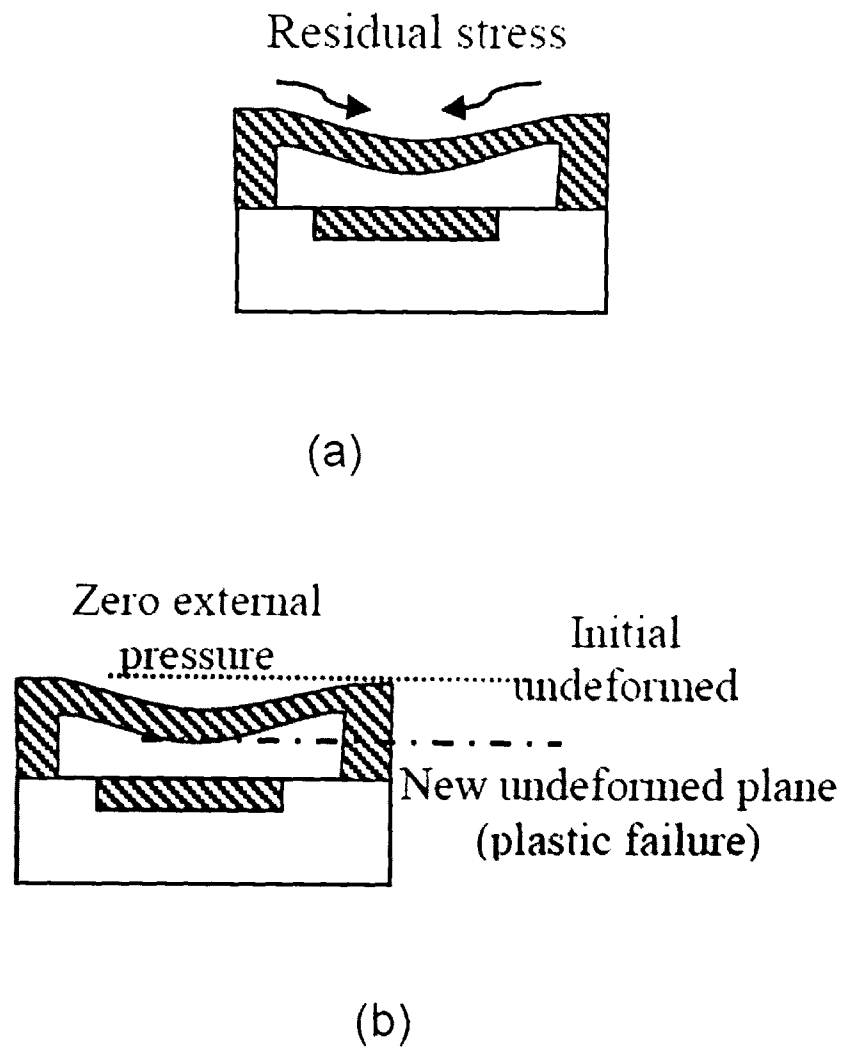


Figure 2 (PRIOR ART)

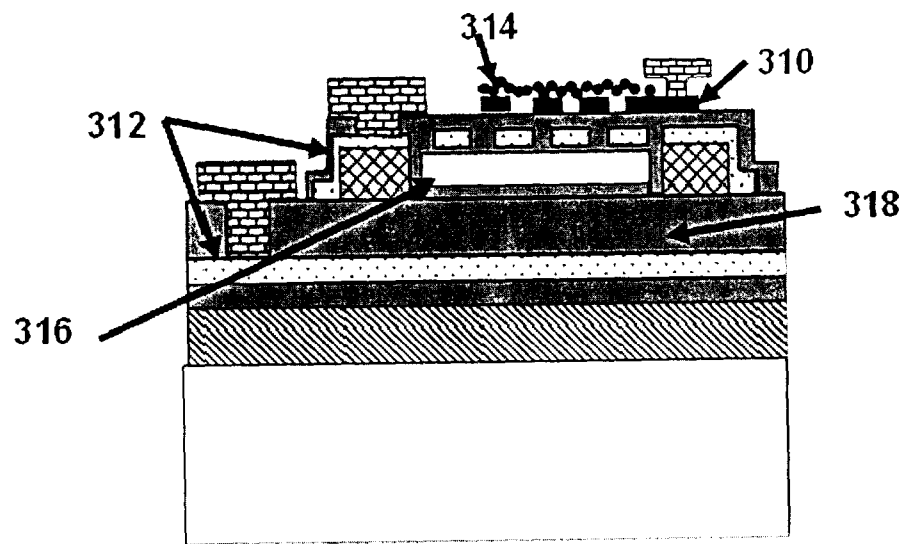
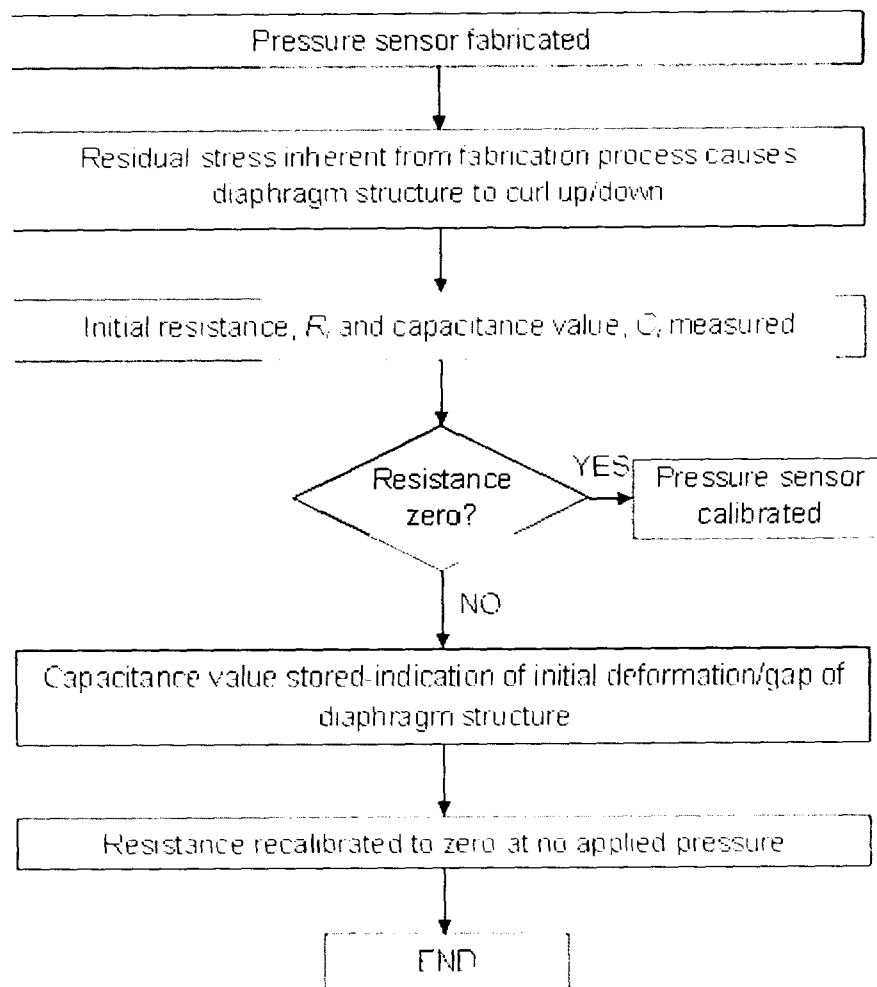
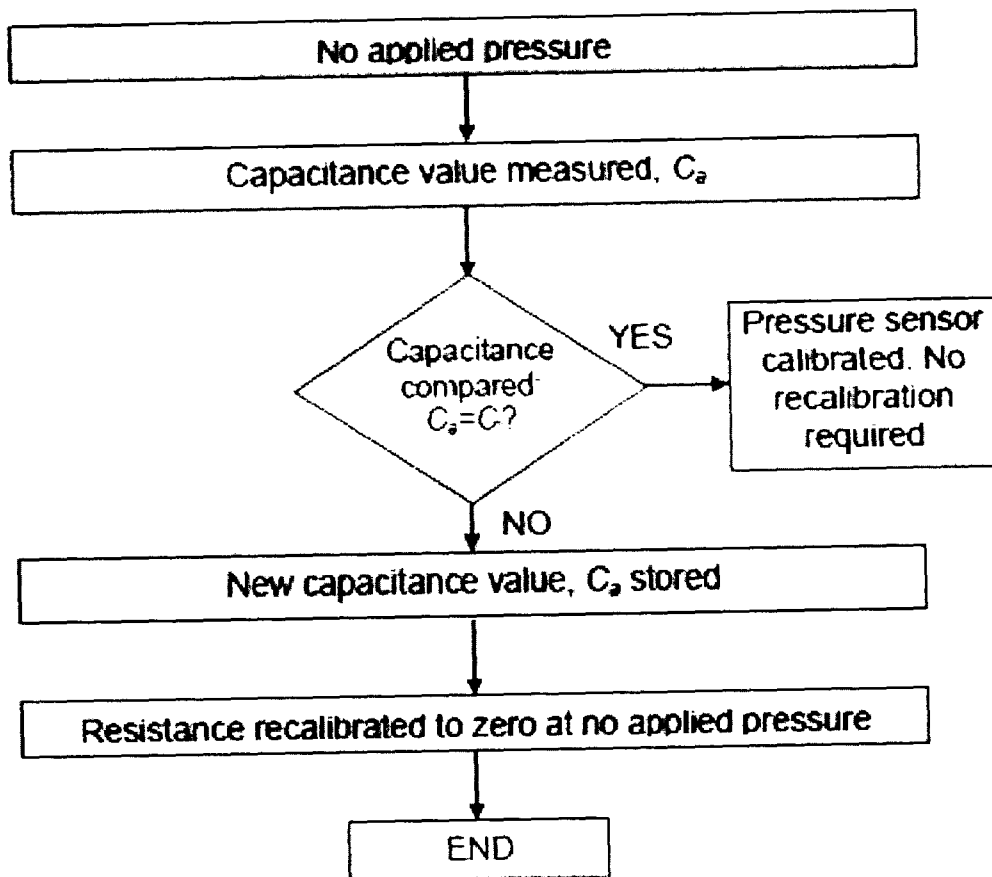


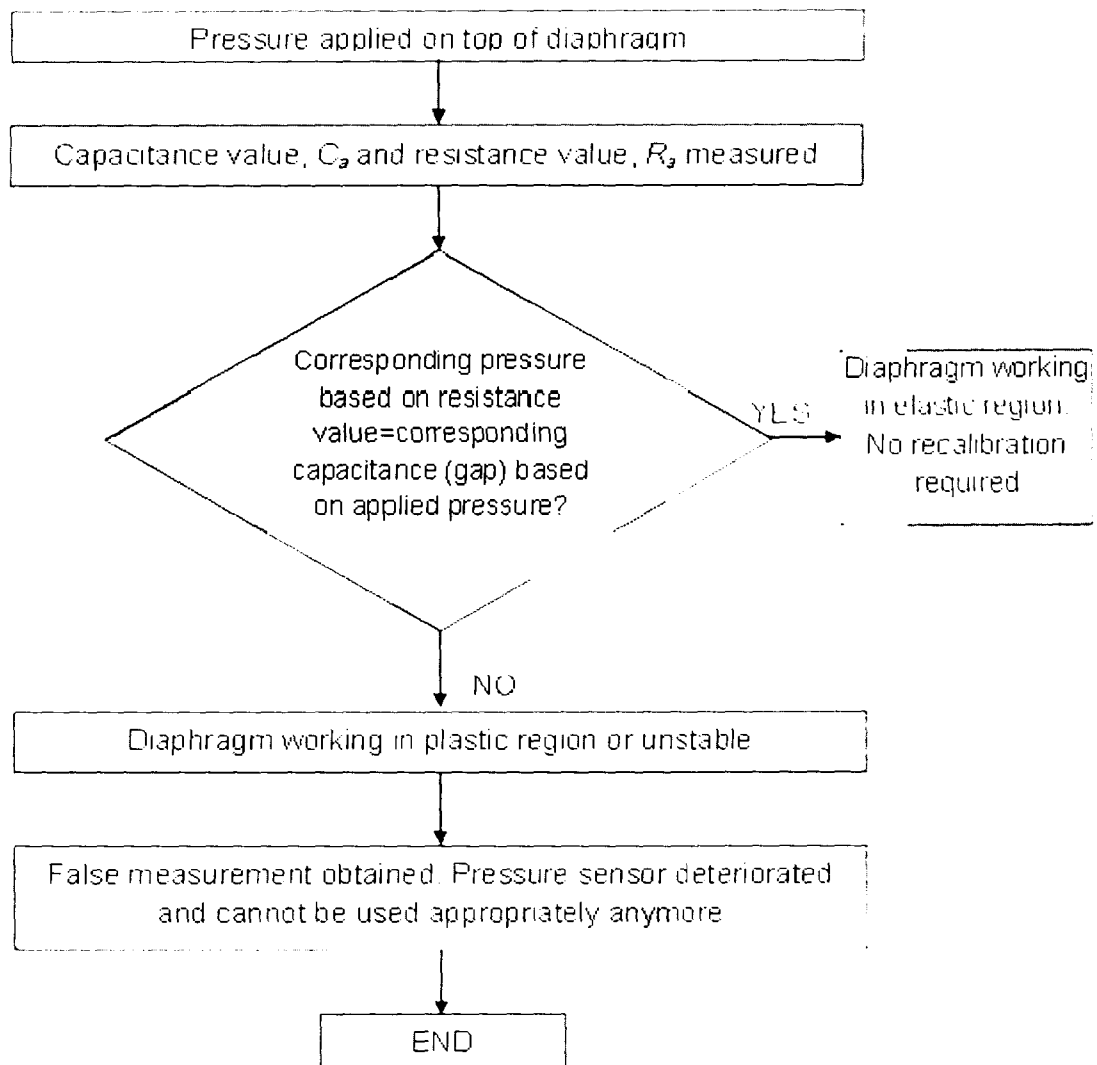
Figure 3

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**Figure 4**

**Figure 5**

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**Figure 6**

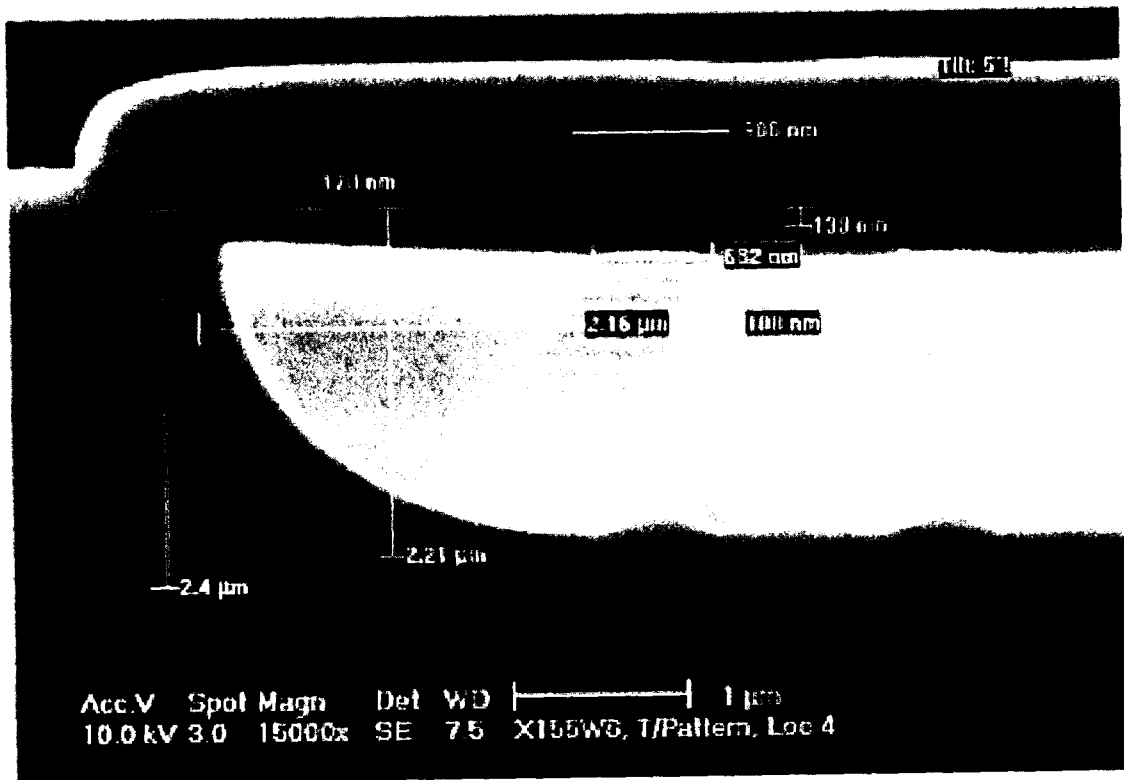


Figure 7

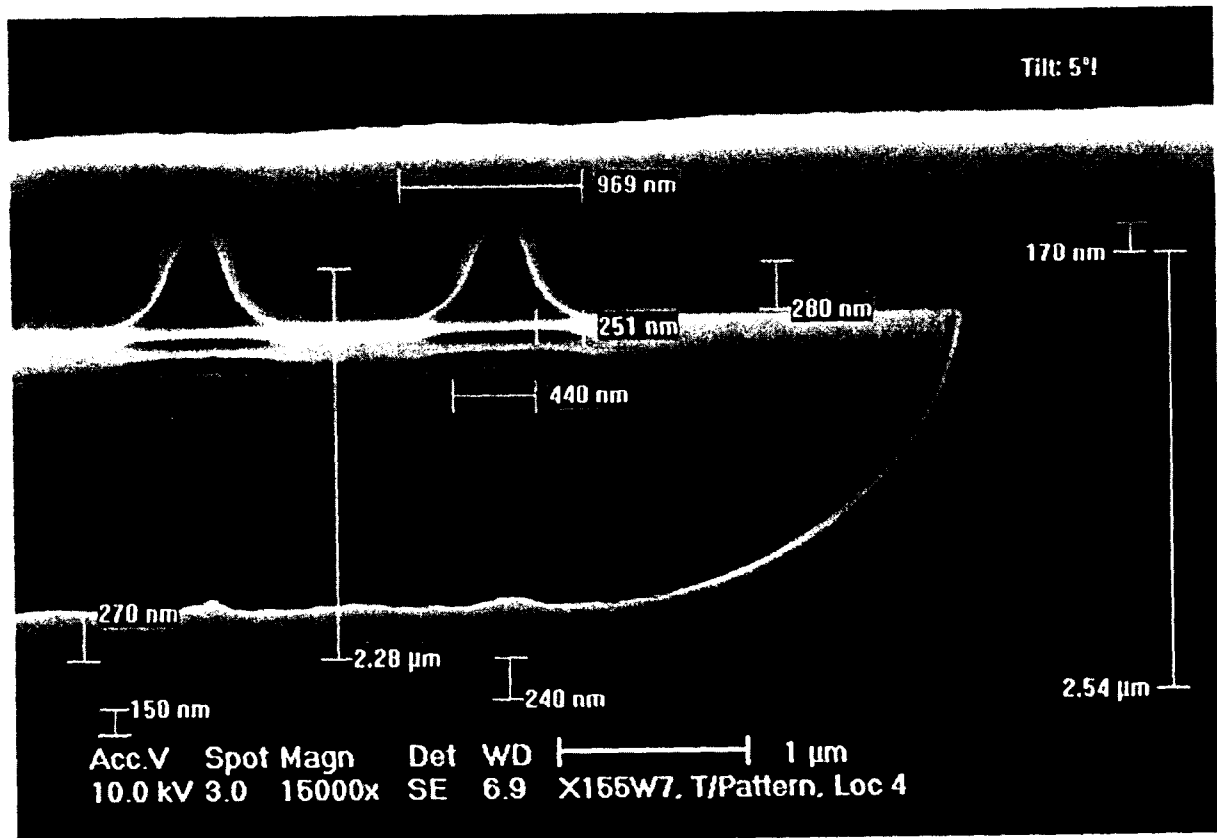
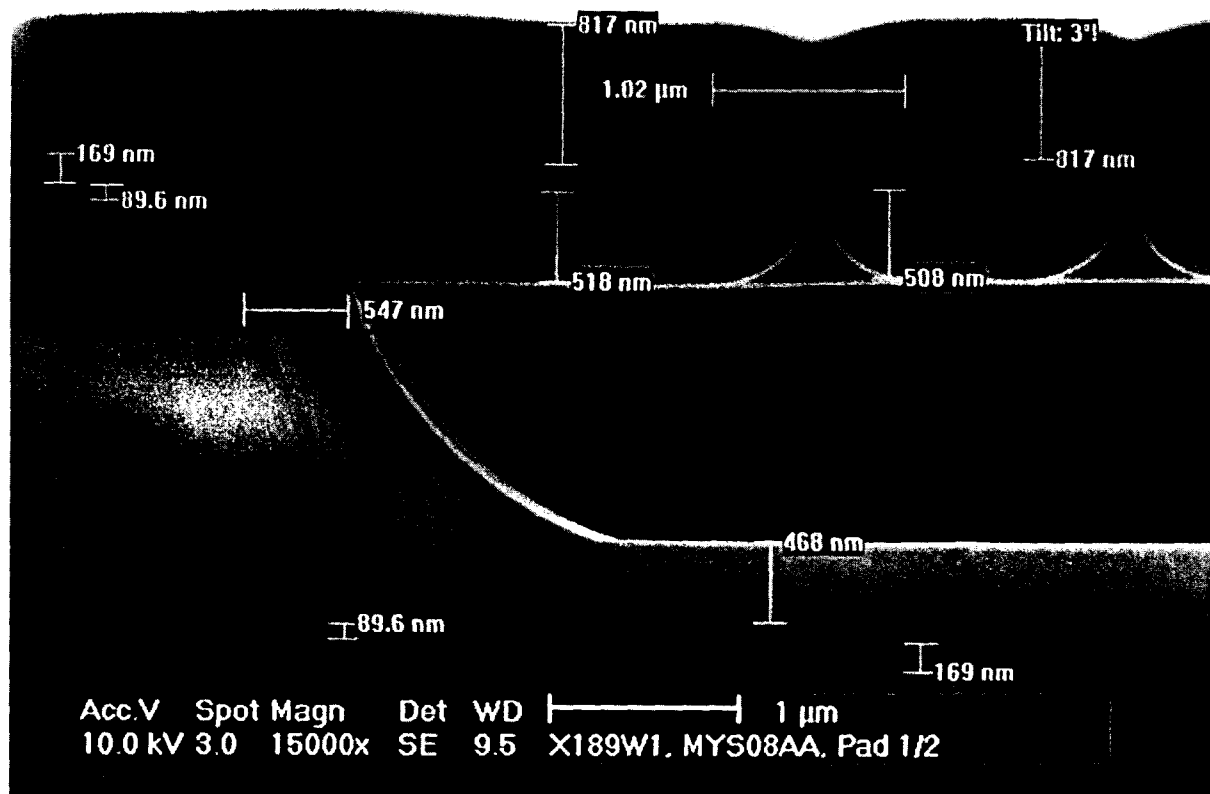
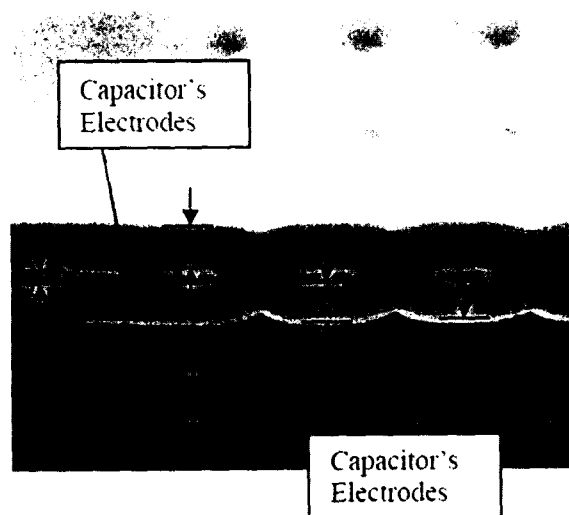
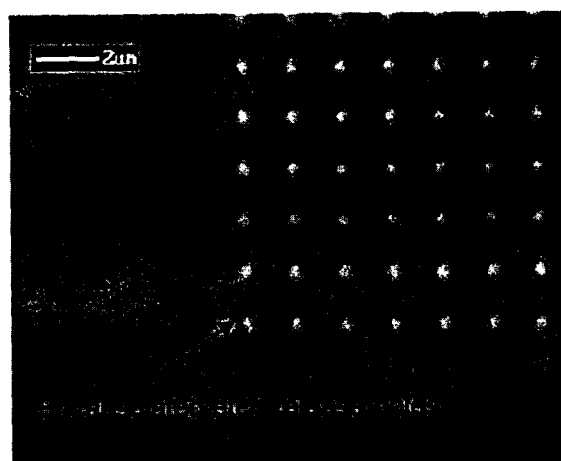


Figure 8

*Figure 9*



(a)



(b)

Figure 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/MY2015/000022

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. G01L9/00 (2006.01) i

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)

Int.Cl. G01L7/00-23/32, 27/00-27/02

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2015
 Registered utility model specifications of Japan 1996-2015
 Published registered utility model applications of Japan 1994-2015

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 07-012667 A (HITACHI, LTD.) 1995.01.17, the whole document, all drawings (family: none)	1-8



Further documents are listed in the continuation of Box C.



See patent family annex.

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