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A New Method to Extract Piezoresistive Coefficients in Polysilicon Through Gauges Placed on a MEMS Membrane

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Abstract

This paper presents a new method to evaluate piezoresistive coefficients of polysilicon in the case of N-doping but valid for other types. We measured and simulated the mechanical stress profile distribution along a bossed membrane using several gauges placed along the radial axis of round membranes. Pressure was applied to the membrane. The electromechanical characterizations of the MEMS membrane are in accordance with the simulations and allowed to extract piezoresistive coefficients of the heavily doped polysilicon.

Keywords : Piezoresistivity, MEMS, Membrane, Polysilicon.

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1. Motivations

The goal of this study is to measure the mechanical stress inside a thin silicon membrane when pressure is applied to the membrane cavity. Polysilicon piezoresistive coefficients are reported with a large dispersion values [1]-[2], as it depends strongly on polysilicon properties. Numerous gauge sensors have been reported [3] but the precise measurement of polysilicon sensors is necessary for optimal use. The new method presented in this paper is aimed at determining more precisely the piezoresistive coefficients of a doped polysilicon film. Exact extraction of those coefficients would allow, for instance, to determine the impact of the ionic implantation level on the piezoresistance of the layer. It will give the sensitivity of piezoresistive sensors.

By studying the relative variation of the sensors along the radial axis of the membrane, we are able to

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determine the best position of the sensors for different membrane shapes to get the highest sensitivity during pressure measurement.

2. Structure design

Sensors are placed at the surface of a 64µm thick silicon membrane and consist of polysilicon piezoresistors that can detect the local stress (Fig 1). Both radial and circumferential orientations of the gauge resistors are designed on the membrane. The dimension of the sensors are 10µm wide and 24µm long. Sensors are spaced from each other by a distance of 1 mm so that six sensors are equally spaced for a 12 mm diameter membrane. Radial sensors correspond to sensors where the supplying current is flowing in the direction of the radial axis of the membrane. The supplying current of circumferential sensors is perpendicular to the radial axis of the membrane. For the simplification of the layout and to reduce the metal connections, a ground line connects all the sensors and is used as an electrical reference for each type of oriented sensors. Those two different orientations are implemented to study the impact of the stress onto the polysilicon layer to better determine the piezoresistive coefficients of doped polysilicon.

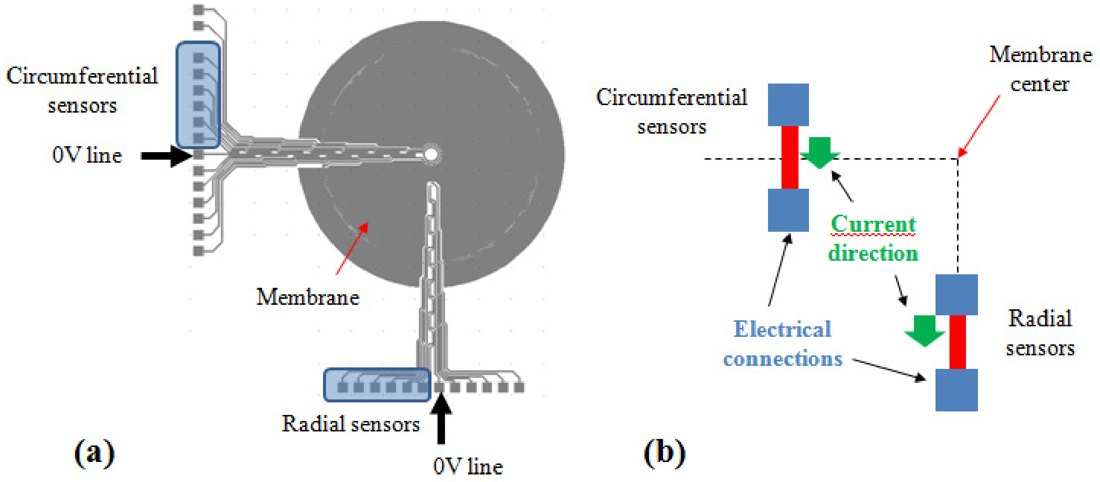

Fig. 1. Position and orientation of the gauge sensors placed on the top of the membrane. (a) Top view of the membrane with associated sensors and connections. (b) Orientation of the sensors relatively to the center of the membrane.

3. Fabrication process

The structure of the membrane is similar to the one described in a previous work [4]. This structure is composed of a silicon membrane sandwiched between two thin silicon dioxide layers (Fig 2). A 400 nm thick silicon dioxide is thermally grown on a 200 mm diameter SOI wafer with a 2 µm thick buried silicon oxide and a 60µm thick top monocrystalline silicon. This oxide is used as the electrical insulator between the top silicon and the 300 nm thick polycrystalline silicon. This polysilicon layer is obtained by *Low Pressure Chemical Vapor Deposition* (LPCVD) of SiH_4 at 600°C. Stress sensors are integrated in the polysilicon layer. An ionic implantation dose of 4.10^{15} atoms/cm^2 with a 70 keV acceleration energy is defining the heavy N-doped level constituting the sensors. A high concentration of dopants (> 5 10^{19} cm^{-3}), is needed to establish an ohmic contact with the electrical connections. A *Plasma Enhanced Chemical Vapour Deposition* (PECVD) of a 200 nm thick silicon dioxide is used as an electrical insulator between the polysilicon and the electrical contacts. To electrically access the sensors, a wet etching (HF of 5% concentration) is carried out to open some areas. The electrical contacts are made by sputtering a 650 nm thick aluminum layer on the top of the structure and chemically etch it. This way, electrical connections to the sensors are reported to the sides of the chip (Fig. 1). The pattern of the membrane is done using an aluminum mask on the back side of the wafers. We are thus structuring a central mass in the membrane. Membranes are then obtained by a backside *Deep Reactive Ion Etching* (DRIE) of the 750 µm thick silicon substrate. The SOI buried oxide is used as an etch stop layer, providing an accurate uniform thickness of the final membrane at wafer level.

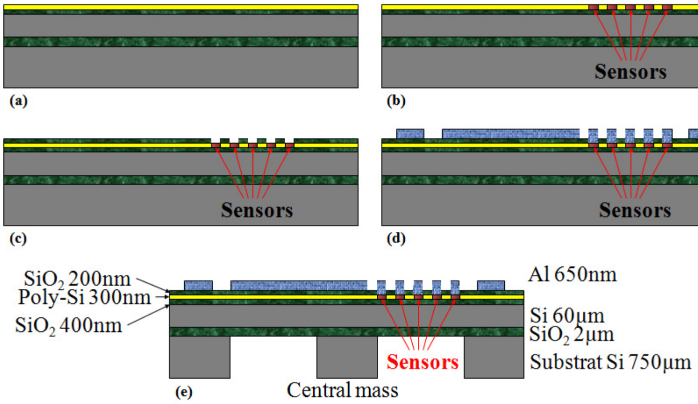

Fig. 2. Cross section of the membrane process flow. (a) Thermal oxidation and LPCVD of Poly-Si, (b) Phosphorus implantation (c) PECVD deposition and wet etching of SiO2, (d) Aluminum sputtering and patterning (e) Backside DRIE, showing the different layers and their associated thicknesses.

4. Characterization and discussion

A specific test bench was developed to apply pressure to the membranes and to monitor their deflection while measuring the resistance of the piezoresistors. This test bench is described in [4]. For a given pressure, radial and circumferential resistances are measured and the relative variation of resistance compared to a 0 bar differential pressure is extracted. Mechanical simulation of the membrane gave the different stresses inside the polysilicon of the membrane. This relative variation of resistance is linked to stresses and piezoresistive coefficients [4]. We can use the least square method in order to extract the best fit between characterization and simulations and extract the piezoresistive coefficients of the doped polysilicon (eq (1)).

$$\begin{bmatrix} \frac{\Delta R_{r1}}{R_{r1}} & \cdots & \frac{\Delta R_{rn}}{R_{rn}} & \frac{\Delta R_{c1}}{R_{c1}} & \cdots & \frac{\Delta R_{cn}}{R_{cn}} \end{bmatrix} = \begin{bmatrix} \pi_l & \pi_t \end{bmatrix} . \begin{bmatrix} \sigma_{l_{r1}} & \cdots & \sigma_{l_{rn}} & \sigma_{t_{c1}} & \cdots & \sigma_{t_{cn}} \\ \sigma_{t_{r1}} & \cdots & \sigma_{t_{rn}} & \sigma_{l_{c1}} & \cdots & \sigma_{l_{cn}} \end{bmatrix} \qquad (1)$$

by taking R_{ri} the radial resistance of the sensor i, R_{ci} the circumferential resistance of the sensor i, n the number of radial sensors characterized, m the number of circumferential sensors characterized, $\sigma_{l_{ri}}$ et $\sigma_{t_{ri}}$ the longitudinal and transverse stresses associated to the radial resistance i, $\sigma_{l_{ci}}$ et $\sigma_{t_{ci}}$ the longitudinal and transverse stresses associated to the circumferential resistance i.

The result of the fit between simulation and characterization is shown in Fig. 3. We obtained a good agreement between simulation and characterization with a maximal error of around 30% for the circumferential sensors placed at the edge of the membrane. We can extract a longitudinal piezoresistive coefficient of $7.4\ 10^{-11}$ Pa^{-1} and a transverse piezoresistive coefficient of $-5.7\ 10^{-11}$ Pa^{-1}. Those coefficients are low because of the heavy doping of the sensors. Moreover, we can observe that the radial sensors exhibit a higher variation than the circumferential ones. Consequently, to get the best efficiency as a pressure sensor, a Wheatstone bridge can be implemented with the two radial sensors that are in opposition and have the highest relative variation. That is to say two sensors placed at the border of the membrane and two sensors at the border of the central mass.

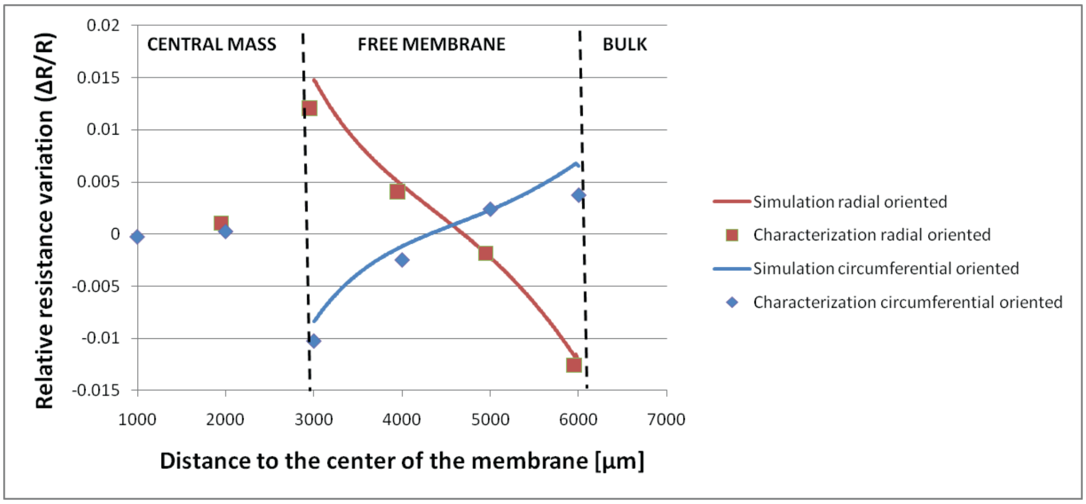

Fig. 3. Relative variation of resistance of the sensors. Comparison between FEM simulation (lines) and characterization (points).

Conclusion

We have developed a new method for extracting piezoresistive coefficients of a polysilicon film using a MEMS membrane with integrated stress sensors. Those coefficients are extracted with better precision than in the case of the use of only one stress sensor. This method is also valid when polysilicon is doped with other types of dopants such as P-doping.

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