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Smart Nanostructured Silicon <100> and Polysilicon Diaphragm Response for Pressure Sensing Applications using IntelliSuite – A New Approach

[1] M. Alagappan,[2] N. Meenakshi Sundaram,[3] K. Sripadaraja and [4] **A.** Kandaswamy

[1,2,4] Department of Biomedical Engineering, PSG College of Technology, Peelamedu, Coimbatore - 641004, India
[3] SriDutt Technologies Pvt Ltd, # 728, 10th Main, 7th Cross, MICO Layout, BTM II Stage, Bangalore – 560076,India

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ABSTRACT

The indispensable parameters such as sensitivity and linearity of pressure sensor also depend on the best suitable diaphragm material selection and thickness. The work on task, a new approach utilises 100 nm thickness Single crystal silicon <100> and Polysilicon (LPCVD) materials for piezoresistive type square diaphragm design using IntelliSuite software. The displacement and stress distribution of both diaphragms are analyzed for the pressure ranges from 0.1 MPa to 0.5 MPa and the device has a better response for Silicon <100> in comparison to Polysilicon (LPCVD).

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INTRODUCTION

Pressure sensor is a potential device used to monitor pressure for various applications in the fields such as biomedical, automobile, instrumentation, textiles and robotics (Fuller *et al*, 2003). Microsystems based piezoresistive pressure sensors are considered to be more robust than other types.

The fabrication process of this sensor is less complicated and it also exhibits stable performance compared to other types (Bian Tian *et al*, 2009). The two main components in a piezoresistive pressure sensor are the sensing element and resistor. One among the important sensing elements is the diaphragm, which provides a considerable amount of displacement and introduces strain to the piezoresistors arranged in the form of wheatstone bridge when pressure is applied. The strain will produce a change in resistance proportional to the pressure and is converted into electric potential. The sensitivity and linearity of the sensor must be improved to meet the high performance demands. Sensitivity can be increased by using the silicon nanowire with a diaphragm (Kim *et al*, 2009) or by reducing the thickness of the diaphragm (Jaspreet Singh *et al*, 2008). For an improved performance, piezoresistive pressure sensor studies are done using materials such as high doped silicon and porous silicon (Kim *et al*, 2009). Silicon is not only inexpensive but also it has good dimensional stability at high temperatures. Si <100> plane is easy to work with than on <110> and <111>. Polysilicon has the better control over the electrical characteristics (Tai-Ran Hsu, 2001).

Hence in this paper, an attempt is made to design a nanoscale diaphragm based piezoresistive pressure sensor using the materials Silicon <100> and Polysilicon (LPCVD) and finds the suitable one for better performance.

Process Flow – Diaphragm:

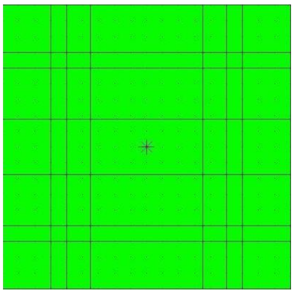
The fabrication of diaphragm includes standard process flow starting from defining substrate, photoresist material deposition, mask definition and etching.The process flow is defined and visualized using IntelliFab. The cross section view of the diaphragm is shown in Fig 1. The diaphragm design utilizes a 180 µm × 180 µm x 100 nm dimension using 3D Builder is shown in Fig 2.

RESULTS AND DISCUSSION

Two important properties such as Young's Modulus and Poisson's Ratio of the two materials Silicon <100> and Polysilicon (LPCVD) are tabulated in Table 1.

Corresponding Author: M. Alagappan, Department of Biomedical Engineering, PSG College of Technology, Peelamedu,Coimbatore, Tamil Nadu - 641 004, India.
Tel: 91-422-2572177 / 2572477; E-mail: man@bme.psgtech.ac.in

Fig. 1: Cross section view of the diaphragm.



Length 180 µm and **Height** 100 nm

Fig. 2: Geometry of thin diaphragm

Table 1: Material Properties.

Material Properties	Young's Modulus (GPa)	Poisson's Ratio
Silicon <100>	130	0.064
Polysilicon (LPCVD)	160	0.226

Young's Modulus characterizes the elastic flexibility of a material. The Young's modulus directly depends on the Stiffness of the material. Poisson's ratio is the ratio of the relative contraction strain, or transverse strain normal to the applied load, to the relative extension strain, or axial strain in the direction of the applied load. From the Table 1, it can be predicted that the Silicon <100> will dominate Polysilicon (LPCVD) by its characteristics. These isotropic values of silicon also show its anisotropic behaviour.

Thermo Electro Mechanical (TEM) tool of the IntelliSuite is used to analyze the displacement and stress distribution or stress component of the nanoscale diaphragm for the applied input pressure. Both the Silicon <100> and Polysilicon (LPCVD) diaphragms are analyzed for the pressure ranges from 0.1 MPa to 0.5MPa. Fig 3 shows the displacement of the Silicon <100> diaphragm in X direction for the applied pressure of 0.5 MPa. The maximum deflection of diaphragm is at its center with increase of pressure.

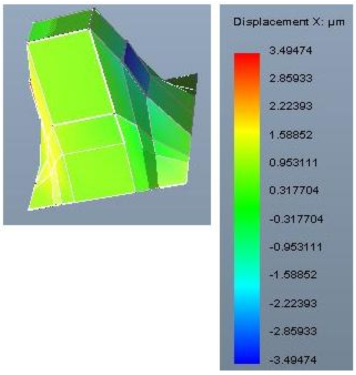


Fig. 3: Large displacement of Silicon <100> diaphragm in X direction for the input pressure of 0.5Mpa.

The displacement of the 'Silicon <100>'and 'Polysilicon (LPCVD) diaphragms for 0.5 MPa pressure in X and Y directions are plotted in the graph as shown in Fig 4.For the silicon <100>,the maximum displacement is 3.49 µm and for the Polysilicon (LPCVD), it is 2.94 µm in X direction.In Y direction,the maximum displacement is 2.17µm and 1.77 µm for silicon <100> and Polysilicon (LPCVD) respectively. But in Z direction, the maximum displacement is 661.26 µm for silicon <100> and 536.04 µm for Polysilicon (LPCVD).The very thin diaphragm experiences maximum deflection or displacement which is out of range in real case. But Silicon <100> diaphragm dominates the other one i.e. Polysilicon (LPCVD) as per its characteristics. It is quite natural that whenever the displacement is high, the resistance variation is more and hence the voltage variation also. This phenomenon reflects that the Silicon <100> diaphragm is the best suited material at nanoscale also if real time fabrication is possible. Fig 5 shows the stress variation among the two diaphragms for the input pressure ranges from 0.1 MPa to 0.5 MPa in three directions i.e. Sxx, Syy and Szz. The stress is distributed outward from the center of the diaphragm.

It is clearly found that the stress variation in the two directions i.e. Sxx and Syy are less in Silicon <100> when comparing to other. There is a negligible variation in stress, in the Szz direction for the Silicon <100> from the Polysilicon LPCVD. But commonly both the diaphragms exhibits minimum to maximum stress component for large displacement. The stress experienced here is compressive and tensile stress. Hence from the simulation results, it is found that the relation between the applied pressure and the maximum deflection of the diaphragm is linear. Following are the limitations which exist in this research.

1. Due to the limitations in the photolithographic process, fabrication of 100 nm thickness diaphragm is a challenging task. By other means it can be done.
2. But there is a possibility for fixing the nanoscale in simulation tool.
3. The maximum displacement of the diaphragm should not exceed the diaphragm thickness (Xiaodong Wang. et.al, 2004). But in this study, it exhibits large deflection or displacement and the diaphragm will burst.
4. Hence the diaphragm dimension has to be optimized to estimate the maximum displacement and stress distribution of the diaphragm for the input pressure.

The actual diaphragm size can also be calculated using equation 1 for Si using KOH etch for thin diaphragm with small deflection (Fuller *et al*, 2003).

$$L_{actual} = L_{mask} - 2\left(\frac{t_{sub} - t_{dia}}{\tan 54.7^0}\right) \qquad (1)$$

Where L_{mask} and L_{actual} are the mask defined and actual length of square diaphragm respectively. t_{sub} and t_{dia} are the substrate and diaphragm thickness respectively. The etching makes 54.7° on Si <100> substrate.

5. The solution has to be arrived to place the resistors on this very thin diaphragm.The resistors can be placed in a suitable position where the maximum stress is created on the diaphragm for applied pressure. The stress on a square diaphragm is directly proportional to the applied pressure and can be calculated using the equation 2 (Fuller *et al*, 2003).

$$\sigma = (0.3)(L/H)^2 . P \qquad (2)$$

6. Strain of the diaphragm and potential analysis of the sensor are to be carried out for the real time achievement.

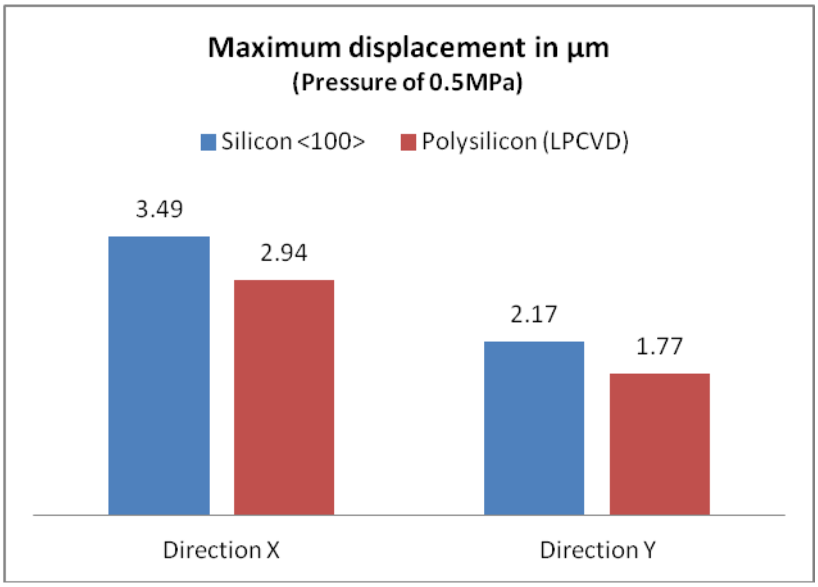


Fig. 4: Comparison plot of maximum displacement in X and Y directions.

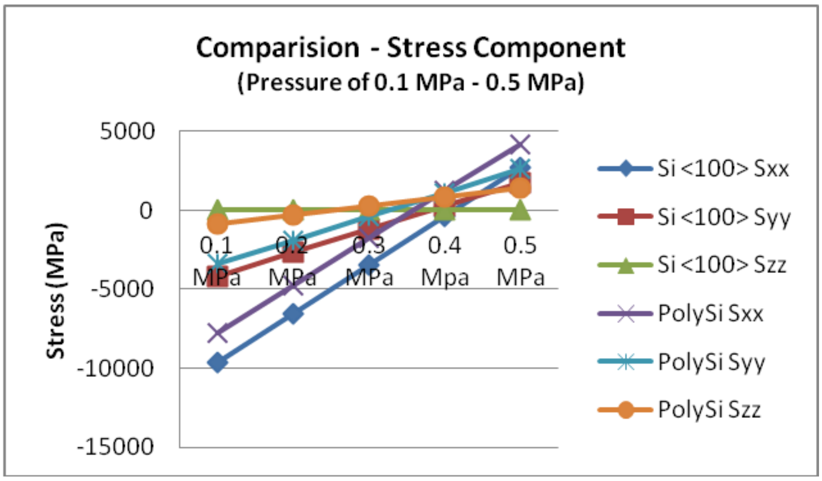


Fig. 5: Comparison plot of stress component

Conclusion:

In the present work, 100 nm thickness square diaphragm for piezoresistive pressure sensor is designed using IntelliSuite®. The displacement and stress distribution of nanoscale diaphragm are analyzed for various input pressures by ThermoElectroMechanical (TEM) tool. The real time nanoscale deposition is tedious process and the results here are purely based on simulation. The simulation result indicates that the Silicon <100> exhibits better performance than the Polysilicon (LPCVD).Further, the device can be optimized based on the facilities and applications, fabricated and compared with simulation studies.

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