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Design and Simulation of SOI Based Piezoresistive Pressure Sensor

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Abstract: **- Amongst various pressure sensors, Piezoresistive type of pressure sensor is widely used because of its simple processing and fabrication. Hence in this paper a Piezoresistive pressure sensor is designed using SOI diaphragm.SOI material used to improve sensitivity and also used to achieve high reliability.The simulation is carried out using COMSOL/Multiphysics by considering the membrane geometry size, shape and location of piezoresistors.**

I. INTRODUCTION

Micro Electro mechanical system(MEMS) is the technique of integrating electronic and mechanical components to create structures of miniaturizeddimensions.Various sensors are designed using MEMS technology .Pressure sensors are widely used various domains.

T.praveen Raj et.al[1] discusses about the effect of resistor size on the sensitivity of SOI Piezoresistive pressure sensor explores the feasibility and sensitivity improvement by adjusting the size of piezoresistors.Low cost and high sensitivity can be achieved are the advantages of work. Major drawback of this work is very critical to design for small size of resistors.

Li Sainan et.al[2] discuss about the high temperature pressure sensing mechanism. Materials used are N-type circular silicon diaphragm along specific crystal orientation. By this Doping concentration and power can be analyzed.

M.Z.Shaik et.al[3] discuss about Piezoresistive low pressure sensor for high temperature environment using SOI.SOI pressure sensors mainly intended for extreme environment conditions and high operating temperatures that are needed in military applications.

II. PIEZORESISTIVITY

Piezoresistivity is defined as change in resistance of metal or semiconductors due to the applied mechanical stress. Piezoresistive effect describes the change in electrical resistance that occurs when an external force is applied to semiconductor. This change only effects the materials electrical resistivity. In Piezoresistive pressure sensor, Piezoresistors are usually implanted on the surface of thin diaphragm. As pressure is applied, diaphragm deforms.Change in electrical resistance can be calculated by using ohm's law.i.e,

$$R = \frac{\rho L}{A}$$

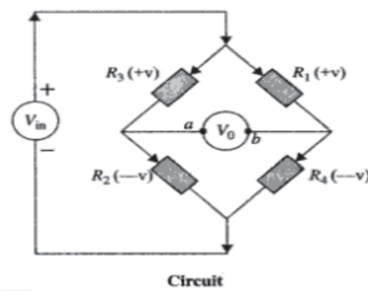

Fig1.1 Wheatstone bridge

Wheatstone bridge format is employed due to its simple connection and reading the output parameters. A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of bridge circuit one leg includes the unknown component. When pressure applied on the diaphragm the length of the resistance of Piezoresistive material changes.
Output voltage across the bridge can be calculated as

$$V_{out} = V_{in}\left(\frac{R1}{R1+R4} - \frac{R3}{R2+R3}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

where

$$V_{in} = applied\ input\ voltage$$

III. PROPOSED WORK

In this proposed work, Piezoresistive pressure sensor using silicon on insulator(SOI) is designed and simulated. The schematic of a proposed model is shown in fig. 3.1. The top view shows four resistors (R1,R2,R3 and R4) implanted on the surface of the silicon die . These piezoresistors convert the stress induced in the silicon diaphragm by the applied pressure into a change of electric resistance, which is then converted into voltage output by a Wheatstone bridge circuit as shown in figure(Fig1.1).

In figure 3.1, the terminal voltage and pressure are input parameters, and their relative displacement and output voltage are output parameters. As pressure increases, the relative displacement and output voltage also increases linearly.

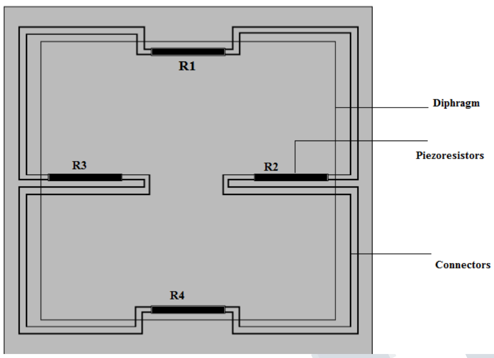

Fig. 3.1 Proposed Model

The dimension of the diaphragm for the proposed model is 400μm*400μm with the 10 μm thickness for upper layer and bottom layer, 5 μm thickness for middle insulator layer as shown in the figure 3.1.

In this proposed model five materials are used ,n-type silicon used as piezoresistors, p-type silicon used for diaphragm, intrinsic silicon used for bottom layer, silicon dioxide used for middle insulator layer because we are using SOI(silicon on insulator) and platinum(Pt) used for connectors.

Performance Parameters

When pressure is applied to the diaphragm deformation takes place at the centre. We measure the displacement analytically by using the equation **3.1.**

D=0.0151(1-v^2)$\frac{pa^4}{Eh^3}$------------------------- (3.1)

Where, p = applied pressure
a = Side length of the diaphragm
E = Young's modulus of silicon
h = Thickness of the diaphragm
v = Poisson's ratio of silicon

The output voltage across the wheatstone bridge depends on the input voltage and applied pressure. We measure the output voltage by using following equation 3.2 .

$V_{out} = \frac{0.75Pa^2(1-v)\pi_t V_{in}}{h^2}$………………… (3.2)

Where

$\pi_t =$ *Piezoresistive coefficient for inverse position*

Material properties

Material used for piezoresistors plays very important role in the deciding application of pressure sensor and range of pressure to be determined. The table shows the properties of material.

MATERIALS	N-TYPE SILICON	P-TYPE SILICON	SILICON	SIO2	PLATINUM
Young's modulus(Gpa)	160	160	170e9	170e9	168e9
Poisson's ratio	0.22	0.22	0.28	0.17	0.38
Density(kg/m^3)	2330	2330	2329	2200	21450
Electrical Conductivity(S/m)	149	149	1e-12	0	8.9e6
Relative permittivity	4.5	4.5	1	4.2	4.5

Table3.1 Material Properties

IV. MODEL PARAMETERS

Totally 6 six blocks are used to form SOI.All six blocks together form SOI(Silicon on Insulator) as shown in fig4.1.

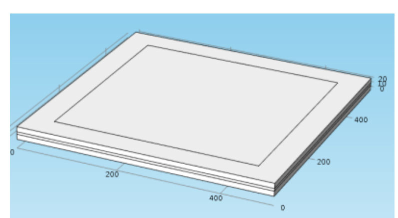
Fig4.1. Square Diaphragm

According to deflection theory, Piezoresistors are placed in maximum stress area as shown in figure.The length and thickness of piezoresistors is selected as 100um and 1um respectively.

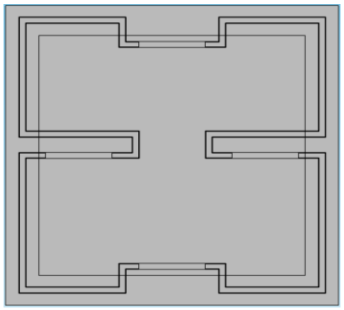

Fig4.2. Connectors connected to piezoresistive pressure sensor

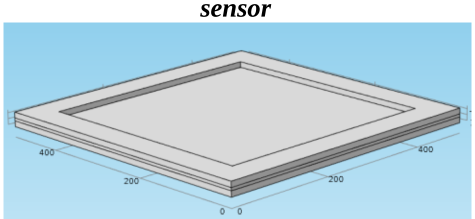

Fig4.3.After etching operation of SOI based Piezoresistive pressure sensor

The above figure 4.2 and 4.3 shows the connectors connected to the piezoresistors. And etch the bottom diaphragm by taking the difference. Apply pressure to bottom surface.

Silicon material is used for bottom substrate(Block1,2,5and6), Insulator (SiO2) material used for middle layer substrate(Block 3 and 4) .n-type silicon used for piezoresistors. P-type silicon used for upper substrate and diaphragm.Platinum used for connectors.Thin Piezoresistive layer and thin conductive layer is used by selecting all piezoresistors and connectors respectively. Fix the edges and bottom substrate layer.To apply the load (pressure) with suitable value by selecting diaphragm area.In the edge selection select the connector where the voltage is to be applied and select terminal type as voltage with input voltage Vin=5V. Select the connector to be grounded.

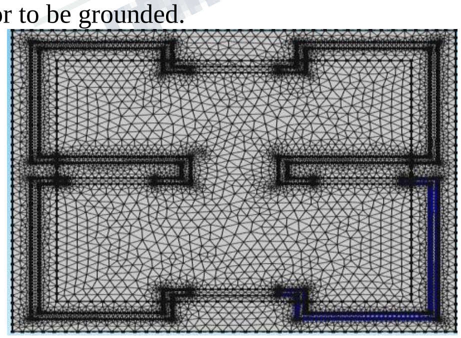

Fig4.4. Meshing

Meshing is used to reduce the complexity of computation, the entire model is disinterested into contiguous smaller units whose differential equations can be solved easily. The meshed model as shown in figure4.5.

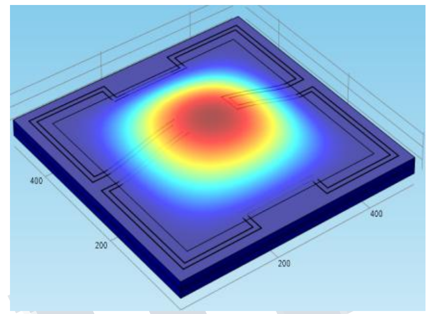

Fig4.5.Deformed piezoresistive pressure sensor

Output voltage to be measured and evaluate by taking two point evaluation.

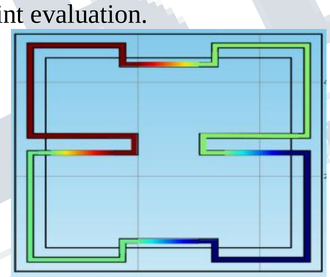

Fig4.6. output voltage

figure4.6 shows the output voltage across the Wheatstone bridge

V.RESULTS

The various parameters are taken into consideration like output voltage and displacement after the simulation of the proposed model for Piezoresistive pressure sensor.

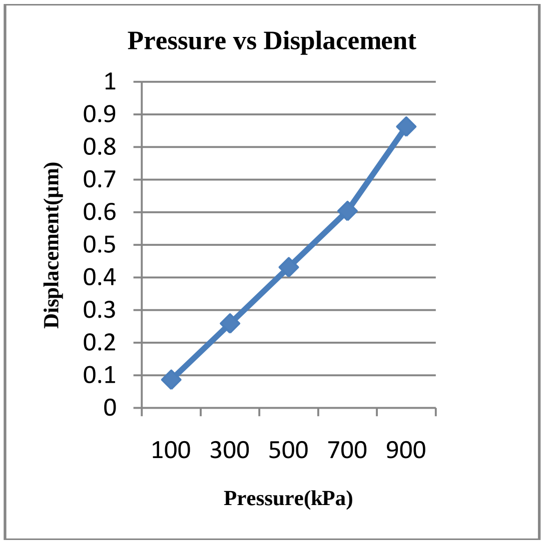

Fig.5.1 Displacement across bridges v/s Pressure

In fig.5.1 the pressure as a function of displacement of the diaphragm at the centre is plotted. Results show that as pressure increases for displacement increases.

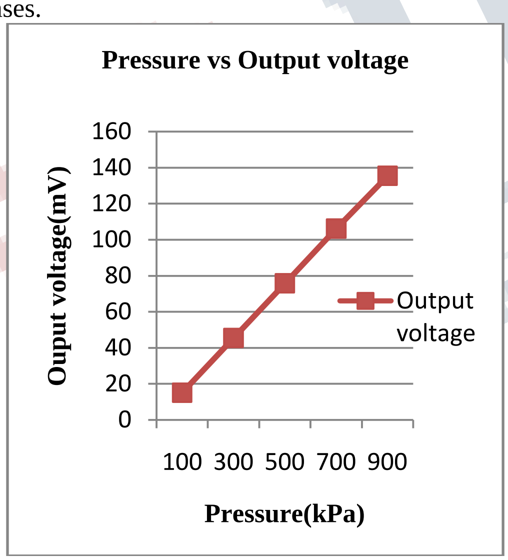

Fig.5.2 Output voltage across bridge v/s Pressure

In fig.5.2 the pressure as a function of output voltage is plotted, as pressure increases the output voltage increases.

VI. CONCLUSION

Various parameters such as deflection of the diaphragm at the centre and the output voltage across the Wheatstone bridge are the parameters considered for the analysis of the proposed pressure sensor. Results shown that the deflection of the diaphragm and the output voltage increases linearly as the pressure applied increases. better sensitivity of 30 nanovolt per Pascal can be achieved. By this we can conclude that Better sensitivity can be achieved using SOI material.The proposed model is designed to sense the pressure in the range of 100 kPa to 1MPa.

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