

Fabrication and Simulation of Piezoresistive Pressure Sensor for Abdominal and Thoracic Pressure Measurement Based on Micro-Electro Mechanical System

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ABSTRACT: Highly sensitive observing and controlling processes require extremely effective and precise sensing device. The control and monitoring inputs for any structure totally rely upon the sensitivity of the sensors. MEMS technology has the ability to outline the complete detecting system on a chip. Single chip can detect temperature, pressure as well as humidity. Typical applications of MEMS are in physical, chemical and biochemical sensors, as well as in optical systems such as the digital micro mirror device of Texas Instruments. Further, MEMS device is a rising device in a few ranges of science and innovation, for example, material science, life science. MEMS based sensors are as of now being utilized as a part of different sensing applications. Pressure measurement is one of the most mature applications of MEMS. The execution of pressure sensor is on a very basic level contingent upon its different physical properties i.e. piezoresistive, piezoelectric, capacitive and resonating.

I. INTRODUCTION

This thesis work is focused on the design of piezoresistive pressure sensor based on MEMS technology. This pressure sensor is designed for the application of measurement of abdominal and thoracic pressure. The electronic industry has, since the beginning of integrated circuits (IC) technology, developed fabrication processes and machinery enabling two dimensional miniaturized structures of micrometer scales and smaller sizes. Silicon was selected as a productive material for its excellent electrical properties. The fabrication technology used in IC production has been further developed into field of Micro Electro Mechanical System. MEMS allude to an accumulation of micro sensors and actuators that can detect its condition and have the capacity to respond to changes in that condition with the utilization of a microcircuit control. MEMS is the integration of mechanical elements, sensors, actuators and electronics on a common substrate through the application of micro fabrication technology.

MEMS are very small systems or systems made of very small components. MEMS concept has grown to encompass many other types of small things including thermal, magnetic, fluid dynamics, with or without moving parts. It includes both electronic and non-electronic components and perform functions that can include signal acquisition, signal processing, actuation, display and control. MEMS devices range in size from 20 micrometre to a millimeter.

II. SYSTEM DESIGN AND WORKING PRINCIPLE

Pressure sensor is a device to measure pressure of gases or liquids. Pressure is an expression of the force required to stop a liquid from expanding. It is generally expressed in terms of force per unit area. A pressure sensor generally goes about as a transducer; it produces a signal as a function of pressure applied. Such type of signal is electrical signal. Pressure sensors are being used for control and monitoring in a large no. of everyday applications. Pressure sensors may also be used indirectly to evaluate other parameters such as gas flow, velocity and water level. Pressure sensors can differ radically in innovation, outline, execution, application and cost.

A conservative estimate would be that there might be more than 50 technologies and at least 300 organizations making pressure sensors around the world.

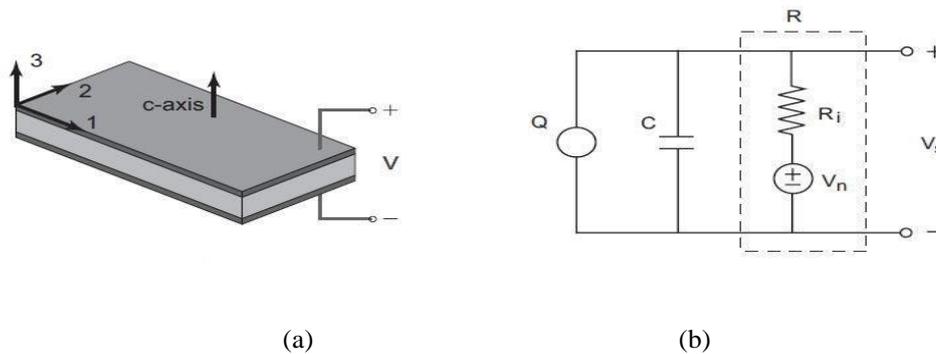


Fig. (a) A conventional MEMS Piezoelectric Pressure sensor (b) the piezoelectric sensor model

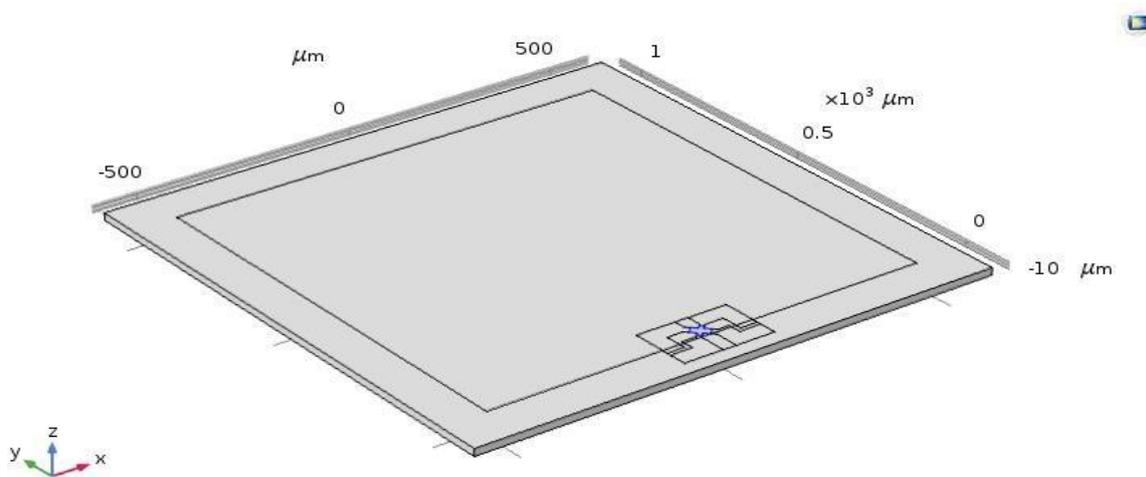
The figure (a) shows the simple model of Piezoelectric pressure sensor which depicts the working of sensor. Piezoelectric material is placed between the two electrodes. As the pressure is applied between these two electrodes, voltage is developed which can be measured by voltmeter. Figure (b) describes the equivalent model of piezoelectric sensor model.

III. DESIGN OF PIEZORESISTIVE PRESSURE SENSOR

This research is focused on finite element modelling of piezoresistive pressure sensor consisting of n-type and p-type silicon material. Simulation and analysis are completed with software package COMSOL Multiphysics version 5.3a using the MEMS module. The designed sensor measures the applied pressure and converts into the corresponding value of voltage. Working of this sensor is based on the principle of piezoresistance effect. On the application of pressure, stress is developed in the material due to which resistance of material is changed. The model consists of silicon substrate upon which diaphragm and piezoresistor are placed. This chapter will provide a detailed explanation of the approach to the design of piezoresistive pressure sensor including materials used and their properties, the geometry for 3-D model and how the solutions to the simulation are analyzed.

This research was conducted using the finite element software COMSOL Multiphysics. COMSOL Multiphysics is a cross-platform finite element analysis, solver and Multiphysics simulation software. It is an adaptable platform that permits even beginners to model all pertinent physical aspects of their designs. Advanced users can go further and utilize their knowledge to create customized solutions, relevant to their special conditions.

The model comprises of square membrane with side 1000 μm and thickness 20 μm , supported around its edges by region 0.1 mm wide, which is proposed to show the remaining part of the wafer. The supporting region is settled on its underside (representing a connection to the thicker handle of the device die). Close to one edge of the membrane an X-shaped piezoresistor and part of its associated interconnects are noticeable.



Geometry of proposed design of piezoresistive pressure sensor

IV. RESULTS AND DISCUSSION.

Simulated Results

Plot of von Mises Stress of the Designed Model

When the von Mises stress becomes equal to the yield stress, material starts to yield. The von Mises stress is used to check the yielding of material when the complex load is applied. Yield stress of silicon single crystal is 6900 MPa . It is observed from the plot that maximum value of von mises stress is 122 MPa developed near at the mid point of the edge of diaphragm. This stress is very less than the yield stress.

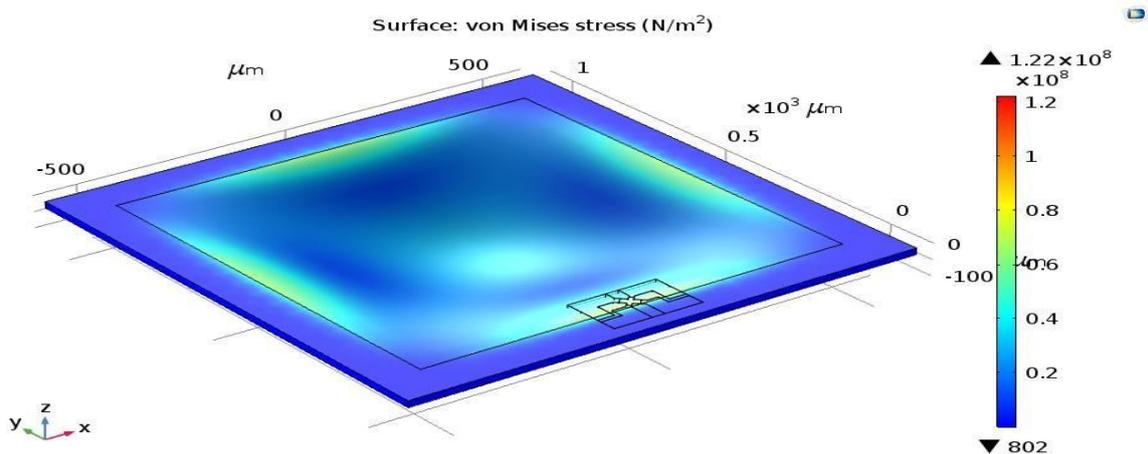


Fig : Plot of Von Mises stress of designed model

Electric Potential Distribution

Figure shows the electric potential distribution along the piezoresistor when the pressure of 100 kPa is applied. It can be seen that current direction is along the direction of pressure applied.

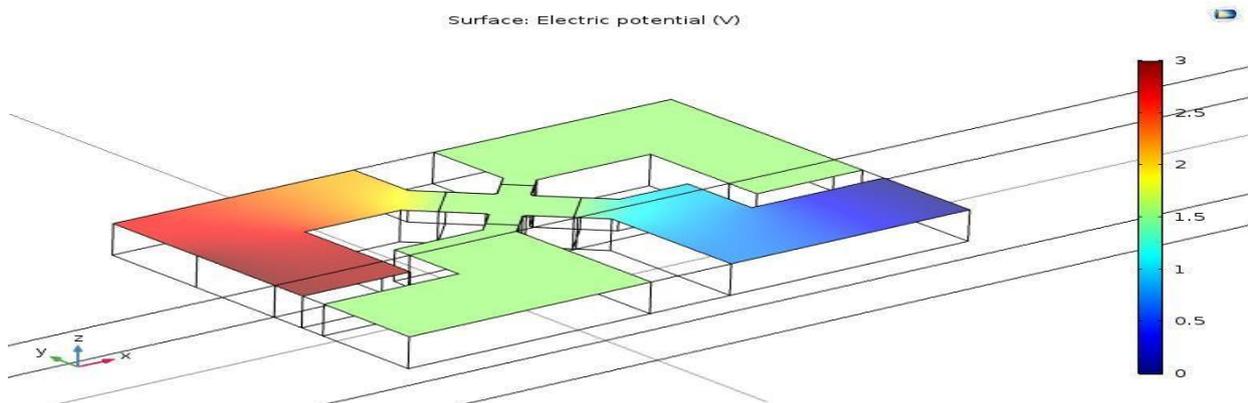
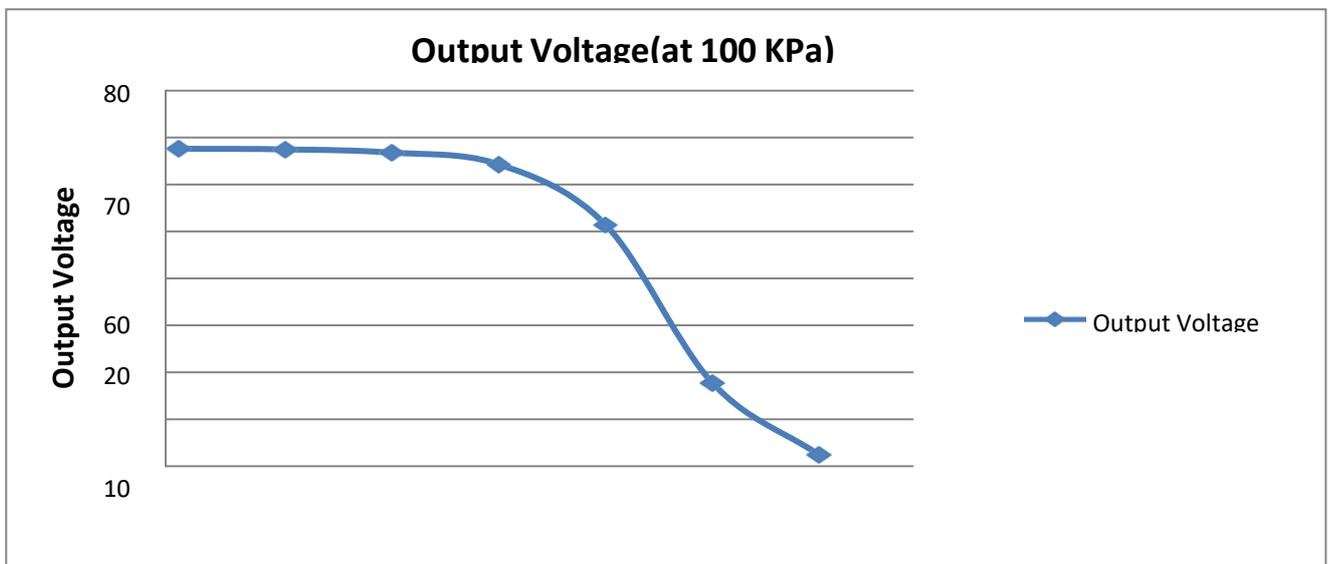


Fig : Plot of Electric Potential Distribution

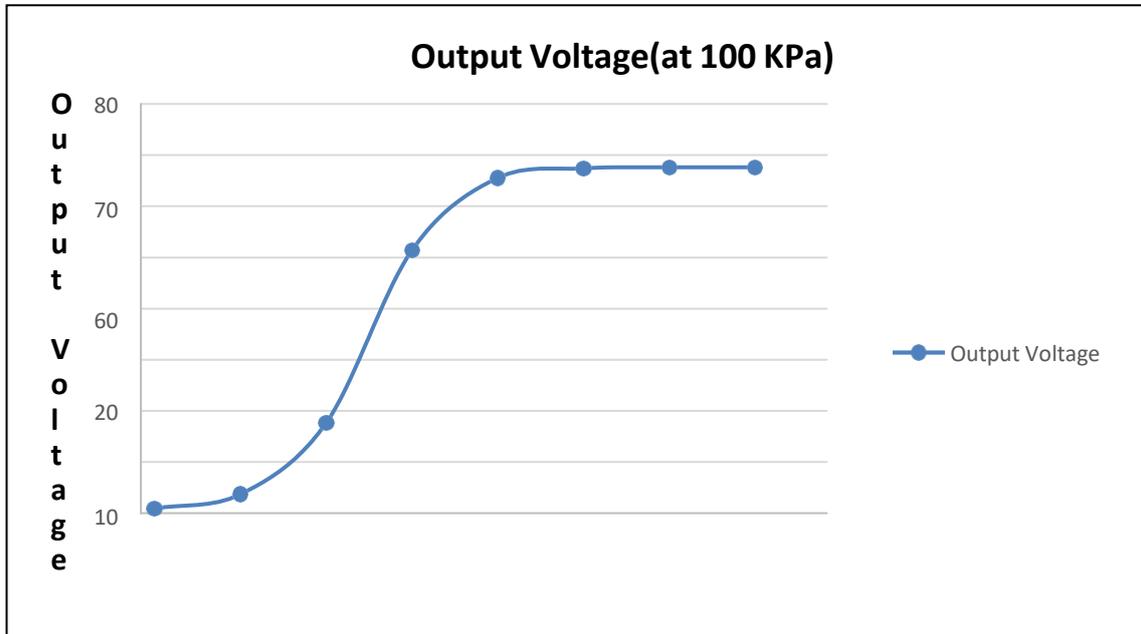
Calculated Results for the Piezoresistor Pressure Sensor

Doping Concentration vs Voltage graph at 100 kPa

Figure shows the variation of output voltage with the doping of piezoresistor. On increasing the doping level of piezoresistor, output voltage starts decreasing. Figure shows the variation of output voltage with the doping of interconnects which shows that on increasing doping level output voltage starts to increase. But due to heavy doping, piezoresistive material may lose their property. Thus a trade-off has done for doping. Doping concentration used for piezoresistor is 1.32×10^{19} per cm^3 and for interconnects is 1.45×10^{20} per cm^3 .



Output Voltage vs doping concentration of piezoresistor (p-type single crystal)



Output Voltage vs doping concentration of interconnects (p-type single crystal)

Pressure vs Output Voltage

Output voltage is calculated for the different types of combinations of diaphragm and piezoresistor material in the range of 0-100 kPa. Different combinations have been shown in table

Table 5.1 Combinations of Diaphragm and Piezoresistor

Combination	Diaphragm	Piezoresistor
1	N-type silicon single crystal	P-type silicon single crystal
2	N-type silicon poly crystal	P-type silicon single crystal
3	N-type silicon single crystal	P-type silicon poly crystal
4	N-type silicon poly crystal	P-type silicon poly crystal

For the four combinations mentioned in table 5.1, output voltage is calculated in the range of 0-100 kPa. Then the comparison is done between all the combinations. Figure 5.8 shows the output voltage for all the four combinations as a result of 0-100kPa applied.

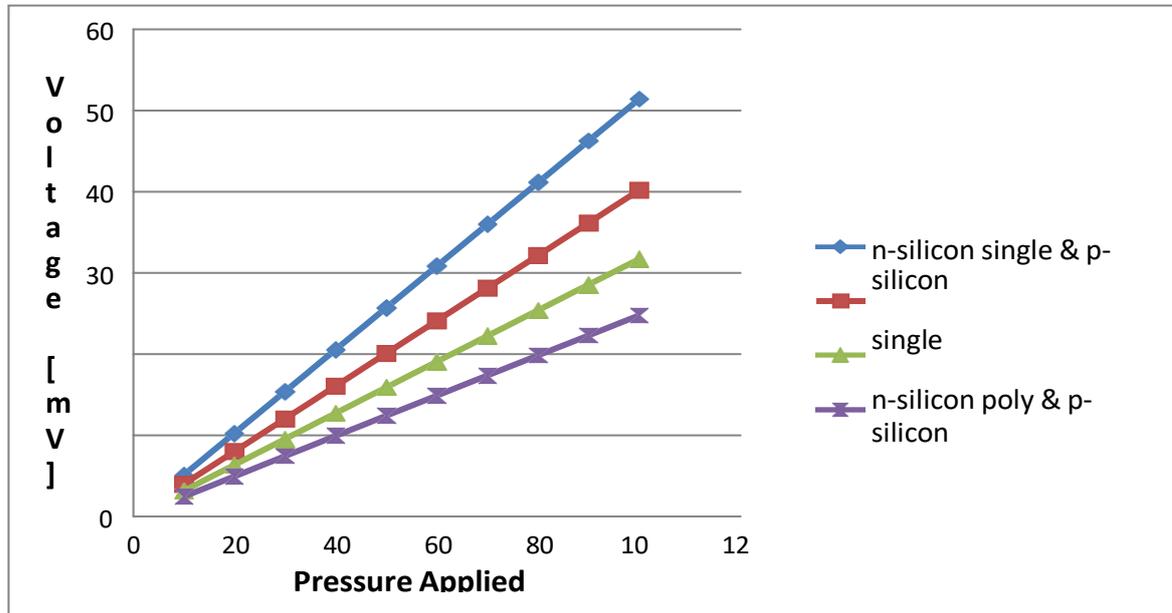


Fig :Voltage vs Applied pressure for different combinations of piezoresistor and diaphragm (0-100kPa)

As the abdominal and thoracic pressure ranges from 0-10 kPa, the output voltage is calculated also for the range of 0-15 kPa.

V. CONCLUSION & FUTURE SCOPE

Conclusion

In this thesis work a MEMS based Piezoresistor Pressure Sensor is designed for the measurement of abdominal and thoracic pressures. As it is shown by the previous research that abdominal and thoracic pressure ranges from 0 to 10 kPa. The designed sensor is simulated in the pressure range of 0-100 kPa and the results are concluded. The material used for the simulation are n-type and p-type silicon of both single crystal and poly crystal type. Output Voltage is calculated for the different types of combinations of diaphragm and piezoresistor in the pressure range of 0-15 kPa and 0-100 kPa. It has been observed that combination of n-type silicon single crystal for diaphragm and p-type silicon single crystal for piezoresistor has better sensitivity among all the combinations. The graph shows linear variations which depicts that piezoresistive pressure sensor shows better linearity in comparison with capacitive and piezoelectric pressure sensor.

It is concluded that MEMS based piezoresistive pressure sensor can be used in the measurement of abdominal and thoracic pressure.

Future Scope

As the silicon material exhibits excellent piezoresistive property for the pressure sensor due to high sensitivity and better linearity. In future optimization of the device can be done by adding some other semiconducting materials to get the more enhanced results from the proposed design for small applied inputs.



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