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Design and Simulation of Piezoresistive Pressure Sensor using Intellisuite

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Abstract

The Piezoresistive Pressure Sensor given in this study describes the best methods for enhancing the sensor's performance. To get findings that are roughly equivalent to theoretical values, finite element analysis is used as part of the design process. The size, shape, and position of the piezo resistors are taken into account during the simulation. The piezo resistors, which are coupled in the shape of a Wheatstone bridge, convert the applied pressure into electricity. By choosing the appropriate membrane geometry and piezo resistor placement, the sensitivity of the sensor can be increased, and the results are also acquired in this manner.

Keywords: Piezo resistors, MEMS, Intellisuite, Pressure sensor.

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1. Introduction

Pressure sensors are frequently employed in a wide range of industries, from the automotive to the medical, aerospace, and consumer electronics. The piezoresistive pressure sensor, which transforms the applied pressure into a change in resistance, is one of the most used varieties of pressure sensors. The piezoresistive effect is based on the idea that under mechanical stress, some materials' electrical resistance varies. In this paper, Intellisuite software is used to build and simulate a piezoresistive pressure sensor. With a full suite of tools for device simulation, optimisation, and fabrication, Intellisuite is a potent tool for designing and analysing MEMS devices. Our goal is to show that constructing and analysing piezoresistive pressure sensors using Intellisuite is feasible and efficient.

2. Pressure Sensor and Software Used

2.1. Piezoresistive Pressure Sensor

A piezoresistive pressure sensor monitors pressure by identifying changes in a material's electrical resistance brought on by pressure or strain. The sensor is made of a piezo resistor, which is a thin, flexible material (often silicon) covered in a pattern of small resistive elements. The piezoresistive material deforms when pressure is applied to the sensor, and the resistance of the piezoresistive elements varies proportionally to the applied pressure. By running a little current through the elements and gauging the voltage across them, the change in resistance may be detected. Numerous products, including consumer electronics, medical equipment, automotive and industrial pressure measurement, use piezoresistive pressure sensors. They are well-liked because they are compact, dependable, and reasonably priced.

2.2. Software used

Micro-electromechanical systems (MEMS) and other micro-systems are designed and simulated using the software tools in Intellisuite. The company IntelliSense Corporation created and updates the software. In both academia and business, Intellisuite is frequently used for MEMS research and development. It offers a complete collection of tools for creating, modelling and simulating MEMS devices, which can aid engineers and researchers in improving their designs and shortening the time it takes for MEMS products to reach the market.

3. Sensor Design

A silicon diaphragm with incorporated piezoresistive sensing components makes up the suggested piezoresistive pressure sensor. Under pressure, the diaphragm is intended to deflect, stressing the piezoresistive components and creating a change in resistance. A Wheatstone bridge design can be used to measure the change in resistance, which is proportional to the applied pressure.

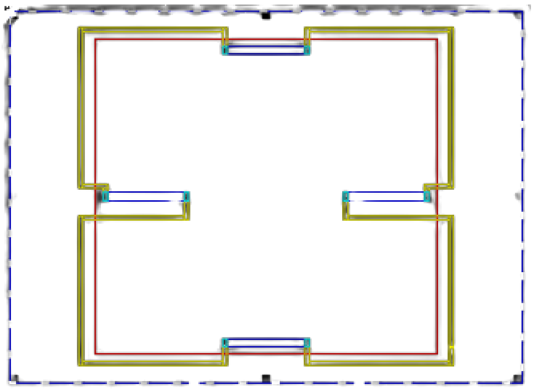


Figure 1. Layout of the pressure sensor

3.1. The sensor design consists of the following components

1. Designing the silicon diaphragm: Using Intellisuite's layout editor, the silicon diaphragm must first be designed. Depending on the desired pressure range and sensitivity, the diaphragm dimensions are selected. The 50 m diaphragm thickness is the one chosen.
2. Piezoresistive element placement: Four piezoresistive elements are arranged in a Wheatstone bridge configuration on the diaphragm surface. The 200 m was chosen as the distance between the piezoresistive elements.
3. Metal wires are used to connect the piezoresistive components to the external circuitry electrically.
4. Packaging: To shield the sensor from outside effects, it is packaged with a glass top.

3.2. Fabrication Process

The following steps are included in the fabrication process:

1. Wafer preparation for wafer (100), flat (01), and 50000 nm in thickness
2. Initial B-ions implant exposure
3. B-ions for piezoresistive structure implant
4. Silicon nitride (Si3N4) for isolating a layer's deposition
5. Second Exposure via Holes
6. Etching via holes in silicon nitride (Si3N4)
7. Deposition of aluminium (Al) for the connecting layer
8. Third metal connection exposure
9. Metal connection using aluminium (Al) etch
10. Silicon nitride (Si3N4) etch to remove unnecessary Si3N4
11. The bottom side's fourth exposure
12. Silicon (Si) etch for the underside

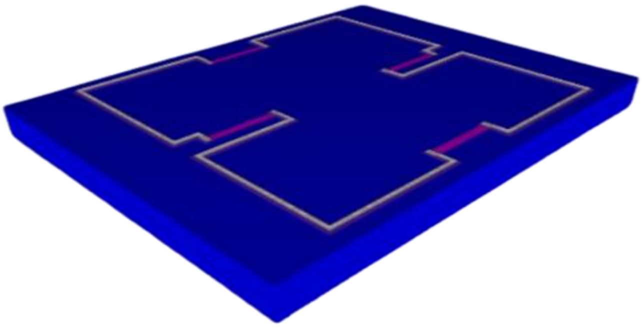


Figure 2. Final structure of piezoresistive pressure sensor

3.3. Meshing

A versatile, intelligent, automated, high-performance product is meshing. It creates the best mesh possible for precise, effective Multiphysics solutions. For any component of a model, a mesh that is best suited for a particular study can be created with a single mouse click. The pressure sensor's meshed model is depicted in Figure 3.

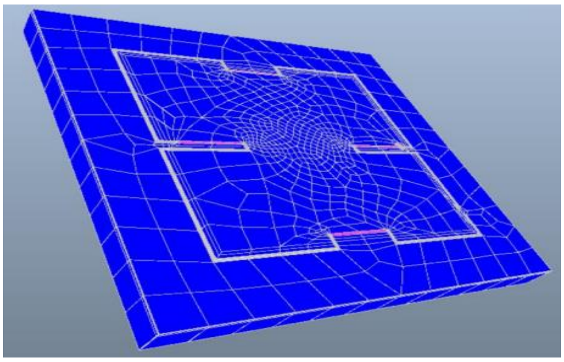


Figure 3. Meshed model in intellisuite

4. Thermo-Electro-Mechanical (TEM) Analysis

4.1. Material properties

Table 1. Main material properties

Entity	**Material**	**Young's Modulus (GPa)**	**Resistivity**	**Piezoresistive Coeff**		
				P_11,1/Mpa	**P_12,1/Mpa**	**P_44,1/Mpa**
Entity 1	**Silicon**	130.18	**-**	-	-	-
Entity 3	**Aluminium**	-	2.8e-006	0	0	0
Entity 4	**Piezo resistor**	**-**	**-**	6.6e-005	-1.1e-005	0.00138

4.2. Boundary Fixing

Before beginning any analysis, the boundary conditions are fixed. The sensor's bottom face and all four of its sides are fixed. Frequency, static, and electrical investigations are conducted in this paper.

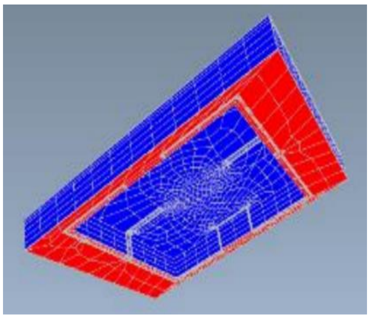
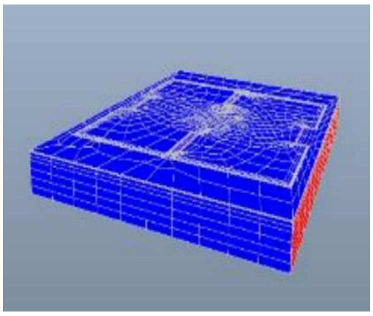


Figure 4



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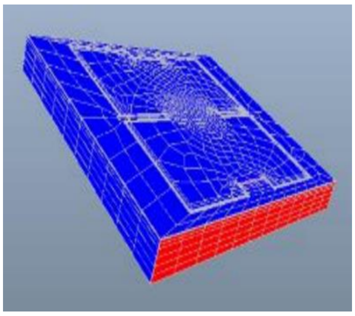


Figure 6

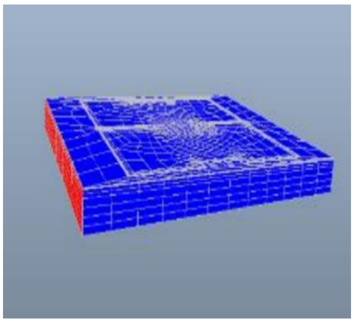


Figure 7

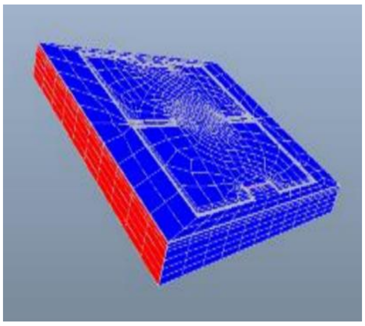
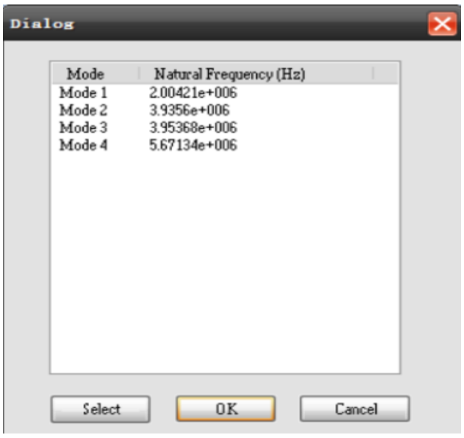


Figure 8

Figure 4 to 8 shows the boundary conditions are fixed in the piezoresistive pressure sensor

4.3. Natural Frequency

In this section, we'll examine the piezoresistive pressure sensor's frequency. We'll examine each of the device's four modes. The simulation's frequency setting is used to launch the frequency analysis. The number of modes is then chosen. Based on the situation, it can be done. The natural frequency is found here after selecting four modes. When there is no external force acting on the system, it oscillates at its natural frequency. The system may sustain permanent harm if operated over its native frequency. Four frequency modes are tested during the design of the piezoresistive sensor.



Mode	Natural Frequency (Hz)
Mode 1	2.00421e+006
Mode 2	3.9356e+006
Mode 3	3.95368e+006
Mode 4	5.67134e+006

Figure 9. Natural Frequency

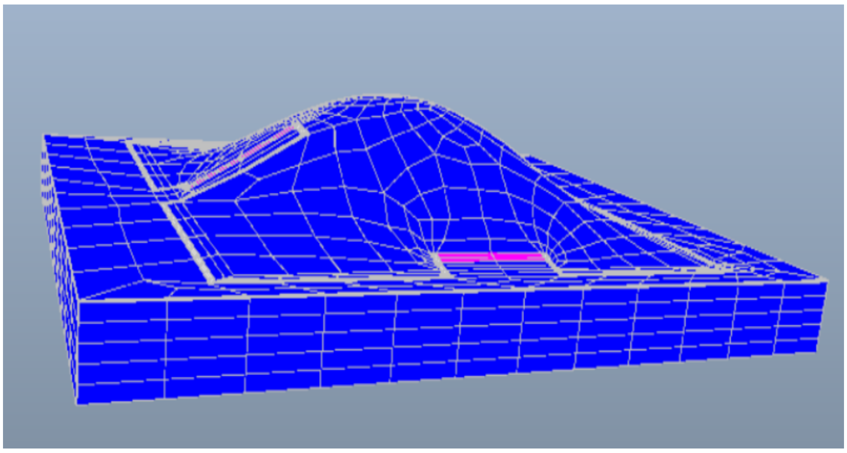


Figure 10. The first mode of Animation

4.4. Mechanical Analysis

This analysis served as the basis for the creation of the piezoresistive sensor. The material property must first be verified by looking at the check/modify button in the taskbar. The sensor could be made of any one of four different things. The next step is to click each entity and then examine each one's property. Here, silicon, metal, aluminium, and piezo resistors are the substances employed. The user can change Young's modulus, resistivity, and piezoelectric coefficient values using Intellisuite. The boundary must then be fixed by applying a few constraints. According to various operating conditions, TEM offers a variety of boundaries. A proper boundary can be established by users. The substrate's bottom side was fixed once its four sides were set. Select each face that has to be corrected individually by clicking boundary fixed.

The portion of the piezoresistive pressure sensor's frequency that can be used for analysis is its natural frequency. We'll examine each of the device's four modes. Frequency mode and the analysis type static stress mode are both selected in the calculation type dialogue box. Finally, we must select OK after selecting Apply. Applying the loads to the relevant faces is the next action. Then type a pressure value, such as 0.1Mpa. By selecting Start static analysis, the simulation procedure must be launched. Click stress invariant as misses once the simulation is complete. after choosing the normal displacement.

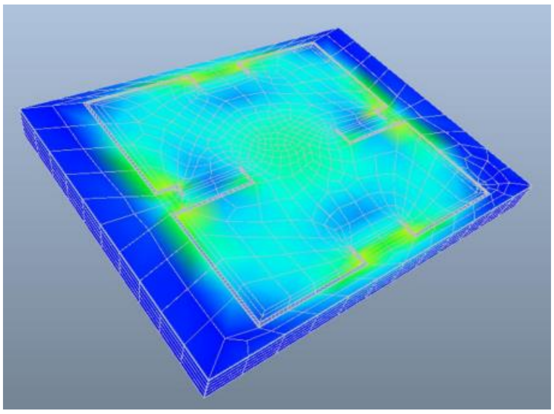


Figure 11. Misses stress distribution (0.1Mpa)

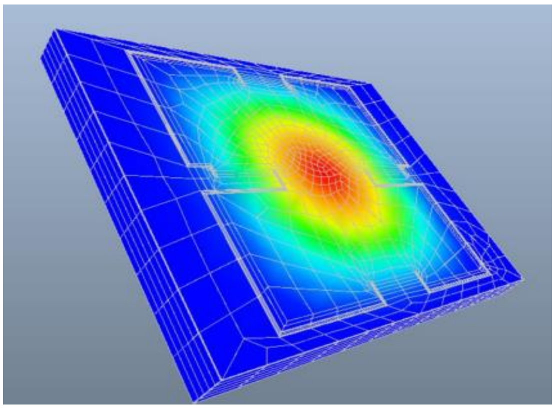


Figure 12. Norm-Displacement (0.1Mpa)

4.5. Electrical Analysis

First, the resistor sub-mode needs to be ready. By selecting the extract resistor mesh option after clicking the mesh, you can now set the piezoresistive. After doing this step, the wire and piezo resistors may be viewed in the programme window. When everything is finished, select the auto mode by clicking on the mesh. The electrothermal loads are applied at the end by choosing loads->voltage->face. Select the treated top surface area, and for the voltage, type 0 volts. Since this is a piezoresistive pressure sensor, the temperature has been evenly spread throughout the faces. The four top faces of the piezo resistors should be set to 25 deg_C. In this illustration of a "heat sink" boundary condition, the resistors are positioned on the membrane, which is continuously at 25 degrees Celsius. Finally, we can view the results of the simulation by choosing the static analysis. The low potential value, or 0v, is represented by the blue colour, whereas the high potential value is represented by the red hue. The node value could be displayed as a little red circle. A potential of 2.50128V exists at the selected node.

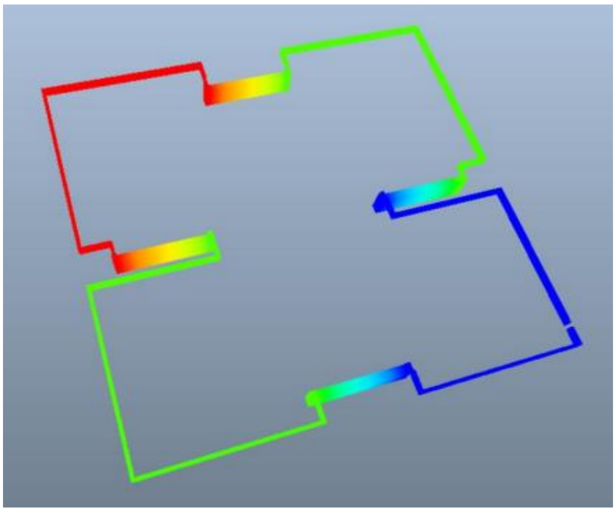


Figure 13. Electrical Analysis

5. Result

According to the simulation results, the suggested piezoresistive pressure sensor design has a high sensitivity and linear response over the desired pressure range. In conformity with the analytical calculations, the diaphragm's deflection and stress distribution around the torn area validates the use of Intellisuite for the design and analysis of piezoresistive pressure sensors. The efficiency of the suggested sensor design is demonstrated by the strong correlation between the change in resistance of the piezoresistive parts and the applied pressure. It is discovered that the Wheatstone bridge's output voltage is linearly proportional to the applied pressure, providing evidence of reliable sensor performance. A close agreement between the simulation findings and experimental data from a manufactured sensor prototype is found, further verifying the accuracy of the Intellisuite simulations.

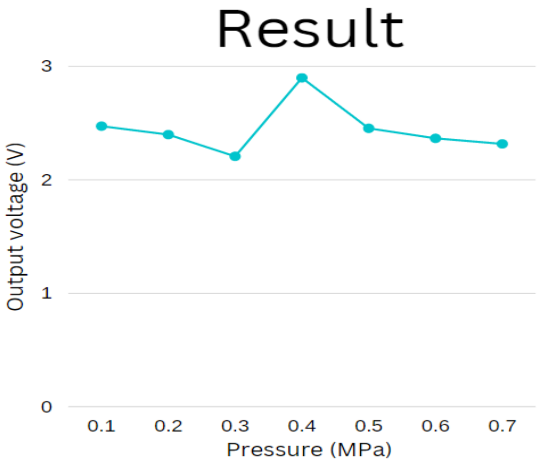


Figure 14. Pressure Vs Output voltage

6. Conclusion

Using Intellisuite software, we have demonstrated the design and modelling of a piezoresistive pressure sensor in this study. The simulation outcomes show how Intellisuite may be used to create and analyse MEMS-based pressure sensors. The suggested sensor design is ideal for a variety of applications due to its excellent sensitivity and linear response over the specified pressure range. The correctness of the Intellisuite simulations is supported by the strong agreement between simulation results and experimental data.

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