International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design and Simulation of MEMS-Based Pressure Sensor

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A B S T R A C T

This study provides a summary of the design, modelling, and simulation of MEMS pressure sensors using Intellisuite software. Offering separate membrane structures (circular and square) with uniform surface area and thickness has been tried to achieve high sensitivity. Additionally, three materials—Silicon—have been assigned to simulations with varying loads ranging from 0.1 to 1MPa. Studies of the simulation results revealed that the pressure sensor with silicon material provided by a circular membrane exhibited increased deformation and high sensitivity thickness. The effects of input load, altered diaphragm dimensions, and material addition on improved sensitivity are carefully explored. For calculating and verifying pressure in a range of environmental and industrial conditions, these studies are particularly beneficial.

Keywords: Intellisuite; Diaphragm; Stress; Displacement; Pressure sensor

1. Introduction:

Micro-sized pressure sensors built using MEMS (Micro-electro-mechanical systems) translate mechanical deformation into electrical impulses to monitor pressure. These sensors are widely utilized in many different applications, including industrial systems, automobiles, and aeronautical and medical equipment. Using microfabrication techniques, which involve etching and depositing microscopic structures on a silicon substrate, pressure sensors based on MEMS are created. A tiny diaphragm serves as the sensor's pressure-sensitive component, and it moves when pressure is applied. Piezoresistive or capacitive sensing components that are built into the structure are used to measure displacement. The compact design and low power consumption of MEMS-based pressure sensors are two of its main benefits. They are perfect for applications where space is constrained since they are simple to integrate into electronic circuits. Moreover, MEMS-based pressure sensors

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1.1 Circular Piezoresistive Pressure Sensor:

A circular piezoresistive pressure sensor is a pressure sensor that measures pressure via the piezoresistive effect. A change in electrical resistance happens when a material is put under mechanical stress or strain. The piezoresistive effect is the name given to this phenomenon. A piezoresistive pressure sensor uses a circular diaphragm made of piezoresistive material, such as silicon, to sense pressure. Under pressure, the diaphragm stretches, altering its resistance. The resistance change, which is inversely proportional to the applied pressure, can be detected using a Wheatstone bridge circuit. Circular piezoresistive pressure sensors are extensively used in a variety of industries, including the automotive, aerospace, and medical device sectors. They offer outstanding accuracy, stability over time, and sensitivity.

1.2 Square Piezoresistive Pressure Sensor:

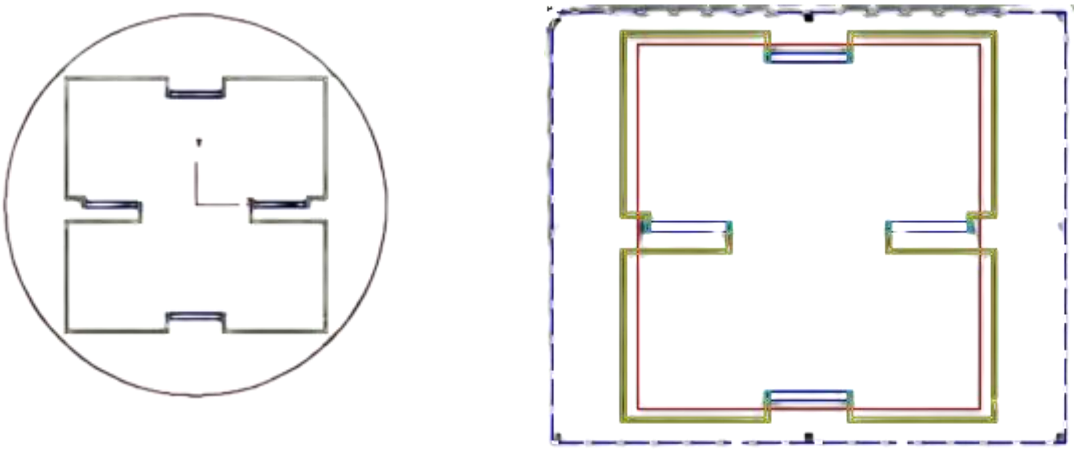
A piezoresistive pressure sensor can measure pressure by sensing changes in a material's electrical resistance brought on by pressure or strain. The material used to create the sensor is a piezo resistor, which is a thin, flexible material (usually silicon) covered in a pattern of small resistive elements. The piezoresistive material deforms when pressure is applied to the sensor, and the resistance of the piezoresistive elements varies in direct proportion to the pressure. By running a little current through the components and measuring the voltage across them, the change in resistance may be identified. Consumer electronics, healthcare equipment, automobiles, and industrial pressure measurement all use piezoresistive pressure sensors. They are well-liked because they are compact, trustworthy.

1.3 Software used:

Micro-electromechanical systems (MEMS) and other micro-systems are designed and simulated using the software tools in Intellisuite. IntelliSense Corporation created and maintains the programme. Both in academia and business, Intellisuite is frequently used for MEMS research and development. It offers a complete collection of tools for modelling, simulating, and developing MEMS devices, which can aid engineers and researchers in creating better designs and speed up the commercialization of MEMS products.

2. Sensor Design:

A silicon diaphragm with integrated piezoresistive sensing components makes up the suggested piezoresistive pressure sensor. Under pressure, the diaphragm is intended to deflect, putting stress on the piezoresistive components and changing the resistance. The Wheatstone bridge design can be used to measure the resistance change, which is proportional to the applied pressure.



(a) (b)

Figures 1. (a) & (b) Layout of Pressure Sensor

3. Square Piezoresistive Pressure Sensor Vs Circular Piezoresistive Pressure Sensor:

A square piezoresistive pressure sensor has a larger sensing area than a circular sensor with an equivalent diameter. A square sensor can monitor pressure across a larger area; therefore it can more accurately depict the pressure distribution. However, if the application requires a specific sensing region, a circular sensor would be a better choice.

2. Output signal: A square piezoresistive pressure sensor's output signal is often more linear when compared to a circular sensor. This is because a square sensor's resistance change spreads out more uniformly across the sensing surface than a circular sensor's, which is more concentrated in the middle. The output signal of a circular sensor could become nonlinear as a result.

3. Installation: The sensor's design may have an impact on where it is placed. A sensor that is square can be easier to install and put precisely because it has defined edges and corners. A circular sensor may be more difficult to position precisely since it can revolve around its core.

4. Price: Depending on the source and the requirements of the specific application, the cost of a square or circular piezoresistive pressure sensor may vary. However, because it requires fewer manufacturing steps, a circular sensor may generally be slightly less expensive to produce.

4. Analysis:

4.1 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-6	0	0	0
Entity 4	**Piezo resistor**	-	-	6.6e-5	-1.1e-5	0.00138

Table 1. key characteristics of Square Pressure Piezoresistive Sensor Piezoresistive Pressure Sensor in a Circle

4.2 Theoretical background:

Based on the geometry of the membrane, the displacement and stress distribution values have been theoretically calculated using the following formulae, and these values have then been verified using simulation results.

The square membrane's maximum stress is determined by

$\sigma_{max} = (P_{max} * t^2) / (0.707 * l^2)$ ………………. (1)

The square membrane's maximum deflection is computed using

$\delta_{max} = (P_{max} * t^3) / (12 * E * (1 - v^2))$ ………... (2)

The circular membrane's maximum stress is determined by

$\sigma_{max} = (P_{max} * r^2) / (2 * t^2)$ …………………… (3)

The formula for calculating the circular membrane's maximum deflection is

$\delta_{max} = (P_{max} * r^4) / (64 * t^3 * E)$ ……………… (4)

5. APPLICATION:

1. Blood pressure monitoring: Sphygmomanometers and other electronic blood pressure monitors often use piezoresistive pressure sensors to detect blood pressure. By monitoring the blood flow pressure in the arteries, they provide accurate systolic and diastolic pressure values.

2. Intracranial pressure monitoring: Devices that measure intracranial pressure measure pressure inside the skull using piezoresistive pressure sensors. For the treatment of conditions including hydrocephalus, intracranial haemorrhages, and traumatic brain injury, this is essential.

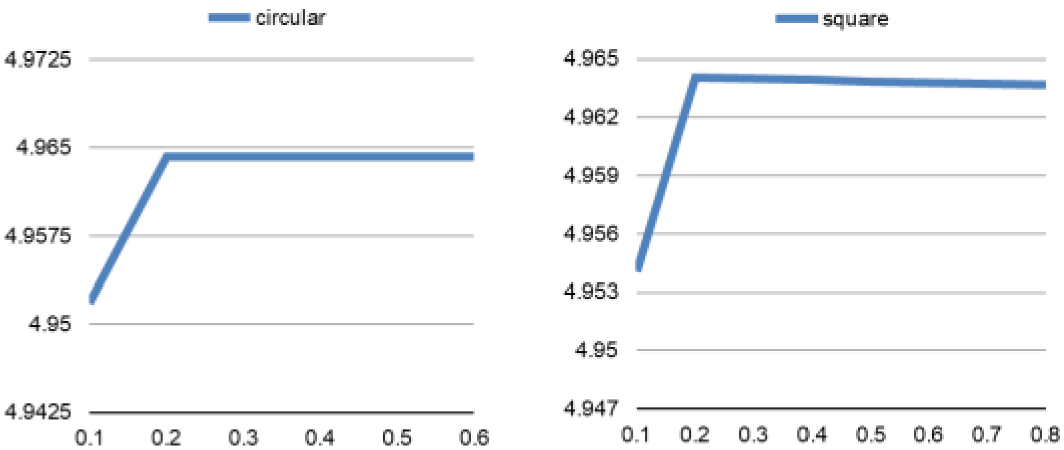
3. Monitoring of respiratory pressure: Systems that measure respiratory pressure monitor changes in airway pressure as a person breathes by using piezoresistive pressure sensors. This is essential for the early diagnosis and management of respiratory diseases like asthma and chronic obstructive pulmonary disease. (COPD).

4. Cardiac catheterization: This procedure uses piezoresistive pressure sensors to track changes in blood vessels and heart pressure. Therefore, it is simpler to diagnose and treat cardiovascular conditions including heart failure and coronary artery disease.

5. Urinary incontinence monitoring systems use piezoresistive pressure sensors to measure pressure changes in the bladder during urination. This can be used to diagnose and treat urinary incontinence and other bladder-related issues.

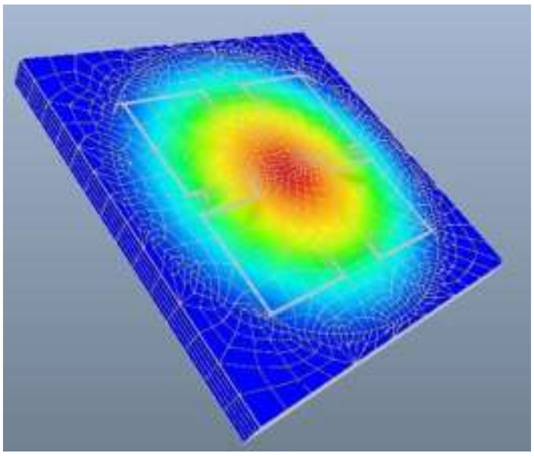
6. Result:

When pressure between 0.1 and 1 MPa is applied to silicon membranes with two distinct forms, it is discovered that the circular membrane exhibits higher displacement than square diaphragms. For each example, simulations corresponding to the constant membrane thickness of 564 & 864 m have been run. From these findings, it was evident that in all circumstances, the membrane with a thickness of 564 m had a higher displacement than one with a thickness of 864 m.

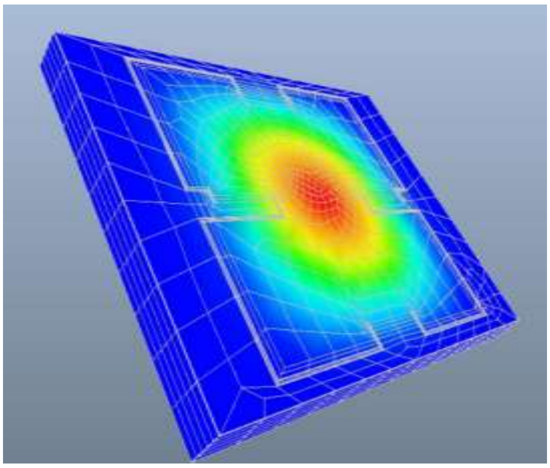


(a) (b)

Figure 2. Pressure Vs Voltage (a) Circle Piezoresistive Pressure Sensor & (b) Square Piezoresistive Pressure Sensor



(a) Circle Piezoresistive Pressure Sensor



(b) Square Piezoresistive Pressure Sensor

Figures 3. (a) & (b) Displacement Versus Applied load

S. No:	Input pressure (MPa)	Circular piezoresistive pressure sensor output voltage (Volt)	Square piezoresistive pressure sensor output voltage (Volt)
01	0.1	4.95176	4.95406
02	0.2	4.9642	4.96406
03	0.3	4.96421	4.964
04	0.4	4.96421	4.96393
05	0.5	4.96422	4.96387
06	0.6	4.96422	4.96381
07	0.7	4.95426	4.96374
08	0.8	4.96421	4.96368
09	0.9	4.96723	4.95355

Table 2. Square and circular silicon membranes with pressure versus voltage

7. CONCLUSION:

Using Intellisuite software, the MEMS-based pressure sensor has been created and simulated under a variety of diaphragms, including square and circular-based piezoresistive pressure sensors, and varied output parameters, including pressure and voltage. According to the analysis of the finding, the square diaphragm produced the most stress, while the circular diaphragm produced the most deflection. The simulation findings allowed us to draw the conclusion that the pressure sensor with silicon material supplied via a circular membrane exhibited more deformation and high sensitivity.

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