Design of Piezoresistive Sensor using FEA in ANSYS

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Abstract. Piezoresistive pressure sensors are widely used in various fields such as in industries, auto mobiles, medical applications and many others. To get proper input from the sensors we must have a good sensor having good sensitivity in every type of environmental conditions. The behavior of the sensor also depends upon its thickness, area, material properties etc. This paper is based on the piezoresistive micro pressure sensor having greater sensitivity made of silicon material. Using finite element analysis (FEA) and ANSYS the sensitivity is determined on different dimensions with different loading conditions. The piezo resistors of silicon material are arranged in different patterns and the sensitivity of each plate is determined by having all the results best design for the sensor is achieved.

1. Introduction
MEMS sensor is the short form of Micro-Electro-Mechanical-System sensor. These sensors will have very small devices with 1μm-100μm size. A MEMS sensor will have at least one mechanical element or functionality. MEMS design consideration is more important than with larger scale mechanical devices due to large surface area to volume ratio. They are generally two types of MEMS - variable capacitive and piezoresistive. Here we will choose piezoresistive sensors due to simple construction means low cost and durability. Some of the qualities of these sensors are having good resistance to shock, vibration, and dynamic pressure changes. The output is linear with pressure and the response time is typically below one millisecond. The output is also stable over time. They can be used for a wide range of pressure measurements from 21 kPa to 150 MPa. [1,2]. These sensors can be operated at higher temperatures and are more suitable for use in harsh environment. The working principle of Piezoresistive Sensor is based on change of resistance. Whenever the tilt is applied to the Piezoresistive Sensor, then a balanced mass makes a difference within the electric potential. This can be measured like a change in resistance. It contains a mass- spring system designed so that the force exerted by the spring exactly equals the force required to accelerate the mass, and the displacement of the mass (deflection) is directly proportional to the acceleration measured by the strain gauge. It contains a built-in Wheatstone bridge circuit to measure the resistance change and produce an electric output. The approach combines analysis of silicon based piezoresistive sensors with simulation and modeling in a circuit simulation environment and relies on a new
class of parameterized behavioral models while giving different parameters with the use of software ANSYS [8].

2. Design with Specification

Design of Diaphragm

The diaphragm is the part where stress distribution will be taken place so for maximum sensitivity, we need different dimensions. Here we use three different case as per our approach, we use different parameters to get higher sensitivity[3, 4]. In First case we use for dimension (1200*1200*15) μm and the pressure varies from 10kPa to 160kPa.

In second case we use for pressure 120kPa with thickness 15 μm and dimension varies from 700 μm to 1200 μm while in third case we take pressure at 120kPa and dimension (1200*1200) μm and thickness varies from 5μm to15μm.

Fig. 1 Layout of diaphragm

1st case

Dimension (1200*1200*15)μm will be fixed and pressure varies from 10KPa to 160KPa.

Fig. 2 Maximum stress

Fig. 3 Variation of Pressure vs M. Stress

This indicates the equivalent (von-Mises) Stress by finite element analysis in software ANSYS R18.0. [5]. Here the pressure varies and dimensional and thickness is fixed. In this deformation showing the areas where the stress is maximum and minimum.

By FEM i.e. finite element method, we analyse the data and according to it the graph is made. The result will be obtained from FEA.
Using FEA we will use sensors from different patterns with fixed dimension and variable thickness while some with fixed thickness and variable dimensions.

Here it showing the total deformation occur by putting dimension and thickness fixed and pressure varies.

*pressure is 120KPa and dimension is 1200*1200*15 \( \mu \text{m} \)

**2nd case**

Dimension varies from 700\( \mu \text{m} \) to 1200\( \mu \text{m} \) with fixed pressure 120KPa and thickness 15\( \mu \text{m} \).
Again, with the given data the equivalent stress is taken out with maximum and minimum stress [5].

For the 2\textsuperscript{nd} case maximum principle stress is taken out as shown in fig. 10
*pressure is 120KPa thickness is 15 μm and dimension is 1100*1100 μm [5]

3\textsuperscript{rd} case
Dimension (1200*1200)μm, pressure 120KPa and thickness varies 5 μm to 15μm [5].
According to the data, here its gives total deformation and the stress is taking place at the center and minimum stress can be seen at the corners.

Here the graph for total deformation showing the thickness varies from 5$\mu$m to 15$\mu$m.

*pressure 120KPa, dimension 1200$\times$1200 $\mu$m and thickness are 5 $\mu$m

3. Pattern of diaphragm

The design of these diaphragms is taken in 4 arrangements, considering different thickness, dimension and pressure to get higher sensitivity, quick response and accurate result [6, 7].
Fig. 20 Pattern of Diaphragm with different arrangement of piezoresistors

The change in piezoresistance can be calculated by using the formula:

\[
\frac{\Delta R}{R} = \frac{\pi \sigma_t + \pi \sigma_1}{R}
\]  

[1]

Where \( \sigma_t \) = \( \nu \sigma_1 \), \( \pi_t \) and \( \pi_1 \) are considered as transverse and longitudinal piezoresistive coefficients respectively.[9]

The value of \( \sigma_1 \) will be taken from graph. The value of \( \pi \) (piezoresistive coefficient) for p-type semiconductors of silicon material is higher compared to n-type semiconductors. So the value of \( \pi_1 \) and \( \pi_t \) will be taken \( 71.8 \times 10^{-11} \) Pa and \( -66.3 \times 10^{-11} \) Pa respectively.

The formation of piezoresistors are arranged in Wheatstone bridge structure as shown below:

Fig. 21 Piezoresistors arrangement in Wheatstone bridge

The orientation of the piezoresistors are taken in such a way so the output should be more precise. The values of each piezoresistors are taken 1kΩ and input voltage 10V. Now to find the sensitivity following formula is used:

\[
S = \frac{V_o}{V_{in}} \times \frac{1}{\Delta P}
\]  

[2]

Where \( \Delta P \) is change in pressure, \( V_o \) is voltage output and \( V_{in} \) is voltage input.[10] The result is shown in the table below by using the above expressions:

| \( \Delta P \) at 120kPa | Output Voltage \((V_o)\) | Sensitivity \((S)\) |
|-------------------------|-------------------------|---------------------|

6
|    | 1st case | 2nd case | 3rd case |
|----|----------|----------|----------|
| 1st case | 1.098 | .91 | .98 |
| 2nd case | 9.15 | 7.63 | 8.36 |

4. Conclusion
In a sensor the main deciding factors are the dimension and thickness of the sensing element to determine the sensitivity at the maximum pressure strength of 120 kPa. In the simulation software ANSYS deformation and stresses are calculated at the different measurements of the sensing element for the varying pressure strength on keeping the safety and factors in mind. From the analysis we can conclude that sensing element having side length of 1200μm and thickness of 15μm gives the good sensitivity i.e. 9.15 which can be used in different conditions. Other sensing element having small dimensions can be used for the better results in terms of sensitivity. The piezo resistors are placed in specific locations to enhance the sensitivity of the system.

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