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Design and Analysis of MEMS based Piezoresistive Pressure sensor for Sensitivity Enhancement [☆]

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Abstract

This paper reported novel high sensitivity and linear 0-1MPa piezoresistive pressure sensor for environmental applications. The proposed work as two different structures of membrane (square and rectangular) having the similar surface area and thickness has been studied. The design and analyzed pressure sensor parameters such as stress, deflection and sensitivity are obtained by using INTELLISUITE 8.8v. The simulated sensor showed a sensitivity of 6.8×10^{-12} for 7μm thickness, 18.5×10^{-12} for 5μm thickness and 84.2×10^{-12} for 3μm thickness of square membrane is prepared through the finite element tool. This deflection change provides the validate of the pressure in that atmosphere. Finally, we observed that the best deflection obtained from square membrane and maximum stress output reactions are obtained from the rectangular membrane with the pressure range from 0.1 MPa to 1MPa and also maximum deformation of 84 μm for 3 μm thickness, 18.55μm for 5μm thickness and 6.9μm for 7μm thickness. The effect of these studies can be used to improve the sensitivity of these devices.

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Keywords: MEMS, Membrane, Piezoresistive, Stress, Displacement and Sensitivity;

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1. Introduction

The MEMS (Micro-Electro-Mechanical-System) pressure sensors are designed with square and rectangular shaped diaphragms which can be used to check and compute pressure in various environments. MEMS sensor has an extensive range of differential, absolute pressure and gauge micro sensors base on various transduction principles have been built-up using MEMS tools. The key parameters of the piezoresistive pressure sensor are nonlinearity, sensitivity, hysteresis, repeatability and stability. [1] Jaspreet Singh et.al has reported as the locations of piezoresistors and diaphragm thickness corresponding modify due to under or over etching in bulk micro machined piezoresistive pressure sensor which holds controlling the device performance. [2] Vidhya Balaji et.al were designed and analyzed the different membranes such as rectangular, square and circular type, while evaluated these parameters are linearity considerations maximum operating pressure, stress distribution and burst pressure. [3] Suja K J et.al have been analyzed and designed a typical silicon square membrane pressure sensor to compute and studies the various performance parameters such as deflection, stress and voltage sensitivities. [4] Ashish et.al was designed pressure sensor to achieve good results for the diaphragm desires to be either large or thin, and measured to improve the sensitivity. [5] Tai-Ram et.al given in present life Si micro fabrication tools developed along with additional popular improvements in the ground of silicon based integrated-circuit (IC) technologies and solid state devices that have modernized. [7] Berns.A et.al discussed as sensing has been approved by circular diaphragm because of sensitivity related it can produce a 60 % improvement in sensitivity. [8] Rajavelu.M et.al has been realizing higher sensitivity from changes the placing of piezoresistors on the diaphragm. [9] Bhat K.N have been testing by locating two resistors at the centre of the membranes to agility the tensile stresses and more two resistors on the edges to perception the compressive stresses. [10] Suja K J were analysed the performance of micro pressure sensor depends on the size of the membrane and change the location of the resistors on the membrane. [11] A.Nallathambi et.al has been discussed MEMS pressure sensor by using square, rectangular and circular diaphragm which were designed and analyzed using Intellisuite. When the considerations such as deformation, Mises stress, and sensitivity. Then also related mutually analysis and simulation. [12] D.Sindhanaiselvi et.al has been designed MEMS pressure sensor which engage sculptured diaphragm for low pressure sensing and also have optimized by a geometric design. In this paper, deals with the design and analysis of square and rectangular membrane for low pressure range from 0-1MPa for environmental applications. We investigated by varying the thickness of diaphragm like 3μm, 5μmand 7μm and sensitivity analyzed to help with Intellisuite software. The present work proposed simple and useful expressions for designers and researchers to analyze and calculate the piezoresistive micro sensors by using FEM modeling.

2. Mathematical Modeling

The one of the first expressions of micromachining technology was introduced as MEMS pressure sensor. This is commercially incredibly victorious because of more than a few important traits, equality and including elevated sensitivity. The process of surface micromachining technology is more compatible with integrated circuits. The MEMS pressure sensors containing a four piezoresistors are locating Wheatstone bridge type method. Hence, the edges of diaphragm were supported with the <110> silicon crystallographic direction. With large piezoresistive coefficients, the <110> –oriented P-type diffused resistors on the N-type growing layer are used in micro pressure sensors. Consecutively to have a huge bridge output with applied pressure, the resistors must be placed so that the sum of the parallel and vertical stresses is maximized for two resistors and minimized for the other two resistors.

2.1. Square Diaphragm

The maximum stress considered by centre of all edge, and the bending of square plates with the whole edges are set [5],

$$\sigma_{\max} = \frac{0.308\, pa^2}{h^2} \tag{1}$$

Maximum deflection as calculated by,

$$W_{\max} = -\frac{0.0138\ pa^4}{Eh^3} \tag{2}$$

The stress at the midpoint of the plate can be derived to be,

$$\sigma = \frac{6p(m+1)a^2}{47mh^2} \tag{3}$$

And strain at the centre is,

$$\varepsilon = \frac{3W}{4\pi h^2} \tag{4}$$

2.2. Rectangular Diaphragm

An altered explanation for the highest deflection and stress for rectangular membrane with each edge fixed is as follow [5]:

$$W_{\max} = -\alpha \frac{pb^4}{Eh^2} \tag{5}$$

$$\sigma_{yy} = \beta \frac{p.b^2}{h^2} \tag{6}$$

Table 1. The Coefficients of deflection and maximum stress values are presented for rectangular membrane

a/b	1	1.2	1.4	1.6	1.8	2	∞
α	0.013	0.0188	0.0226	0.0251	0.0267	0.0277	0.0284
β	0.3078	0.3834	0.4356	0.4680	0.4872	0.4974	0.5000

3. Design Parameters

The proposed sensor was designed using the on top of analytical models for square diaphragm of length and width of 400µm and various thickness of 3µm,5µm and 7µm measured because of fabrication limitations. Similarly, the rectangular diaphragm length as 314µm, width as 400µm and thickness is 3µm, 5µm and 7µm. The micro piezoresistive pressure sensor is designed for a pressure range from 0.1MPa to 1MPa typical of the atmospheric pressure range for environmental application and consequently the sensor design parameters are specified in Table 1. Here, the FEM (Finite Element Method) model of both square and rectangular diaphragm are shown in Fig.1 (a) and 1 (b). Then the schematic diagram of the cross sectional view of piezoresistive pressure sensor is shown in Fig.2.

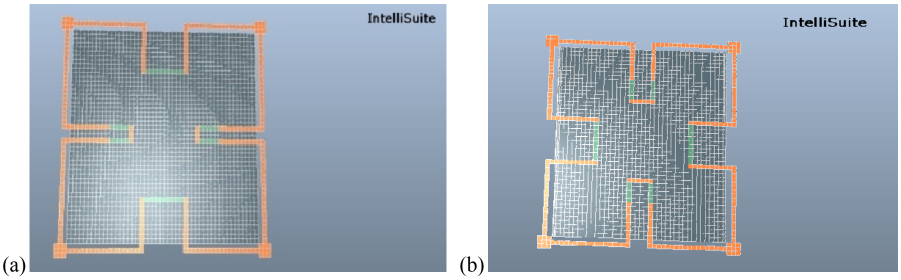


Fig.1. (a) FEM model of Square diaphragm; (b) FEM model of Rectangular diaphragm.

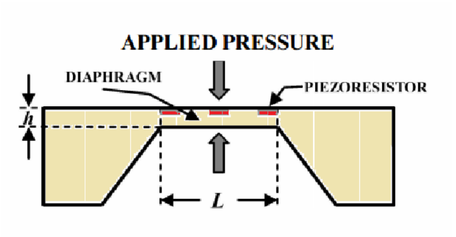


Fig.2.Cross sectional schematic of the piezoresistive pressure.

4. Finite Element Analysis Modeling

The FEA (Finite Element Analysis) analysis modeling tool can be used to simulate MEMS device. The proposed membrane based piezoresistive micro pressure sensor was simulated by using Intellisuite software .The micro pressure sensor square membrane of side length 400 µm and various thicknesses of 3µm, 5µm and 7µm, rectangular membrane of dimensions 400 µm x 312 µm and thickness same has made such that they have the similar surface area and thickness. Hence, the properties of material such as silicon and polysilicon are given in table 2. The substrate material as can be used silicon and piezoresistive material can be used polysilicon. The highest deformation and stress induced in the membrane with various thicknesses are determined and evaluated with the analytic explanation for a pressure range of 0.1 Mpa – 1Mpa.

Table 2. Dimensions and Properties of Materials

Materials				
Layer	Material	Young Modulus (Gpa)	Poisson Ratio	Density (gm/cc)
Substrate &Diaphragm	Silicon	170	0.26	2.32
Piezoresistors	Polysilicon	160	0.226	2.3
Piezoresistive Coefficients		P_11:6.6e-5 P_12:-1.1e-5 P_44:138.1e-5		
Dimensions				
Diaphragm	Material	Length	Width	Height
Square	Silicon	400	400	3,5,and 7
Rectangular	Silicon	314	400	3,5,and 7

The simulation results are found from the FEA tool which is shown in Fig.3 (a) and (b). Since the analysis completed it can be observed that the highest stress stimulated at the edge of the membrane and the highest deformation bent at the centre of the membrane are in concurrence with an investigative expressions specified by equations (1-6). From Fig.3 (a) and (b) shows the simulated deformation outputs of both square and rectangular diaphragm.

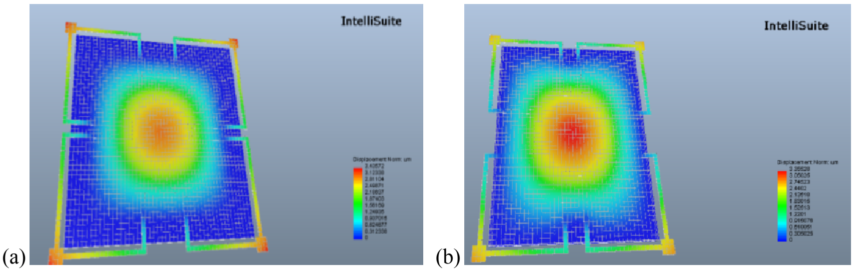


Fig.3 (a) Membrane deformation on the Z axis of the Square diaphragm with pressure of 0.5 Mpa. (h=7µm); (b)Membrane deformation on the Z axis of the Rectangular diaphragm with pressure of 0.5 Mpa (h=7µm)

From Fig.4 (a) and (b) which can be observed that the induced stress is symmetrical in case of square membrane where as it is not symmetrical in the case of rectangular membrane. Here the table 3, 4 and 5 are shown deflection, maximum stress and sensitivity of both square and rectangular diaphragm when the thickness of diaphragm is considered as 3µm, 5µm, and 7µm.

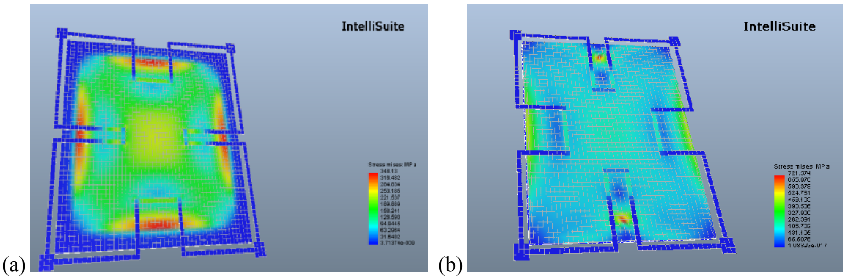


Fig.4.(a) Mises Stress on the Z axis of the Square diaphragm with pressure of 0.5 Mpa; (b)Mises Stress on the Z axis of the Rectangular diaphragm with pressure of 0.5 Mpa.

Table 3. Displacement analysis with pressure at 0.5MPa

Diaphragm	h=7µm	h=5µm	h=3µm
Square	3.44	9.22	41.96
Rectangular	3.35	9.09	41.44

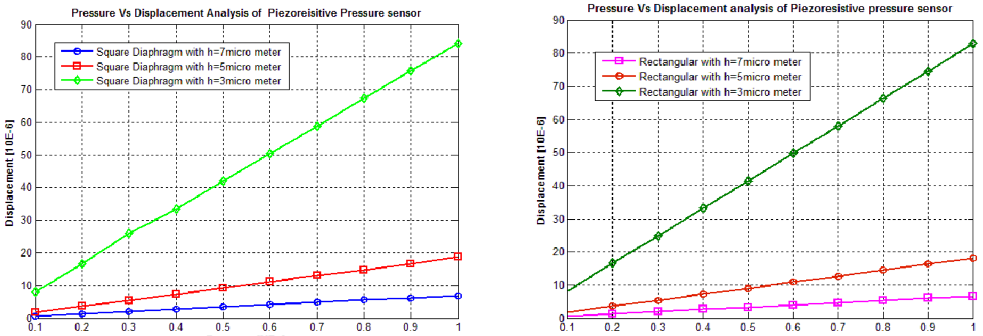
Table 4. Mises Stress analysis with pressure at 0.5MPa

Diaphragm	h=7µm	h=5µm	h=3µm
Square	348.1	686.6	1536.13
Rectangular	721.6	1507.94	3794.75

Table 5. Sensitivity analysis with pressure at 0.5MPa

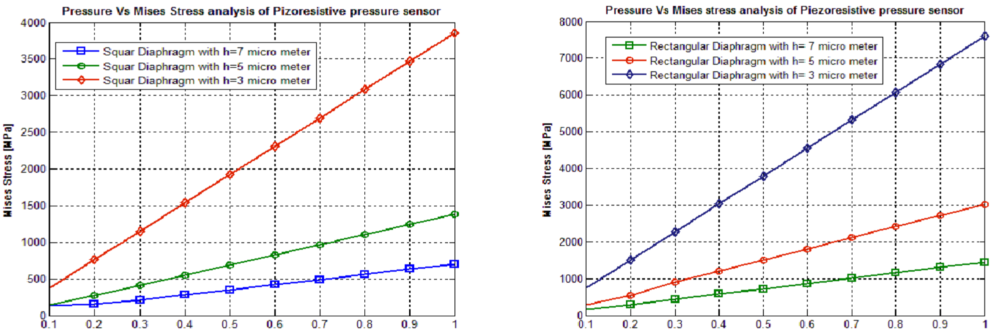
Diaphragm	h=7µm	h=5µm	h=3µm
Square	6.9 e-12	18.4 e-12	83.9 e-12
Rectangular	6.7 e-12	18.2 e-12	82.9 e-12

Fig.5 illustrates the relationship of deformation of the three different thicknesses of the square and rectangular shaped diaphragms. Along with these square membrane is show the highest deformation when compared with rectangular membrane.



(a) (b)

Fig.5. (a) Square diaphragm; (b) Rectangular diaphragm for simulation results of maximum deflection with a pressure range between 0.1-1MPa.



(a) (b)

Fig.6. (a) Square diaphragm; (b) Rectangular diaphragm for simulation results of maximum stress with a pressure range between 0.1-1MPa.

Fig.6 illustrates the evaluation of induced stress in various membrane thicknesses which can be observed that the induced stress in a square membrane is larger than rectangular membrane. The Fig.7 illustrates the sensitivity of both square and rectangular membranes when applying pressure value between 0.1– 1MPa and also the thickness of the diaphragm are varied such as 3 µm,5 µm,and 7µm. Finally we observed that the results of maximum sensitivity produced by square diaphragm. Hence, the table 6 as shows the various stress are occurred in different modes like S_{xx} ,S_{yy} and S_{xy}. The corresponding table 7 as shows the validate the output parameters are stress, deflection and sensitivity of both square and rectangular diaphragm.

Table 6. Observed various stress modes of S_{xx}, S_{yy} and S_{xy} when the diaphragm thickness as 7µm.

Stress	S_{xx}	S_{yy}	S_{xy}
Square	691.3	698.5	179.5
Rectangular	526.5	766.4	117.5

Table 7. Comparison of the parameters in different shapes of layout

Diaphragm	Sensitivity	Deflection	Stress
Square	Maximum	Maximum	Minimum
Rectangular	Minimum	Minimum	Maximum

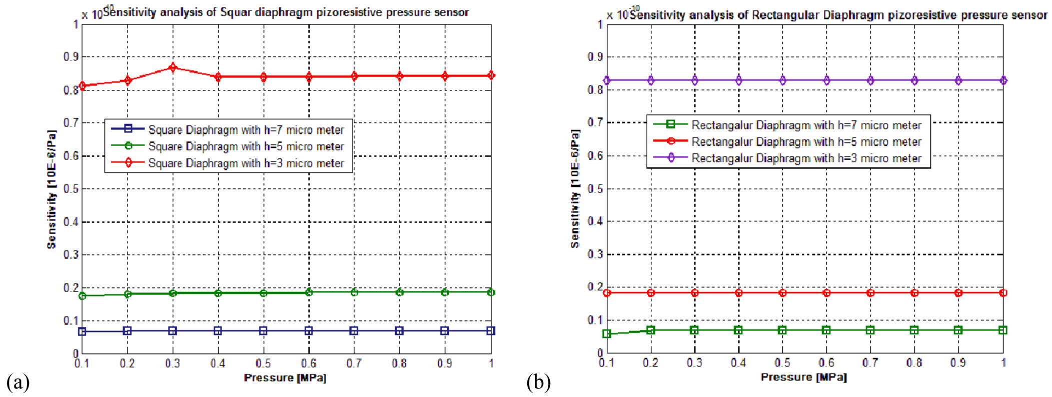


Fig.7. (a) Square diaphragm; (b) Rectangular diaphragm for sensitivity analysis of piezoresistive micro pressure sensor with a pressure range between 0.1-1MPa.

5. Conclusion

We investigated both square and rectangular diaphragm based pressure sensor for environmental applications which are designed and simulated output parameters such as stress, deflection and sensitivity by using Intellisuite software. The piezoresistive pressure sensor which simulated results of maximum deflection obtained from the square diaphragm and maximum stress are getting from rectangular diaphragm. Finally, we observed that the square diaphragm can be used to get maximum pressure compared with rectangular diaphragm. Simulated results of maximum displacement for square diaphragm is 6.9×10^{-6}, 18.5×10^{-6} and 84.5×10^{-6} similarly, the thickness of the diaphragm is 7μm, 5μm and 3μm.

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