Category: MEMS and Sensors

Design of Piezoresistive MEMS Absolute Pressure Sensor

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***Abstract*—Piezoresistivity involves change of electrical resistance due to an applied stress or strain. Piezoresistive pressure sensors involve using this property of Piezoresistivity to measure the applied pressure. In the present work, the design and optimization of 30 Bar range pressure sensor is carried out using CoventorWare CAD tool. Also the accuracy of Numerical (FEM) solution over the conventional analytical approach for such high pressure ranges is shown.**

***Index Terms*— Piezoresistivity, CoventorWare and Pressure Sensor**

I. INTRODUCTION

Pressure Sensors are one of the most widely used microsensors. The property of Piezoresistivity in Silicon causes deformation of energy bands on application of stress leading to change in resistance. Usually a Silicon diaphragm with four Piezoresistors connected in a Wheatstone bridge fashion is used to measure the change in resistance. Fig.1 shows this arrangement on the diaphragm. When a pressure is applied on the diaphragm, the resistance of top and bottom piezoresistor decreases and the resistance of other two piezoresistors increase. The diaphragm is fabricated by etching bulk silicon using DRIE till the required diaphragm thickness is achieved. The cavity is vacuum sealed using anodic bonding.

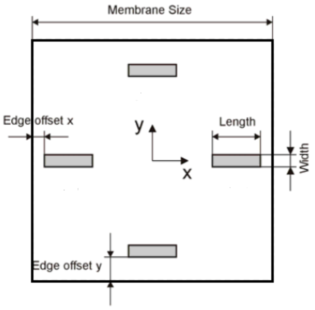

Fig.1. Piezoresistor arrangement on the diaphragm

II. DESIGN THEORY

The relative change in resistance for a piezoresistor is given by the equation below. This equation consists of the transverse and longitudinal piezoresistive coefficients (π) and stresses (σ) [1]. The stresses must be averaged over the area of piezoresistors in order to obtain accurate results.

$$\boxed{\frac{\Delta R}{R} = \pi_l \sigma_{x\ avg} + \pi_t \sigma_{y\ avg}}$$

$$\sigma_{y\ ave} = \frac{1}{A}\int_y \int_x \sigma_y \, dx\, dy \qquad \sigma_{x\ ave} = \frac{1}{A}\int_y \int_x \sigma_x \, dx\, dy$$

The important design parameters for a pressure sensor are sensitivity (mV/V/Bar) and Nonlinearity error (% full scale output - FSO). The sensitivity is found using the slope of the Voltage output Vs Applied pressure curve. Because of the stretching effect in a diaphragm there is nonlinearity in this curve. The design goal is to maximize Sensitivity and minimize Nonlinearity error. The thicker the diaphragm lesser is the sensitivity and nonlinearity error, and vice versa.

Often the modeling of a pressure sensor is carried out with an assumption that the diaphragm acts like a rigidly clamped plate [2]. But it is found that the results so obtained are inaccurate compared to those obtained by FEM simulations performed with appropriate modeling and clamping. The difference in clamping in the two cases is shown in Fig.2.

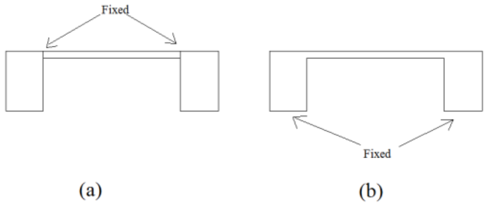

Fig.2. (a) Clamping in a plate (b) Clamping in an actual pressure sensor

III. RESULTS AND DISCUSSIONS

The maximum stresses in a diaphragm are found close to the edges. In the actual modeling of a pressure sensor the stress at the edges of the diaphragm spread slightly outside the diaphragm [3] and also the value of the stress experienced is lesser then the case when the diaphragm is modeled as a rigidly clamped plate. This is because of the fact that in an actual model of pressure sensor the diaphragm is not rigidly clamped as is assumed in the modeling using a rigidly clamped plate. Fig.3 shows the comparison between the x-direction stresses in two cases for a diaphragm thickness of 60 um and a pressure of 30 Bars.

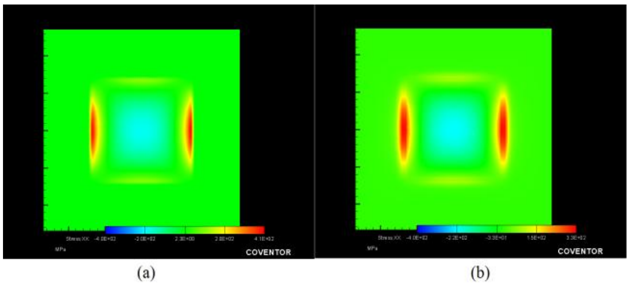

Fig.3. (a) Diaphragm with clamped edged (b) Real diaphragm in a pressure sensor

A MATLAB Program was made and the output (sensitivity and nonlinearity error) for different approximate solution [4,5] of the plate equations were analyzed. A significant difference in the result was obtained, confirming the inaccuracy in the method which models the pressure diaphragm as a plate.

Design optimization of pressure sensor is done by varying the diaphragm thickness, shape of piezoresistors and the position of piezoresistors. Meander shaped piezoresistors as shown in Fig.4 are found to be quite effective for increasing the sensitivity and decreasing the nonlinearity error [3,5]. A diaphragm thickness of 60 um is found to be appropriate for the present design. The size of the diaphragm is chosen to be 1400 um.

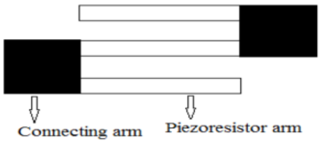

Fig.4. A typical Meander shaped piezoresistor

Simulations were carried out for different patterns by varying the number of arms in all the piezoresistors. The shape of the piezoresistors as shown in Fig.5 is found to be most suitable from output and fabrication considerations. The connecting arms are highly doped and act like conductors. The length of the piezoresistors is divided between the arms so that all the four piezoresistors have same resistance (without stress).

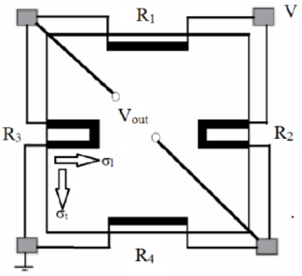

Fig.5. Shape of Piezoresistors used for optimal output

The optimized position for the piezoresistors is found out iteratively [6]. In this position the Nonlinearity error is minimized. Both the longitudinal and transverse piezoresistors are symmetrically placed. An input of 5V is used and the output of Wheatstone bridge is obtained. Similar procedure is followed for a circular diaphragm also. The results are shown in Table.1.

Table.1. Optimized parameters for a square and Circular diaphragm pressure sensor with diaphragm thickness of 60 um

Diaphragm shape	Edge offset x (um)	Edge offset y (um)	Non-linearity error (%)	FSO (V) (at 30 Bar)	Sensitivity (mV/V/Bar)
Square (Edge-1400 um)	-7	53	0.02	0.7767	5.18
Circular (Diameter-1400 um)	0	-11	0.011	0.5545	3.69

The plot for sensitivity (Output voltage vs. applied pressure) and nonlinear output for the square diaphragm case is shown in Fig.6 and Fig.7 respectively.

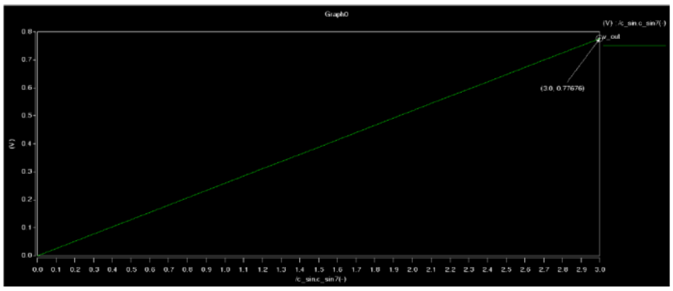

Fig.6. Sensitivity plot for the square diaphragm pressure sensor

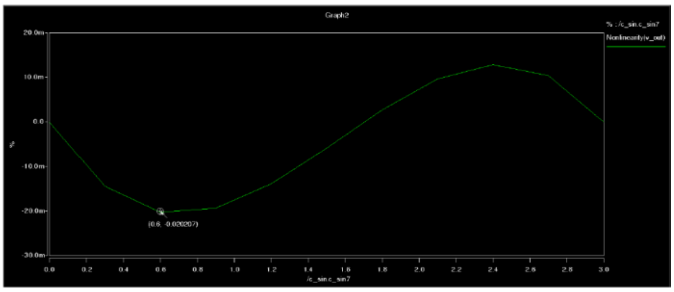

Fig.7. Nonlinearity error plot for the square diaphragm pressure sensor

IV. CONCLUSIONS

A pressure sensor of 30 Bar is designed both for the square and the circular diaphragm. Excellent sensitivity and nonlinearity is obtained after optimization of the parameters. Also it is shown that the analytical equations for a plate cannot accurately model the stresses on pressure sensor diaphragm. An SOI approach can also be used in order to eliminate the problem of leakage current at high temperature.

V. REFERENCES

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