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Influence of Slotting and Boss Radius on the Response of MEMS Based Intracranial Pressure Sensor

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Abstract

In the present paper, we design a Microelectro-Mechanical System (MEMS) piezoresistive pressure sensor for intracranial pressure monitoring. The pressure sensor design presented in this paper consists of a square diaphragm. The slots were introduced to square diaphragm increases the stresses developed thus enhancing the sensitivity of the sensor In addition to slots, a central boss was introduced to enhance the sensitivity of the sensor. We carried out numerical simulation to evaluate the sensitivity of the sensor. Parametric studies were done to optimize the central boss radius to enhance the sensitivity of the sensor

Key words: Pressure sensor, MEMS, Piezoresistance, Sensitivity.

1. Introduction

Intracranial pressure sensing plays an important role in case of diagnosis with head injury and neurosurgical disorders [1]. Intracranial pressure is a gauge cerebral pressure. Traditional present day methods of measuring intra-cranial pressure are invasive in nature, for example-Epidural catheters, sub-cronoid bolts and fibre optic catheters [1]. MEMS Based Pressure sensor [2] implementation only requires a lumber needle [1], which can be inserted via acupuncture and is much less invasive. This removes a lot of discomfort from the patient and is thus very much desired. The MEMS pressure sensor is inserted between the skull and dural tissue (the outermost layer of the meninges surrounding the brain and spine. The sensor is placed through an acupuncture hole drilled in the skull. This procedure is less invasive than other methods [1].

MEMS pressure sensors consist of mechanical element

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diaphragm and the pressure load on the diaphragm gets translated to the electrical output either through capacitive or piezoresistive readout [1-3]. However in capacitive pressure sensors, non-linearity and the parasitic capacitances give erroneous results [2]. On the other hand, piezo-resistive pressure sensors are linear and give quality output [3], thus are the favoured choice. This will also be used for the device design in this study.

In the case of piezoresistive system, stresses in the diaphragm gets modulated to electrical output [3], thus it is necessary to optimize the mechanical design of the diaphragm to increase the sensitivity of the sensor. In the present study we consider a square diaphragm [2-4], as it is easily amenable to fabrication unlike circular diaphragm [2], and is the most ideal shape for pressure sensing device design, as it produces the highest stress for a given applied pressure.

We consider the basic square diaphragm model given in the referred papers [1] as a benchmark problem, and subsequently build and optimise the model to get the best stress possible using certain design changes.

2. Experimental

2.1. Numerical Studies

The basic design consist of A 50 μm × 50 μm diaphragm, eight slots of 6.94 μm × 3.33 μm were chosen to be added on the earlier design. The structure is assumed to have uniform thickness (2 μm) [1]. The structure is meshed with eight noded brick element. A normal cerebral pressure of 1333 Pa [1, 4-6] was applied on the diaphragm, and stress analysis was carried out to evaluate the stresses in the structure.

To study the influence of center boss on the stresses induced, we introduce a central boss to the previous design and we carryout stress analysis to evaluate the stresses induced in the structure. Parametric studies were carryout to optimize the radius of the central boss.

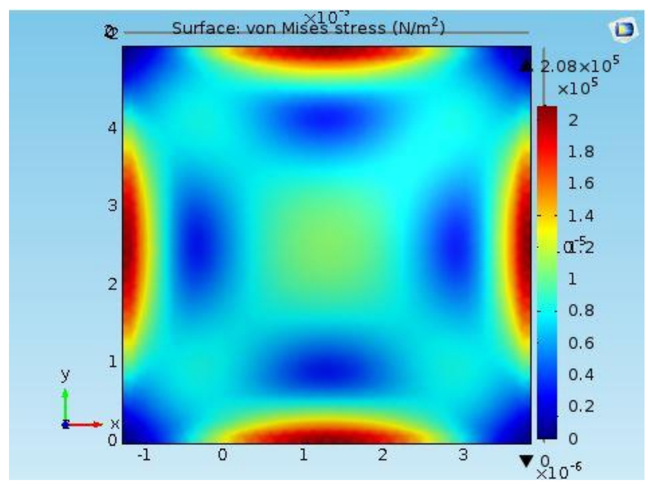
Coupled field simulations were carried out to evaluate the overall sensitivity of the device.

3. Results and Discussions

3.1. Stress Analysis

3.1.1. Square Diaphragm

The basic square diaphragm for intracranial pressure sensing is a 50 × 50 × 2 micrometre frame made of n type single crystal silicon. Cerebaral pressure of 1333 Pa was applied on the structure. Figure 1 shows the stress developed for the application of normal cerebral pressure. It can be noticed that maximum stress in the diaphragm is 208 kPa. This is the exact value as obtained by S H Abdul *et al*. [1].



Fugure 1. Stress distribution in square diaphragm.

3.1.2. Slotted Model

To further increase in the stress generated for the applied cerebral pressure, slots are cut out at the edges of the diaphragm. Figure 2 shows the stress developed for the application of normal cerebral pressure. A substantial increase in the stress generated (322 kPa), which is a considerable improvement from the previous design. This is for two slots per side. A comparison will be done to determine the ideal number of slots per side.

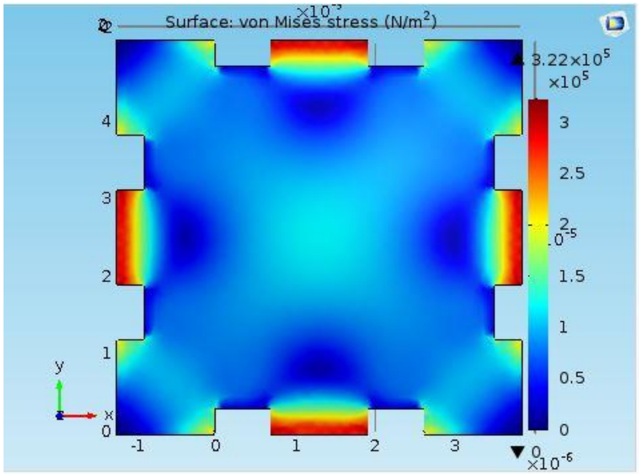


Figure 2. Stress distribution in slotted design.

3.1.3. Central Boss Design

As a final improvement, the stress can further be enhanced by implementing a groove at the centre, also known as a central boss. Stress analysis was carried out; Figure 3 shows the stress developed for the application of normal cerebral pressure. This increases the sensitivity of the device since the stress generated is more. The new value of stress is 324 kPa. The radius of the central boss is taken to be 5 micrometre . This is observed to be the most ideal value, as all other radius values give a lower reading of stress.

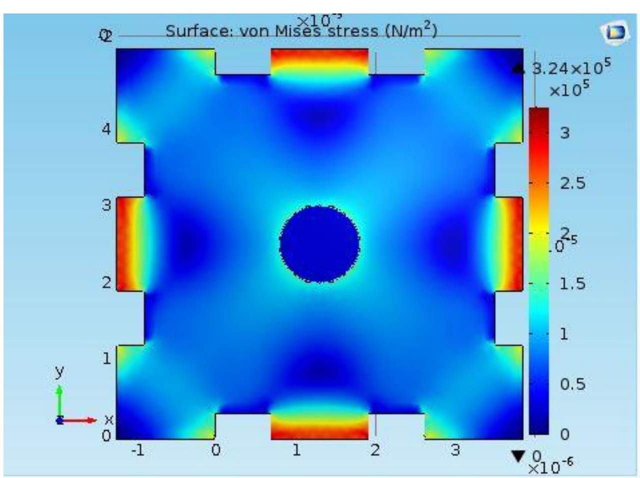


Figure 3. Stress plot for Central boss design with slots.

3.2. Optimization

3.2.1. Slot Optimization

A comparison was done to figure out the ideal number of slots. Since it is impractical from the fabrication point of view to create more than 4 slots per side, a comparison was done between 2 and 4 slots per side. The results are as follows.

Table 1. Maximum stresses in the structure with and without central boss.

Parameter	Two Slot (kPa)	Four Slot (kPa)
Without Central Boss	322	318
With Central Boss	324	298

As it is obvious from the Table 1, the two slot per side design is much more effective as compared to the four slot per side design, for both stress components.As the number of slots increases we tend to move towards the original design. The stress plots of sensor with and without centre boss are shown in Figure 4.

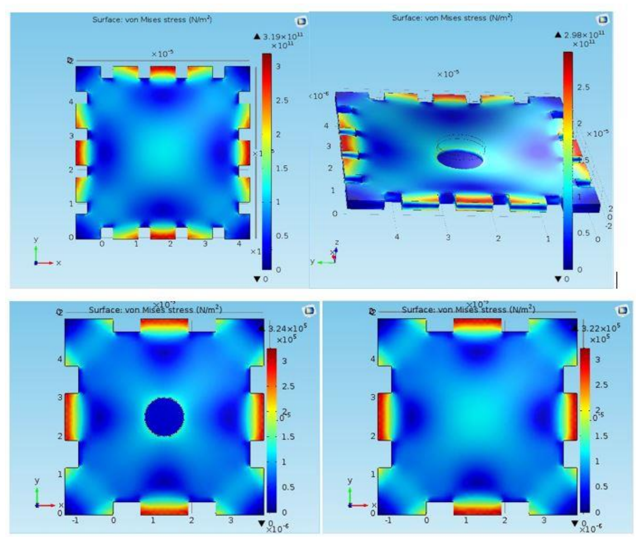


Figure 4. Comparison between two slot and four slot design

3.2.2. Centre Boss Radius Optimization

We carryout parametric studies by changing the radius of the central boss, maximum stresses developed in the structure was extracted as a function of boss radius, Figure 5 shows the graph of stress as a function of radius It was noticed that central boss radius of 5 µm provides the maximum, stresses in the structure. Hence from this analysis we have arrived at the optimal boss radius, the same dimensions will be used for further analysis.

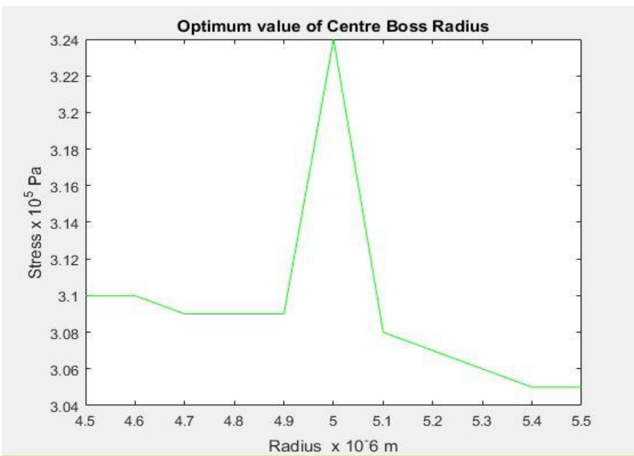


Figure 5. Stress induced in diaphragm as a function of boss radius

3.3. Coupled field simulations

After diaphragm optimization was completed, the device, to be made operational, a piezoresistive layer was added to measure the stress changes on the surface of the diaphragm. The piezoresistive layer was made of p type single crystal silicon, and to measure the change, a potential of 2 V was applied to one side while a ground node was created on the other side. The piezoresistive block was placed on the slot edges, where the maximum stress was generated (Figure 6).

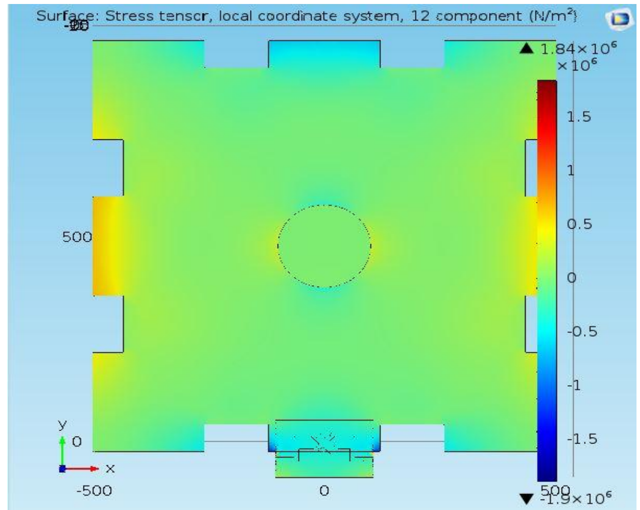


Figure 6. Stresses induced with piezoresistor and optimised diaphragm structure.

To simulate the complete device, a membrane was taken with two slots and a central boss of 5 µm radius, and a cerebral pressure of 1333 Pa was applied on it. Figure 6 and 7 shows the induced stresses and displacements of the structure.

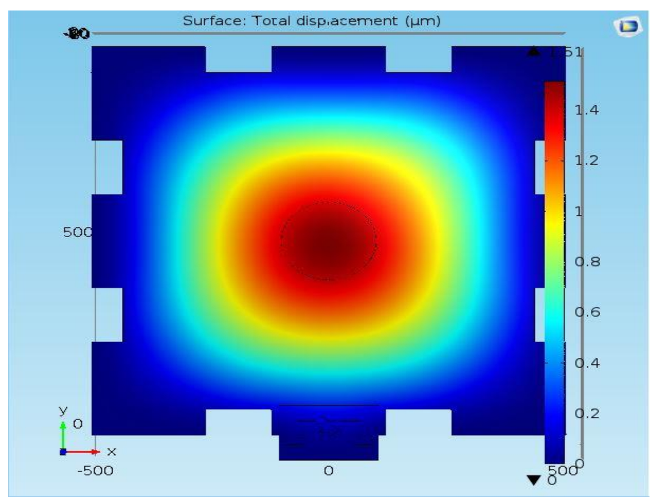


Figure 7. Displacement Plot for boundary load of 1333 Pa.

The stresses obtained from the structural analysis were transferred on to the piezoresistive layer to obtain the current output from the piezoresistive layer. Figure 8 shows the plot of current output from a piezoresistive layer. From the current we evaluate the relative change in resistance. As the resistors are connected in Wheatstone bridge configuration provides an equivalent voltage output, corresponding to the applied pressure. For the present design the sensitivity of the device was estimated as 0.5069 mv/Pa.

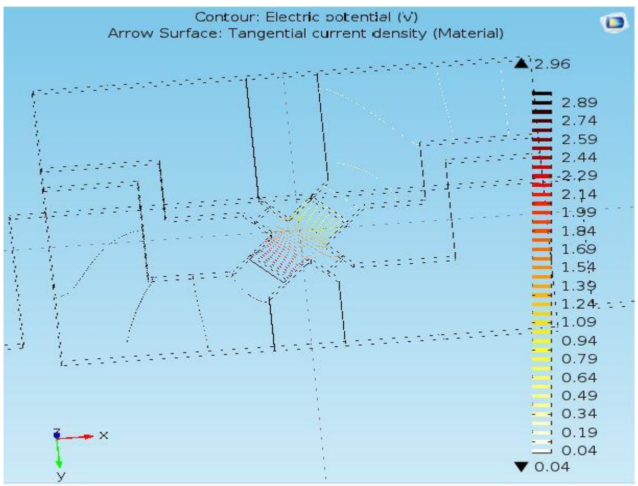


Figure 8. Current density distribution in a piezoresistor.

4. Conclusion

The Numerical Simulation model is presented using the Finite Element Method software. The model is able to predict the stresses and the corresponding voltage output from a micromachined pressure sensor. In this study, we focus on optimizing the dimensions of the structure and study the influence of center boss on the overall sensitivity of the device. It was noticed that addition of two slots per side, and a central boss implementation of radius 1/10th of outer side length produces additional improvements in stress generation. This improves accuracy of the design and is better than the pre- existing devices implemented.

5. Conflicts of Interests

The author(s) report(s) no conflict(s) of interest(s). The author along are responsible for content and writing of the paper.

6. Acknowledgments

NA

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