Design and Analysis of Perforated Diaphragm Employed Piezoresistive Pressure Sensor

G.Kalaiarassan
Mechatronics Engineering Division,
Vellore Institute of Technology,
Vellore- 632014,Tamil Nadu,India

A.Tony Thomas, Varun.S, A.Muthukrishnan
Department of Mechatronics Engineering, Kongu engineering College,Erode- 638052,Tamil Nadu,India

***Abstract*—The details of a study on perforated and non-perforated diaphragms for pressure sensing in piezoresistive Micro Electro Mechanical System (MEMS) pressure sensors are presented in this paper. Perforated diaphragms of different thickness have been considered to study and evaluate the performance of perforated diaphragms for pressure measurement in terms of load-deflection sensitivity. The IntelliSuite MEMS design tool has been used to create and analyze the pressure sensors with non-perforated and perforated silicon diaphragms. The results show that it is possible to achieve 55% improvement in deflection sensitivity with a 40% perforated area irrespective of the thickness of the diaphragm. This leads to the conclusion that the perforations realized on thicker diaphragms are suitable alternatives with a more satisfactory performance than very thin non-perforated diaphragms.**

Keywords-diaphragms,perforated,piezoresistive;MEMS, sensitivity

I.INTRODUCTION

In current scenario, miniature level manufacturing is more essential for every used product. Because, we have to give the better accuracy and reliability at low cost. Basically a MEMS pressure sensor is composed of a diaphragm structure that converts the pressure into a linear deflection and certain sensing elements corresponding to their sensing principles, e.g., capacitive, piezoelectric or piezoresistive effects. However, most of them use silicon for diaphragm and piezoresistive property of silicon or polycrystalline silicon as sensing mechanism. In such sensors, the deflection sensitivity of the diaphragm in μm/bar is crucial and it should be higher for better performance. However, larger deflection sensitivity is possible only with thin diaphragms and employing very thin films results in more non-linearity. In addition to this, realization and processing of thin film is very difficult in practical situations. Hence it becomes essential to find suitable techniques to achieve larger deflection sensitivity with thicker diaphragms but modified to achieve larger sensitivity with reasonable linearity

II. LITERATURE REVIEW

Orthner et al (2010)a proposed sensor design to measure the hydrogel swelling pressure and they have fabricated and tested perforated diaphragm employed piezoresistive pressure sensor arrays that couples the pressure sensing diaphragm with a perforated semi-permeable membrane. An optimized geometry of micro pores was etched in silicon diaphragm to allow analytic diffusion into the sensor cavity where the hydrogel material is located. The 14-step front side wafer process was carried out and diaphragm pores were created using combination of potassium hydroxide (KOH) etching and deep reactive ion etching (DRIE). Sensor characterization was performed using a simulations showed that the sensitivity was slightly improved for the perforated diaphragm designs while empirical electrical characterization showed that the perforated diaphragm sensors were slightly less sensitive than solid diaphragm sensors. All perforated diaphragms are mechanically robust and able to withstand pressure greater than 200 kPa.

Orthner et al (2010)b developed two types of sensor arrays used for the detection of hydrogels swelling pressure, one version with perforation, acting as analyte diffusion pores etched directly into the piezoresistive diaphragm, the other with pores etched into the backing plate while using a solid diaphragm. Hydrogels which swell in response to changes in ionic strength of physiological buffer solutions (PBS) solution were integrated into the sensor chips and used in the characterization of the sensors. The sensors were placed into solutions of ionic strengths ranging from 0.025 to 0.15 M. Sensors with pores directly etched into the diaphragm exhibit higher sensitivity.

Fraga et al (2010) explains about the fabrication and characterization of a SiC/SiO2/Si piezoresistive pressure sensor. The sensor structure consists of six thin-film piezoresistors configured in Wheatstone bridge on a thermally oxidized micro machined silicon diaphragm. In order to fabricate this sensor, three lithographic masks were designed. One to define the square diaphragm (1800 µm × 1800 µm), another for the piezoresistors and the third for the Ti/Au metal lines. The diaphragm was formed by anisotropic etching of Si in KOH solution. The sensor chip size is 4.5 mm × 4.5 mm. It was bonded on an alumina substrate using silicon and an aluminum cup was used for protection. The output voltage of the sensor was measured for applied pressure range from 0 to 12 psi and voltage supply of 12V.

Li et al (2012) developed a single crystal silicon pressure sensor based on oxide isolation. The silicon-oxide layer was manufactured using the ion implantation of oxygen technique. For piezoresistive detection, the top silicon layer (0.23 µm thick) is used as the active material. At the high temperatures, Si <110> crystal direction has a larger longitudinal and transverse piezoresistive coefficient, making it suitable for high temperature piezoresistive pressure sensor production. The pressure gauge chips are manufactured using MEMS techniques. The fabricated pressure sensors exhibit better performances at high temperatures. The research shows that this piezoresistive pressure sensor could work reliably at a temperature up to 300 .

Wang et al (2006) proposed the design guidelines for micro diaphragm-type pressure sensors that have been established by characterization of the relationships among diaphragm thickness, side length, sensitivity, and resonant frequency. According to the study, the thickness need to be thin and the side length need to be small in order to get the sensitive diaphragm with high resonant frequency. A Fabry–Perot based pressure sensor has been designed based on the guidelines, fabricated and characterized. In principle, the sensor is made according to Fabry–Perot interference, which is placed on a micro-machined rectangular silicon membrane as a pressure-sensitive element. A fiber-optic readout scheme has been used to monitor sensor membrane deflection. The experimental results show that the sensor has a very high sensitivity of 28.6 mV/Pa, resolution of 2.8 Pa, and up to 91 kHz dynamic response.

Madhavi et al (2013) studied the effect of diaphragm geometry and piezoresistor dimensions on the sensitivity of a piezoresistive micro pressure sensor and analyzed the same using finite element tools ANSYS and IntelliSuite. The investigation clearly indicates the outcome of using different geometries for the diaphragm and enables the estimation of piezoresistor dimensions. From their analysis they arrived at the following conclusions. The square diaphragm has a greater deflection and lightly higher induced stress for a given pressure compared to a rectangular one and hence it is more sensitive and has a higher gauge factor. The induced stress remains more uniform at the center of a rectangular diaphragm than a square one hence making the placement of the piezoresistors in that area less error prone during fabrication. The variation in the length of the piezoresistor plays a greater role in determining the sensitivity of the sensor than width and thickness variations.

Rajavelu et al (2012) investigated the measurement of oxygen flow by the differential pressure method in a pediatric ventilator system , Investigations on thin film silicon diaphragms with embedded piezoresistors for sensing upstream and downstream pressures show that it is essential to employ thin diaphragms for pressure sensing in this application to achieve higher sensitivity with reasonably good linearity. Methodology.The sensitivity enhancement using perforations has been focused in this work and in order to achieve this goal, three groups of sensors namely T3, T7 and T9 have been considered with circular shaped diaphragm (7µm).The effect of perforated diaphragms has been extensively investigated in this study by formulating five different levels of perforations in each group in such a way that the perforated area is 0%, 10%, 20%, 30% and 40% of the total diaphragm area. The number of perforations varies with the percentage perforation area since the diaphragm size (π × 25µm × 25µm) and kept uniform for all the cases. The number of perforations for different devices is calculated using the following equation (1).

$$N = \frac{PA}{100 \times PS} DS \qquad (1)$$

Where PA is the percentage perforated area,

DS - the diaphragm size & PS - perforation size.

III.DESIGN SOFTWARE

A.IntelliSuite Software Version 8.6

IntelliSuite is the dedicated software for Design and Analysis of MEMS. It is specially designed solver from the ground up for unparalleled performance, and at the same time integrated electro kinetics and electrochemical reactions and heat transfer in fluids, capabilities not found in other tools.Similarly, it was built an Electromagnetic module specifically for MEMS applications.

B . Modules of IntelliSuite software

- IntelliSuite consists of the following modules
- IntelliFab-fabrication simulation
- MEMaterial-thin film material property database
- AnisE-anisotropic etch simulator
- IntelliMask-layout editor
- 3DBuilder-manual model geometry creation ThermoElectroMechanical analysis-device simulation.”

IntelliFab is the fabrication simulation module of IntelliSuite. It is used to automatically generate visualizations and analysis files based on a fabrication process and mask layout. IntelliFab contains an extensive database of micro processing steps, including deposition (metals, compounds, and polymers), etching, mask definition, and bonding.

MEMaterial is the thin-film material database within IntelliSuite. It predicts Thin-film material properties based on fabrication process parameters (Machine settings). MEMaterial contains a wide variety of materials common in MEMS processing, including metals, compounds, and polymers. Every process included in the IntelliFab process database has an associated MEMaterial entry to define material properties.

AnisE is the Anisotropic Etching simulator in IntelliSuite. It is used to predict the 3 -dimensional geometry resulting from anisotropic etching of a silicon wafer. AnisE currently includes etch rate databases for etching

IntelliMask is the layout editor tool in IntelliSuite software. It can be used to create or edit mask files. IntelliMask fi extension. Multi-layer masks can be created and edited with IntelliMask. It can use a cellular hierarchy to define the layout of a single die or an entire wafer.

3DBuilder is the manual model creation module of IntelliSuite. It is used to create models for the Thermo Electro Mechanical Analysis module without including processing information. It allows the user to have maximum control over the creation and refinement of the mesh that will be used to simulate the device performance.

The Thermo Electro Mechanical Analysis module is used for performance simulations on MEMS devices. It can incorporate mechanical, thermal, and electrostatic effects. The current version of the Thermo Electro Mechanical Analysis module uses ABAQUS as the underlying thermo mechanical (finite element) solver.

IV.RESULT & DISCUSSIONS

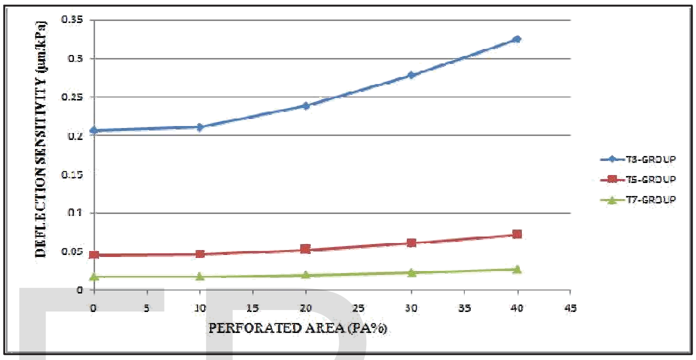
IntelliSuite simulation results

IntelliSuite has been used in this study to obtain the load-deflection response for the designed sensor. The structure depicted in figure.1 has been created for simulation using Intelli FAB module. The important parameters used in the simulation are as follows: Young's modulus of silicon diaphragm=106.8 GPa. Poisson's ratio =0.42 and Young's modulus of silicon piezoresistor=170 GPa, Poisson's ratio=0.26. The sensitivity of all the sensors have been estimated by operating the sensors in the small scale deflection region and hence in the linear region. The deflection responses have been measured in the pressure ranges of 0-1 KPa, 0-5 KPa and 0-25 KPa respectively for the device groups T3 and T5so that the deflection (δ) is well within the small d ensure linearity. The deflection sensitivity for various perforation levels of the sensor groups T3 and T5 respectively is presented in Table1.

TABLE1. DEFLECTION SENSITIVITY OF THE DEVICE GROUPS

Perforated Area PA (%)	**Deflection sensitivity (μm/KPa)**		
	Group T3	*Group T5*	*Group T5*
0	0.206727	0.045556	0.017015
10	0.211221	0.046207	0.017116
20	0.238674	0.052606	0.019431

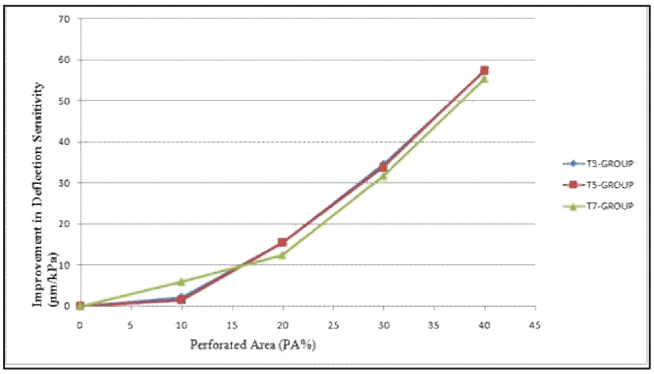
It is evident from the data that the deflection sensitivity is increasing with increasing percentage of perforated area irrespective of the diaphragm thickness. The percentage improvement in deflection sensitivity at various perforation levels from the non-perforated condition of the three sensor groups have been calculated and presented in the Table II.



TABLEII: PERCENTAGE IMPROVEMENT IN DEFLECTION SENSITIVITY

Perforated Area PA (%)	**Deflection sensitivity (μm/KPa)**		
	Group T3	*Group T5*	*Group T5*
0	0	0	0
10	0.02173	0.01429	0.05935
20	0.15453	0.15475	0.12433
30	0.34599	0.33797	0.31807
40	0.57226	0.57447	0.55474

These results show that it is possible to achieve improvement to extent of 55% with 40 percent perforated area. . The comparison result drawn from the fig 3 show that the improvement in deflection sensitivity is almost equal for a given perforated area irrespective of the diaphragm thickness.



V.CONCLUSION

This study investigated the effects of the employment of perforated diaphragm for sensing pressure in piezoresistive MEMS pressure sensors it was found that the deflection responses obtained on the different devices falling under each category shows that it is possible to achieve 55% improvement in the deflection sensitivity with 40% perforated area irrespective of the diaphragm thickness thus indicating that perforated diaphragms are better alternatives for piezoresistive pressure sensors. Finally a modified analytical model developed by suitably modifying the bending rigidity term in the conventional load-deflection response for clamped circle diaphragms to account for the reduced bending rigidity because of the introduction of perforations to increase the sensitivity has been used. Future scope of the experiment is to to investigate the effect of diaphragm pore size directly on response time and sensitivity. This study can be also extended by researching the life time of diaphragm with perforations.

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