Designing and Simulating the Performance Analysis of Piezoresistive Fluid Flow Pressure Sensor

K. Praveenkumar*[1], P. Suresh[1], K. Subash[1], M. Alagappan[1], A. Gupta[1]
[1]PSG College of Technology, Coimbatore.
*email: prvn2010@gmail.com

Abstract: In this work, we present the performance analysis of novel micro machined piezoresistive fluid flow pressure sensor using COMSOL Multiphysics. The principle of the sensing mechanism is based on the deflection of four sensing Si membranes. The fluid passes through it causes the deflection of these sensing layers which leads to the electrical output for the flow. The simulation results demonstrate the feasibility of the new concept and open the new area of research in the design of flow pressure sensors to obtain the higher level of sensitivity with lower power consumption.

Keywords: FEM analysis**,** piezoresistive, deflection, fluid flow, pressure sensor, sensitivity.

1. Introduction

In the fast growing technical world the micro and nano research plays a major role in reducing the size of the products and also improved performance in the field of automobiles, aircraft, mechanical, electrical, medical systems etc. Among these the development of sensors are the focused research for the application development. The pressure and flow sensors are the main components used in the fields such as monitoring and feedback analysis systems. A piezoresistive based flow pressure sensor is reported in this paper and silicon membrane is used as a diaphragm. The integrated flow - pressure sensor reported already for simultaneous measurement of fluctuating pressure and wall shear stress in fluid flow. Most of the reported integrated flow pressure sensors are based on heat transfer technique. The additional heating element and thermal isolation structures are inevitable and the fabrication of these sensors is also relatively complex. In the past two decades, several research groups have developed micro machined flow pressure sensors based on momentum transfer principles, for example, using cantilever as the sensing element. Such devices have the advantages of simple process and fast time response. In this research work, the flow pressure sensor is simulated for two different kinds of elements using COMSOL Multiphysics software. This design also meets some of the key criteria of sensors, such as miniaturization, low power consumption, reliability, stability, sensitive performance with lower fabrication and packaging cost.

2. Flow Sensor Design

The flow pressure sensor design proposed by Dan Li, et al consists of four piezoresistive polysilicon element on the diaphragm. The application of pressure over the sensor causes a deflection of the membrane and causes a change in resistors also. The design of sensing elements of the flow sensor is shown in Fig. 1, whose parameters are the same to the normal pressure sensor, except the symmetrically arranged cantilever diaphragms to minimize the output nonlinearity caused by the distortion of the diaphragms. Dan Li et al also implemented one extra step of the DRIE process from the front side to the pressure sensor to form the flow sensor.

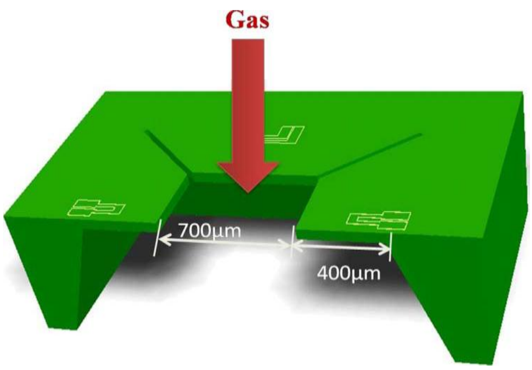

Figure 1: Schematic of flow sensor.
(Reference: "A Monolithic Piezoresistive Pressure-Flow Sensor with Integrated Signal-Conditioning Circuit" by Dan Li et al.)

3. Flow sensor design and analysis

The structure consists of a block with dimensions of 1000µm x 1000µm and is considered as a fluid flow channel. There are four diaphragms with dimensions of 950µm x 400µm x 5µm is placed inside the flow channel. One end of the each diaphragm is fixed in the wall of the block. In each diaphragm the piezoresistive material with dimensions of 20µm x 10µm x 2µm is placed over it and is shown in figure 2. When the fluid is flow through the channel, it is compressed and passed through the opening between the diaphragms. Hence the pressures in the edges of the diaphragm near by the openings are increased. This change in the pressure over this region makes the free end of the diaphragms displaced in the fluid flow direction. For the displacement of the diaphragms, stress is induced in the fixed ends also which makes the change in resistivity of the piezoresistive material. Hence causes change in conductivity. From this the pressure of the flowing fluid is measured.

The maximum displacement at the free end when load on the diaphragm is uniform from the fixed edge to the free end will be (Dan Li et al)

$$w = \frac{3\Delta P L^4}{2Eh^3}$$

Where **E** is the Young's modulus of Si and **L**, b and h are the length, width, and the thickness of the diaphragm, and **P** is the pressure difference on the diaphragm, respectively.

The stress on the piezoresistor induced by the input flow is (Dan Li et al)

$$\sigma = \frac{3\Delta P L^2}{h^2}.$$

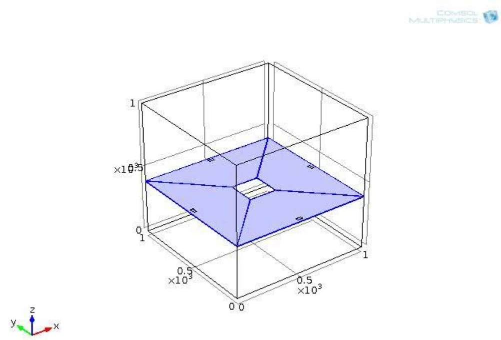

Figure 2: Flow Pressure Sensor Geometry using COMSOL Multiphysics

The pressure difference between the top and bottom surface of the diaphragm, which is induced by a fluid is obtained by (Dan Li et al)

$$\Delta P = \frac{1}{2} C_D \rho V^2$$

Where V is the flow velocity, ρ is the fluid density, C_D and is drag force coefficient. The resistivity of polysilicon, a piezoresistive material used for the resistors is totally strain dependent. COMSOL Multiphysics software tool is employed to model the geometry of this flow pressure sensor and the deformation is high at its centre for the applied input.

4. Results and Discussion

The input elements such as air and gasoline with various velocities are passed through the channel separately to study the superior response of the sensor. The displacement and stress of the diaphragm for both the inputs are recorded. One of the reasons for the diaphragm displacement is the velocity of the input element. Here, first the air is an input with varying velocity from 0.1 m/s to 1 m/s and the maximum displacement and stress obtained are shown in figures 3(a) and 3(b) for 1 m/s. Figures 3(c) and 3(d) shows the displacement of the diaphragm and stress induced for the pressure levels respectively. The figures 3(c) and 3(d) also clearly exhibits the linearity in the displacement and stress for the inputs. Hence this will lead to the linearity in the conductivity also.

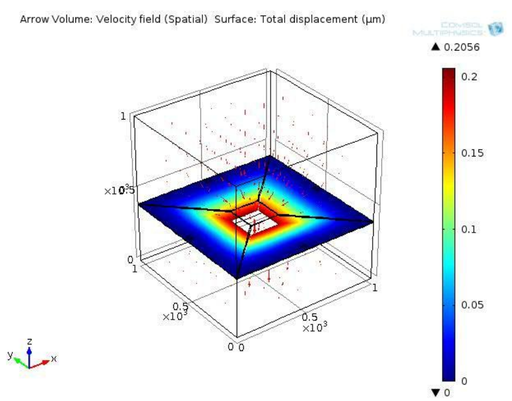

Figure 3(a): Displacement of the Sensing Membrane for the applied velocity of 1m/s. (air)

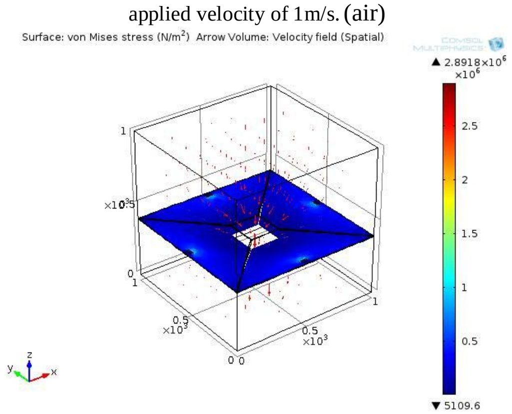

Figure 3(b): Stress distribution in the Sensing Membrane for the applied velocity of 1m/s. (air)

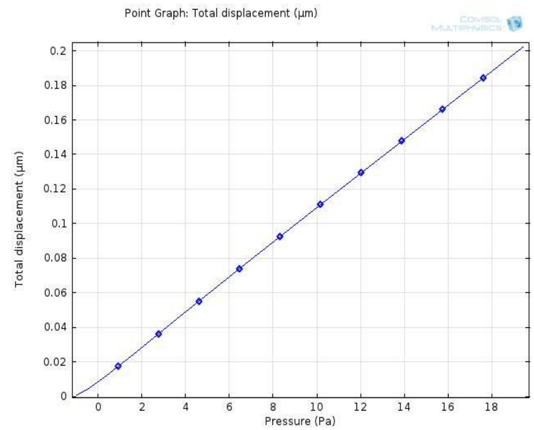

Figure 3(c): Displacement vs. pressure for the air input

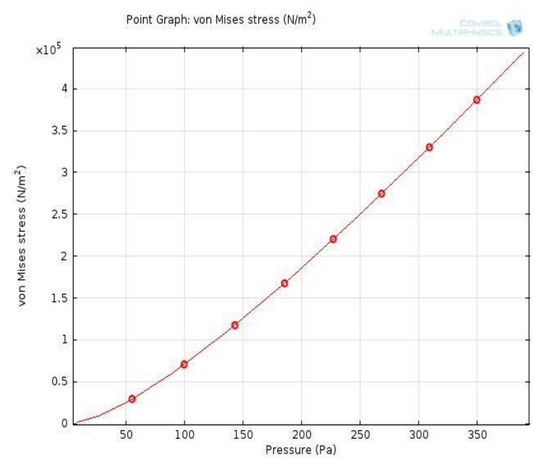

Figure 3(d): Stress vs. pressure for air input

Then the gasoline is an input with varying velocity from 0.1 m/s to 1 m/s and the maximum displacement and stress obtained are shown in figures 4(a) and 4(b) for 1 m/s. Figures 4(c) and 4(d) shows the displacement of the diaphragm and stress induced for the pressure levels respectively. The figures 4(c) and 4(d) also clearly exhibits the linearity in the displacement and stress for the inputs. Hence this will also lead to the linearity in the conductivity.

From these simulation results, it is also found that the gasoline input exhibits higher pressure inside the channel than the air input and also leads to the higher level of displacement. Hence the former will provide better electrical response than the later.

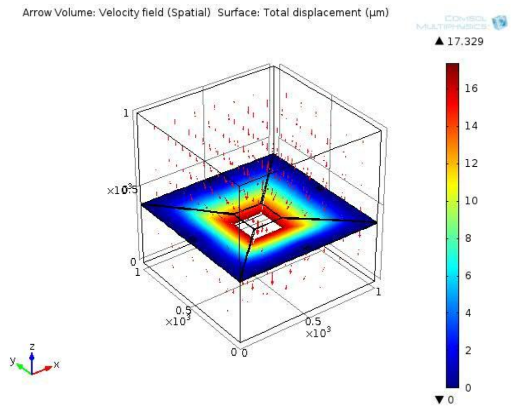

Figure 4(a): Displacement of the Sensing Membrane for the applied velocity of 1m/s. (Gasoline)

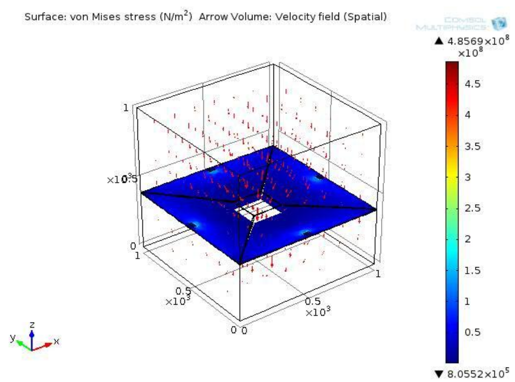

Figure 4(b): Stress distribution in the Sensing Membrane for the applied velocity of 1m/s. (Gasoline)

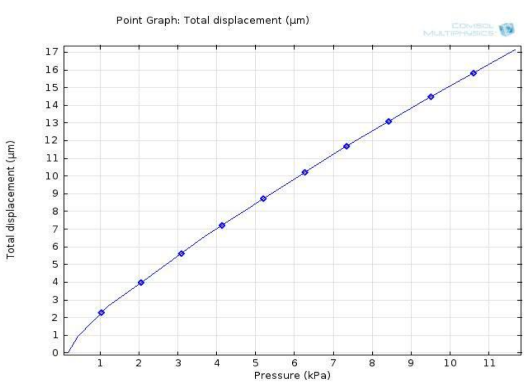

Figure 4(c): Displacement vs. pressure for the Gasoline input

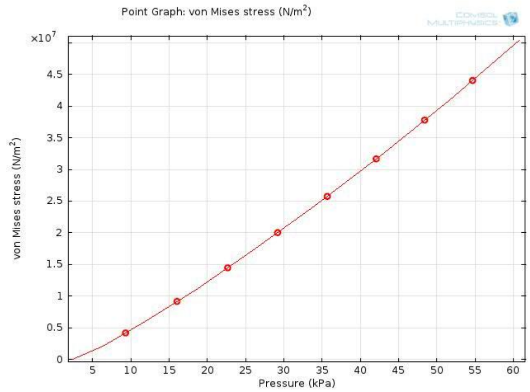

Figure 4(d): Stress vs. pressure for Gasoline input

5. Conclusion

The novel flow pressure sensor is designed and its performance is analysed for two different kinds of inputs such as air and gasoline. For both of these inputs the displacement of the sensing membranes is recorded for velocities from 0.1m/s to1m/s. The displacement of the sensing mechanism is linear for both the inputs. The sensor also exhibits better response for gasoline input than air input. Hence this simple sensor can be effectively implemented for the application like flow measurement of fuel tanks in automobiles. This idea also opens the new research scope for flow sensors.

6. Acknowledgements

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7. References

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