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DESIGN AND ANALYSIS OF A MEMS AIR FLOW SENSOR

Shailendra Sharma*, Jitendra Prasad Yadav, Dr PS Kaushik*****

**(Electronics & communication)*
***(Electronics & communication, Shree Digamber Institute of Technology, Dausa)*
****(Mechanical Engineering, Shree Digamber Institute of Technology, Dausa)*

Abstract - *Micro-electromechanical system (MEMS) is one of the prominent technologies at present stage. Microcantilever based sensors play a very important role in the field of MEMS, because most of the MEMS sensors are based on the micro-cantilevers that use a series of different structures and design materials. MEMS technology provides a number of benefits such as devices with lower cost, enhancement in performance and reduction in power consumption. In this paper we proposed an air flow sensor based on the micro-electro-mechanical system (MEMS) technology. The designing of sensor includes, design of a microcantilever beam with different shapes of paddles, generation of Stress Concentration Region (SCR) at the surface of microcantilever and measuring the stress. The microcantilever is followed by placing piezoresistive layer on it, which results in change of resistance due to alteration in shape of cantilever when the stress is induced on it. This change in resistance is calculated by Wheatstone bridge circuit, which provides the results in terms of output voltage. The proposed air flow sensor exhibits a sensitivity of 0.40009475 mV/ms^{-1}, which is an appropriate value of the sensitivity. We have proposed and simulated the air flow sensor using structural mechanics module of Comsol multiphysics 4.4 and analysis for different parameters and verification of result has been done.*

(Key Words: *MEMS, Micro cantilever, Paddles, Differential pressure.*)

1. INTRODUCTION

In the present situation, MEMS technology has wielded a major impact in the field of physical sensing and a little but flourishing impact in the field of gas sensing. Fluid analysis software, FLUENT was used for analyzing the coupling characteristics between the solid and fluid. Gogoi, Uday Jyoti *et al.* (2014) investigated that sensitivity is greatly affected by different structured beam. This study shows the designing and simulation of different geometries of cantilever beam i.e. rectangular, triangular and inverted trapezoidal. The given paper provides detailed description of the MEMS based air flow sensor. In the proposed work, analyzation and comparison of various performance parameters related to sensitivity of sensors such as stress, displacements are discussed By comparing the change in resistance between upstream and downstream cantilever beams, air flow velocity as well as direction can be obtained. Firdaus, S.M. *et al.* (2008)designed half cut stress concentration (HCSC) region at the cantilever surface, in order to increase the stress occurred at the piezoresistive layer, so that the cantilever sensitivity can be enhanced with the help of the increased amount of stress In order to enhance the performance of the sensor a comparative study of different shapes of paddles and appliance of SCR (stress concentration region) at the surface of microcantilever based sensor is performed. All the simulations and result analysis are done with the help of software COMSOL Multiphysics 4.4. Sensitivity of the flow sensor can further be improved by changing the sensing material and dimensions of the microcantilever. Graak, P. *et al.* (2015) generated a power generator using structural mechanics module of the Comsol multiphysics 4.4.Rahim Rosminazuin *et al.* (2008) proposed a piezoresistive microcantilever based sensor in which the optimization of the capability of sensor was done by using finite element method.

2. DESIGN AND OPERATING PRINCIPLE

2.1 Designing Microcantilever

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

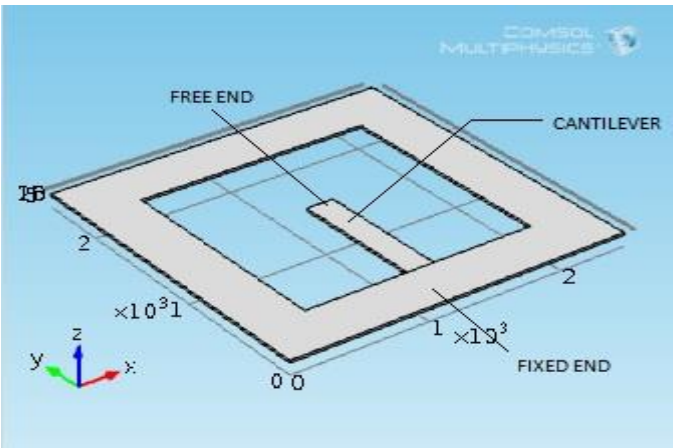


Fig. 2.2: A Microcantilever with its Both Ends; Free End and Fixed End

2.2 Selection and Placement of Paddles on the Microcantilever

The stress generated due to the external pressure applied on the microcantilever, is further increased by availing the different shapes of paddles. A paddle is a structure affixed at free end of the microcantilever and plays an important role in increasing the overall performance of the mechanical structures. In the respective experiment, three different paddles of different shapes, i.e. hexagon, rectangle and triangle are stipulated for the experiments.

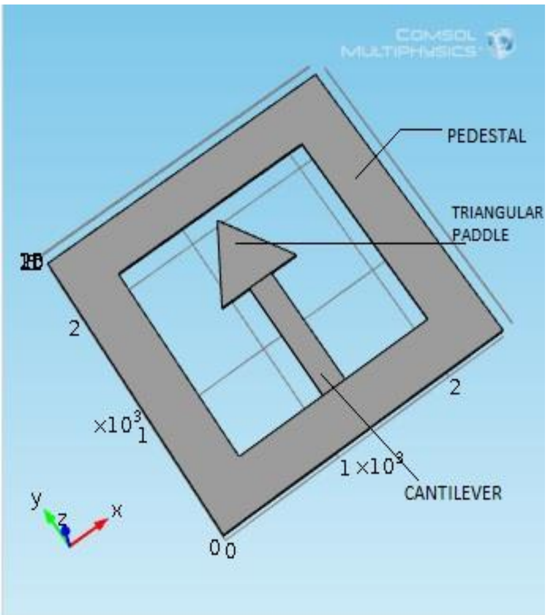


Fig: 2.3 Triangular Shaped Paddle

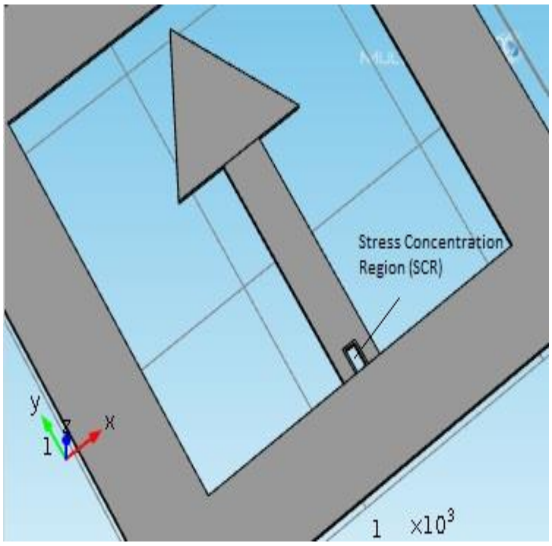


Fig: 2.4 Location of Stress Concentration Region (SCR)

2.3 Placement of Piezoresistors on the Microcantilever

After the generation of stress concentration region (SCR) in the cantilever, Piezoresistors are placed on the cantilever. Piezoresistors work on the principle of piezoresistivity. Piezoresistivity is the effect which accounts that when the mechanical stress is applied to the resistor, the electrical resistance of the resistor changes. In the given experiment, four Piezoresistors are placed on the cantilever. The material used for the piezoresistors is p-type silicon. Implanted piezoresistors are shown in the Fig 3.5.

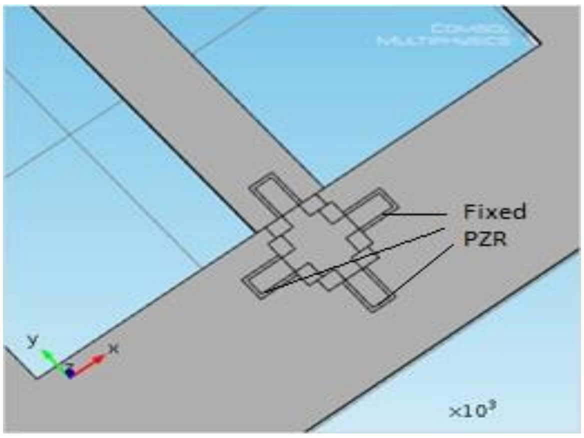


Fig: 2.5 Piezoresistors (PZR) Implanted on the Microcantilever

3. Implementation of Fluid Structure Interaction (FSI)

In an air flow sensor, the interaction between the air and the mechanical structure is the main requirement. Since the interaction between the two is not directly possible, another type of physics i.e. Fluid Structure Interaction (FSI) is used.

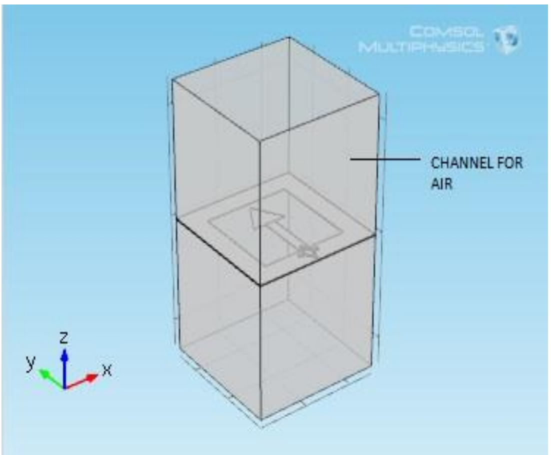


Fig: 3.1 Cantilever Enclosed in the Channel Using Fluid-Structure Interaction (FSI)

4. Analysis

4.1 Calculation of Sensitivity

The sensitivity of the air flow sensor is the ratio of the output voltage drop to the air flow velocity. It is expressed by using the given formula:

$$Sensitivity = \frac{Outout\ voltage\ (mV)}{Flow\ velocty\ (m/s)}$$

Therefore, sensitivity of the air flow sensor is directly proportional to the performance of the air flow sensor.

4.1 RESULTS AND DISCUSSION

In the first experiment a T-shaped cantilever is designed using different shapes of paddles. The stress and displacement generated on the cantilever is calculated and compared for different shapes of paddles. The paddle with maximum stress and displacement i.e. triangular paddle (as shown in Table 4.1) is then selected on which SCR is created to further increase the stress. Table 4.1 shows the comparison between stress and displacement using different paddle shape.

Table: 4.1 Comparison Table for Stress and Displacement

Shape	Stress (N/m^2)	Displacement (μm)
Normal T-shaped	1.56×10^6	0.24
T-shaped with hexagonal paddle	5.13×10^6	1.92
T-shaped with rectangular paddle	5.16×10^6	1.71
T-shaped with triangular paddle	5.17×10^6	2.02
T-shaped with triangular paddle and SCR	8.76×10^6	2.2

Table: 4.2 Stresses and Displacement at Different Pressures

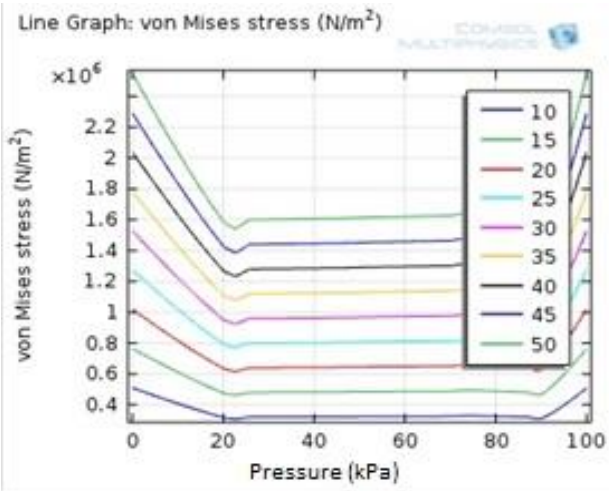
Pressure (kPa)	Stress (N/m^2)	Displacement (μm)
10	5.22×10^5	0.11
15	7.83×10^5	0.17
20	1.04×10^6	0.22
25	1.31×10^6	0.33
30	1.57×10^6	0.28
35	1.83×10^6	0.33
40	2.09×10^6	0.44
45	2.35×10^6	0.5
50	2.61×10^6	0.55

After designing T-shaped cantilever with triangular paddle, a pressure sensor is designed. The stress and displacement is calculated at different pressure range i.e. 10 kPa to 50 kPa. Table 4.2 shows the values of stress and displacement generated at different pressures. The change in resistance is calculated from the device output which is generated by the device itself. Table 4.3 shows the analysis of resistance at different pressures.

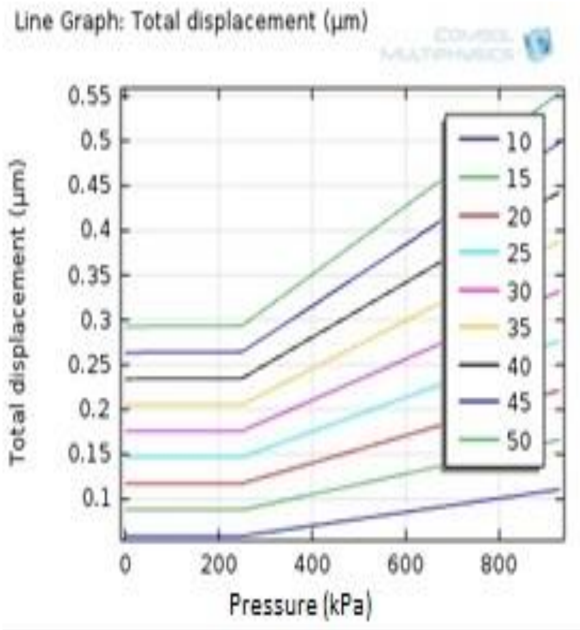
Table: 4.3 Analysis of Resistance

Pressure (kPa)	Terminal Current (mA)	Device Output (mV)	Resistance (Ω)	Change in Resistance (Ω)
0	0.57302	0.13395	0.233753315	-
10	0.57304	0.11589	0.202237191	0.031516124
15	0.57303	0.10687	0.186496579	0.047256736
20	0.57303	0.09784	0.170741497	0.063011818
25	0.57303	0.08881	0.154983159	0.078770156
30	0.57303	0.07978	0.139224822	0.094528493
35	0.57303	0.07076	0.123483936	0.110269379
40	0.57303	0.06173	0.107725599	0.126027716
45	0.57303	0.05271	0.091984712	0.141768603
50	−0.57303	0.04368	0.076225045	0.15752827

Fig: 4.1 (a) and (b) shows the graphical representation of stress and displacement at different pressures.



(a)



(b)

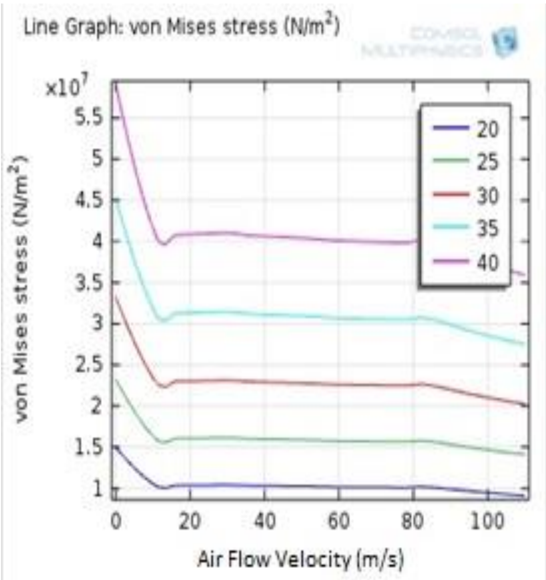
Fig: 4.1 (a) Comparison Graph of Von Mises Stress (pzrb) at Different Pressures (b) Comparison Graph of Total Displacement at Different Pressures

Fluid structure interaction is then applied to the pressure sensor to design the air flow sensor. The different values of Von Mises stress and displacement at different flow velocities of the air is calculated. Table 4.4 shows the values of stress and displacement at different air flow velocities.

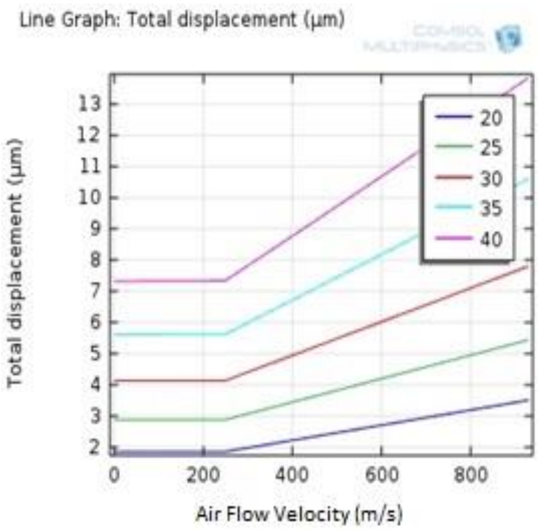
Table: 4.4 Stresses and Displacement at Different Air Flow Velocities

Flow Velocity (m/s)	Generated Pressure(Pa)	Stress fsi (N/m^2)	Displacement fsi (µm)	Stress pzrb (N/m^2)	Displacement pzrb (µm)
20	379	2×10^7	29	1.6×10^7	3.51
25	587	3.07×10^7	36.2	2.48×10^7	5.44
30	840	4.38×10^7	43.4	3.55×10^7	7.8
35	1139	5.93×10^7	50.7	4.83×10^7	10.6
40	1484	7.74×10^7	58	6.3×10^7	13.8

The graphical representation of the stress and displacement at different air flow velocities is shown in the Fig 4.2.



(a)



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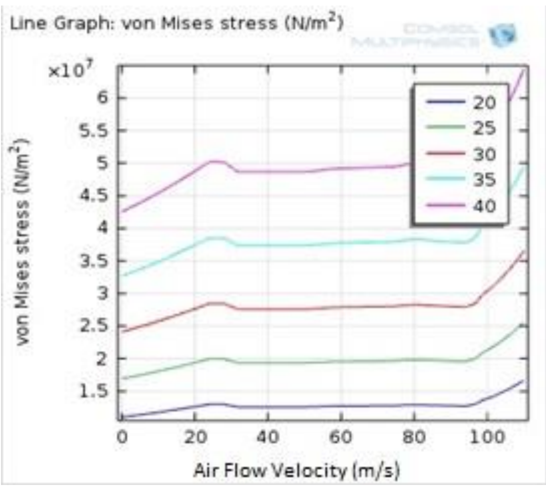

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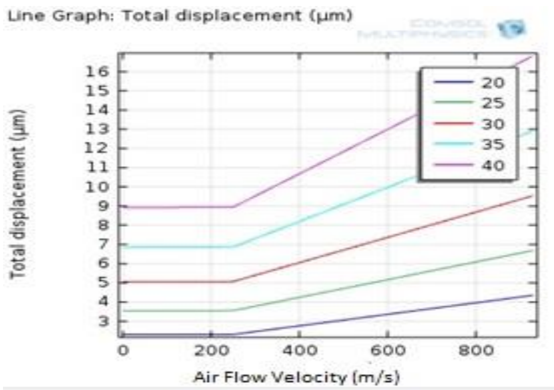

(d)

Fig: 4.2: (a) Comparison Graph of Von Mises Stress (pzrb) at Different Air Flow Velocities, (b) Comparison Graph of Total Displacement (pzrb) at Different Air Flow Velocities, (c) Comparison Graph of Von Mises Stress (FSI) at Different Air Flow Velocities, (d) Comparison Graph of Total Displacement (FSI) at Different Air Flow Velocities The performance of the sensor corresponds to the sensitivity of the sensor which indicates the change in its output value upon change in its input value. Table 4.5 shows the analysis of the sensitivity at different air flow velocities.

Table: 4.5 Sensitivity Analysis at Different Air Flow Velocities

Flow Velocity (m/s)	Terminal Current (mA)	Device Output (mV)	Resistance (Ω)	Change in resistance (Ω)	Sensitivity (mV/ms^{-1})
0	0.57452	0.33821	0.588682726	-	-
20	0.57372	-3.84359	-6.699417834	7.28810056	0.1921795
25	0.57328	-6.13334	-10.69868127	11.287364	0.2453336
30	0.57275	-8.92331	-15.5797643	16.16844703	0.297443666
35	0.57212	-12.21439	-21.34934979	21.93803252	0.348982571
40	0.57139	-16.00379	-28.00852308	28.59720581	0.40009475

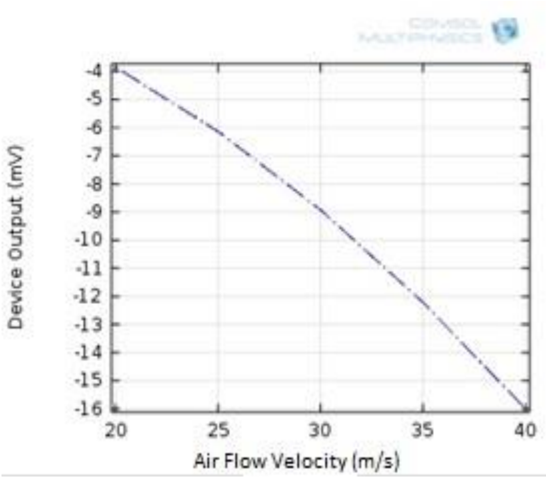

Fig: 4.3 Output (Voltage) of the Sensor at Different Air Flow Velocities (m/s)

Fig 4.3 represents the output voltage signal of the sensor at different air flow velocities. It is inferred that there is a linear relationship between output voltage and air flow velocity. This output voltage is totally dependent on resistance variation, caused by pressure exerted by flow of air.

The proposed air flow sensor exhibits a sensitivity of 0.40009475 mV/ms^{-1}, which is an appropriate value of the sensitivity.

In this chapter we have discussed about the results. In the next chapter we are going to discuss conclusion and future scope of MEMS technology.

5. Conclusion & Recommendations

MEMS devices provide us many advantages over the normally adopted conventional methods used for sensing air flow such as low manufacturing cost, high precision, less power consumption, small size and fast response.

From the results it has been observed that the sensitivity and reliability of MEMS based flow sensor is improved by various methods such as by changing the shape of the microcantilever, by adhering the paddles to the cantilever, by creating stress concentration region (SCR) at the surface of microcantilever which increases the stress and displacement levels of the microcantilever. Apart from this, different shapes of paddles such as rectangular, triangular and hexagonal are also employed in the experiment. These paddles are connected at the free end of the cantilever to increase the sensitivity of the sensor. Thus, from the results, we can see that the paddle and the SCR can increase the stress and displacement levels to a higher percentage.

Sensitivity can further be enhanced by using different materials, working with different shapes of cantilever and different shapes and dimensions of stress concentration region. These all parameters play an exemplary role in designing of the MEMS devices. Thus MEMS technology finds its application in almost every field of engineering, industrial field and research field.

The proposed air flow sensor exhibits a sensitivity of 0.40009475 mV/ms^{-1}, which is an appropriate value of the sensitivity

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