Design of three layer U-shaped MEMS piezoresistive cantilever Using COMSOL Multiphysics

K. Durga Aparna[#1], D.V.Rama Koti Reddy[*2] , B.Rajesh Kumar[#3]

[#]Research Scholar, Department of Instrument Technology, Andhra University,India
[*]Professor, Department of Instrument Technology,Andhra University, India
#Associate Professor,Department of Electrical,Electronics & Communication Engineering, Gitam University,India

Abstract: *This paper presents the design of three layer U shaped Piezoresistive cantilever to produce enhanced sensitivity with insulation layers on both sides of cantilevers. The analytical simulation of design is done by FEM (COMSOL MULTIPHYSICS). Micro cantilevers can detect mass either in static or dynamic mode. The effect of change in length, width and thickness are studied and it is observed that the sensitivity and stiffness are increasing when compared with the conventional rectangular cantilever.*

Keywords: *MEMS, COMSOL, Three layer, U shape, Piezoresistive.*

I. INTRODUCTION

The most researched area of micro-machines is with micro-electromechanical systems (MEMS). These systems are a combination of mechanical and electrical components built into incredibly small devices that are fabricated using sophisticated integrated circuit (IC) batch processing technologies (Pryputniewicz, 2002a). MEMS began in the mid 1980's and some of the first products were accelerometers. MEMS are intricate devices that can have several different moving parts and coupled together with other MEMS can sense, analyze and perform complex operations in addition to being able to control and actuate motion on the microscale (Hilbert et al., 2000). MEMS have been labeled one of the most promising and relevant technologies of the 21st century (Hilbert et al., 2000). Revolutionizing industrial and consumer products and processes, their steady infiltration into everyday life has begun to dramatically improve and change the way we live (Madou, 2002).The acronym MEMS is used today to define both the fabrication processes and the devices resulting from these processes (Pryputniewicz and Furlong, 2003). The processes are a result of merging of advanced micromechanical and integrated circuit (IC) technologies. The methods used for making MEMS are similar to those used in the silicon wafer/chip market (Baltes et al., 2002). They are in fact mostly fabricated using silicon wafers or some variation of them. The packaging of MEMS devices also still is, for the most part, based on how chips are made (Pryputniewicz, 2003a). Packaging is a technological barrier that must be worked out, at this time, for each specific application of MEMS.A U-shape cantilever is designed in this paper. That is the mass of the cantilever is considered constant and the shape of the cantilever is modified to enhance the sensitivity of the cantilever. The shape of the cantilever is modified because it not only enhances the sensitivity but also retains the stiffness. The U-shape of the cantilever helps is capturing the maximum stress created by the loading of the VOC molecules. Thus the design and its response characteristics are shown. Micro cantilevers have been widely used over the past two decades. If the elastic constant of the structure is to be diminished or if the sensitivity is to be augmented, the dimensions of the beams should be decreased. In particular, width was desired to be small as possible, in order to do that, the best design for this kind of structures is the so called U-shaped cantilever.

II. DESIGN PARAMETERS

A simple rectangular cantilever is designed. The material used is Polycrystalline silicon. The dimensions and material properties are given in the table.

Table 1

S.No	Variable	Value
1	Length	200µm
2	Width	100µm
3	Thickness	2µm
4	Young's Modulus	160GPa
5	Density	2320kg/m^3
6	Poisson's Ratio	0.22
7	Load Applied	10pN

The clamping is provided at one end and the load is applied on other end. The stoney's equation states that the deflection is dependent on all the three parameters.

$$\delta = 4fl^3/Ewt^3$$

The rectangular cantilever is shown in fig.1.

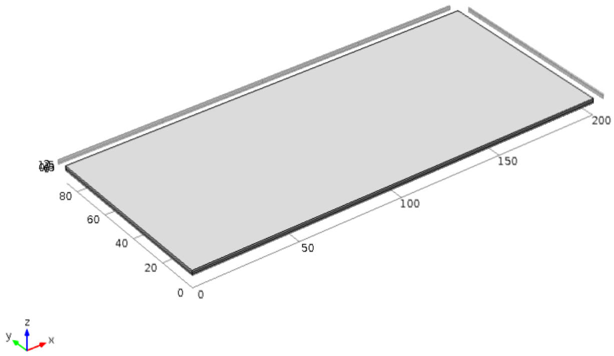


Fig.1

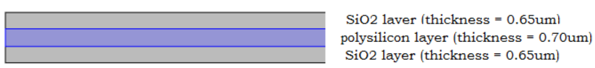
The proposed three layer U shaped cantilever is designed. The middle layer is the sensing piezoresistive layer while the top and bottom layers are the sensing surfaces on which the analytes may to be deposited to create deflection in the cantilever to produce stress.

Table 2

U-shape	Length (µm)	Width (µm)	Thickness (µm)	Material
Layer 1	200	100	0.65	SiO2
Layer 2	200	100	0.7	PolySi
Layer 3	200	100	0.65	SiO2

The width 100µm includes the air gap between the two legs.

The side view of the proposed cantilever is shown below.



The shape of the U shaped piezoresitor is shown in fig.2 .

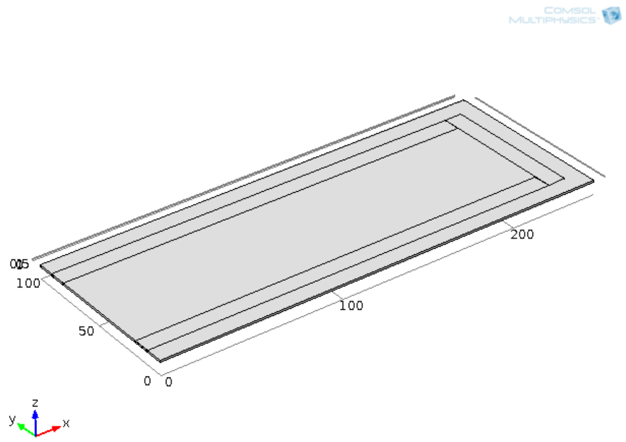


Fig. 2.

Thus for U shaped cantilever proposed if the analyte makes a contact with the piezoresistive surface there occurs a change in the piezoresistive properties. The top and bottom are the insulators while the middle will be the piezoresistor sensing the stress. The three layer U shape cantilever is shown in fig.3.

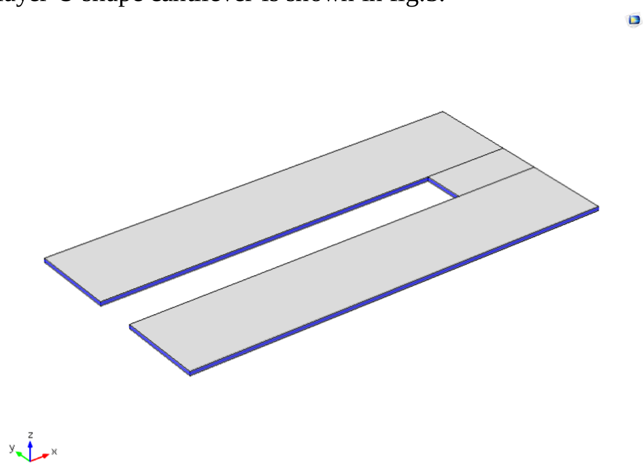


Fig.3

III. EXPERIMENTAL ANALYSIS

The FEM analysis of rectangular cantilever is shown in fig.4.

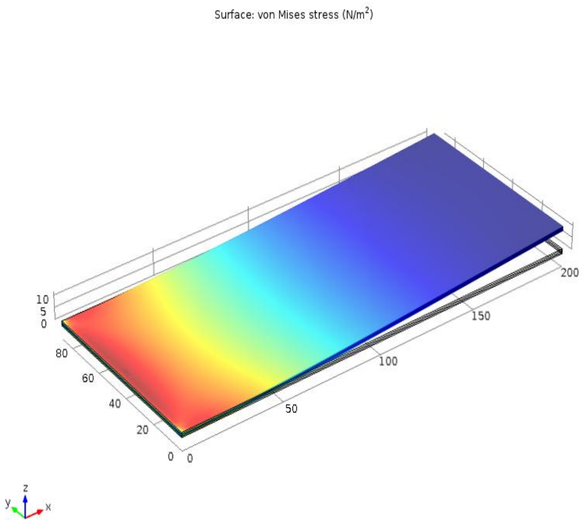


Fig. 4.

The FEM analysis of three layer U shaped cantilever is shown in fig.5.

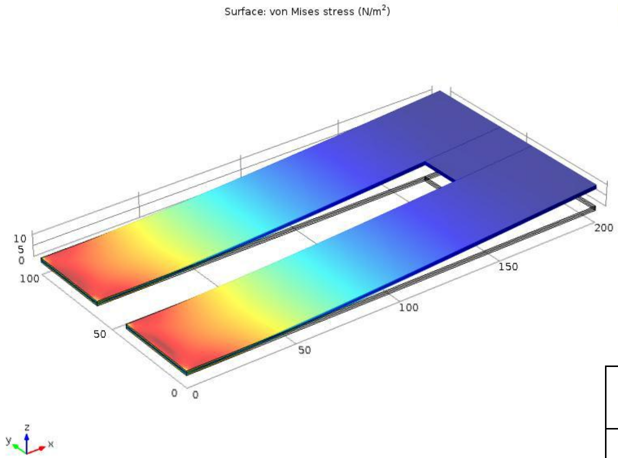


Fig. 5.

1. Effect of change in length on Rectangular cantilever

The deflection is varying proportionally with the length so as the length is increasing with deflection the sensitivity in increasing but the stiffness is reducing.

Table 3

S.No	Length (µm)	Deflection (nm)	Sensitivity	Stiffness
1	20	0.1013846	23.431952	0.10985
2	40	0.0553846	46.863905	0.01373
3	60	0.1246153	70.295857	0.00406
4	80	0.2215384	93.727810	0.00171
5	100	0.3461538	117.15976	0.00087
6	120	0.4984615	140.59171	0.00050
7	140	0.6784615	164.02366	0.00032
8	160	0.8861538	187.45562	0.00021
9	180	1.1215384	210.88757	0.000150686
10	200	1.3846153	234.31952	0.00010985
11	220	1.6753846	257.75147	8.25319E-05
12	240	1.9938461	281.18343	6.35706E-05

The length vs stiffness graph is shown in fig.6.

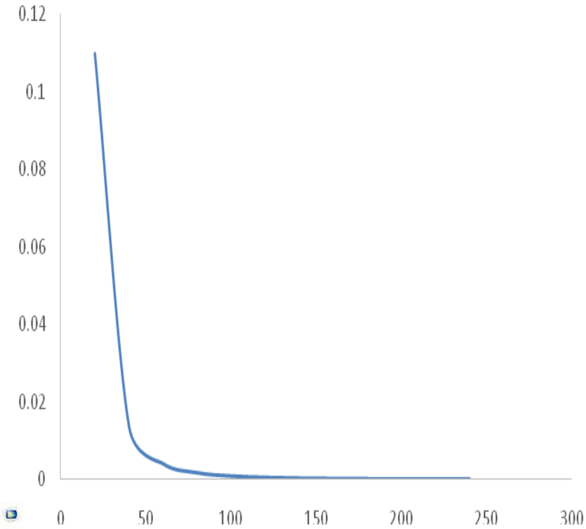


Fig.6.

2. Effect of change in Thickness on Rectangular cantilever

The thickness is increasing the sensitivity decreases but the stiffness increases. Thus an optimum condition has to be reached where the sensitivity is maximum.

Table 4

S.No	Thickness (µm)	Deflection (nm)	Sensitivity	Stiffness
1	0.35	4.775510204	0.80816326	0.000017
2	0.40	3.65625	0.61875	0.000025
3	0.45	2.888888889	0.48888888	0.000036
4	0.50	2.34	0.396	0.00005
5	0.55	1.933884298	0.32727272	0.000066
6	0.60	1.625	0.275	0.000086
7	0.65	1.384615385	0.23431952	0.000109
8	0.70	1.193877551	0.20204081	0.000137
9	0.75	1.04	0.176	0.000168
10	0.80	0.9140625	0.1546875	0.000204
11	0.85	0.809688581	0.13702422	0.000245
12	0.90	0.722222222	0.12222222	0.000291

The thickness vs stiffness graph is shown in fig.7.

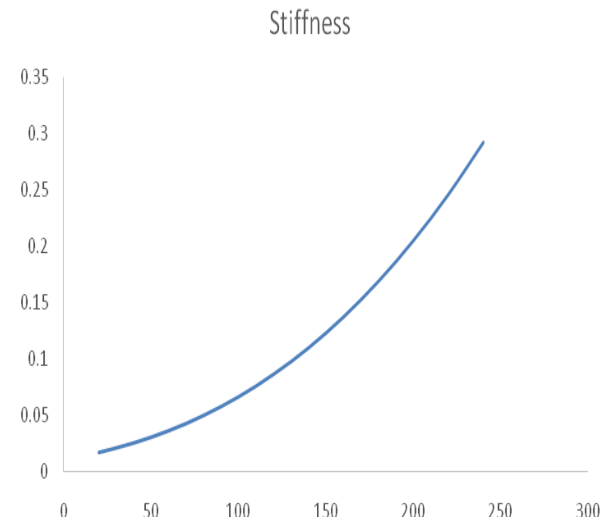


Fig.7

3. Effect of change in Width on Rectangular cantilever

The stiffness can be retained by changing the width of the cantilever keeping the thickness and length constant. With the increase in width both sensitivity and stiffness are increasing. Thus the width is optimized to length and thickness.

Table 5

S.No	Length (µm)	Deflection (nm)	Sensitivity	Stiffness
1	20	0.1246153	21.088757	0.0002746
2	40	0.4984615	42.177514	0.0005492
3	60	1.1215384	63.266272	0.0008238
4	80	1.9938461	84.355029	0.0001098
5	100	3.1153846	105.44378	0.0001373
6	120	4.4861538	126.53254	0.0001647
7	140	6.1061538	147.62130	0.0001922
8	160	7.9753846	168.71005	0.0002197
9	180	10.093846	189.79881	0.0002471
10	200	12.461538	210.88757	0.0002746
11	220	15.078461	231.97633	0.0003020
12	240	17.944615	253.06508	0.0003295

The width vs stiffness graph is shown in fig.8.

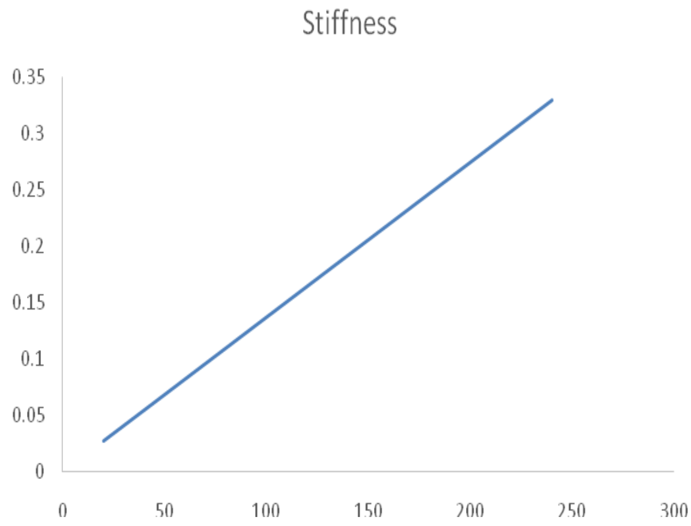


Fig.8.

4. Effect of change in length on U shaped cantilever.

The length of the cantilever is increasing the sensitivity is increasing.

S.No	Length (µm)	Deflection (nm)	Sensitivity
1	200	18.2	19.6
2	180	13.3	14.4
3	160	9.32	9.41
4	140	6.24	5.06
5	120	3.93	4.02
6	100	2.28	2.32
7	80	1.17	1.21
8	60	0.492	0.501
9	50	0.284	0.298

5. Effect of change in thickness on U shaped cantilever.

The change in thickness has maximum effect on sensitivity when compared with change in length and width. Thus it is proposed to have change in thickness with three layers instead of one single layer of p-type polysilicon.

S.No	Length (µm)	Deflection (nm)	Sensitivity
1	3	1.85E-12	1.40E-14
2	2.5	3.20E-12	2.03E-14
3	2	6.25E-12	3.17E-14
4	1.5	1.48E-12	5.66E-14
5	1	5.00E-12	1.25E-14
6	0.65	1.82E-12	2.96E-14

6. Effect of change in width of U shaped cantilever with respect to the gap between the legs of the Cantilever.

The distance between the two legs of the cantilever is optimized to increase the sensitivity and stiffness of the cantilevers.

Table 6

S.No	Gap (µm)	Deflection (nm)	Sensitivity	Stiffness
1	2	0.152307692	25.7751479	0.30208
2	4	0.609230769	51.5502958	0.06041
3	6	1.370769231	77.3254437	0.09062
4	8	2.436923077	103.100591	0.12083
5	10	3.807692308	128.875739	0.15104
6	12	5.483076923	154.650887	0.18125
7	14	7.463076923	180.426035	0.21146
8	16	9.747692308	206.201183	0.24167
9	18	12.33692308	231.976331	0.27187
10	20	15.23076923	257.751479	0.30208
11	22	18.42923077	283.526627	0.33229
12	24	21.93230769	309.301775	0.36250

7. Comparison of Rectangular and U shaped cantilever.

The sensitivity and stiffness are inversely propotional to each other. The sensitivity comparision and stiffness comparision of rectangle and U shape cantilevers are shown in fig.9 and fig.10.

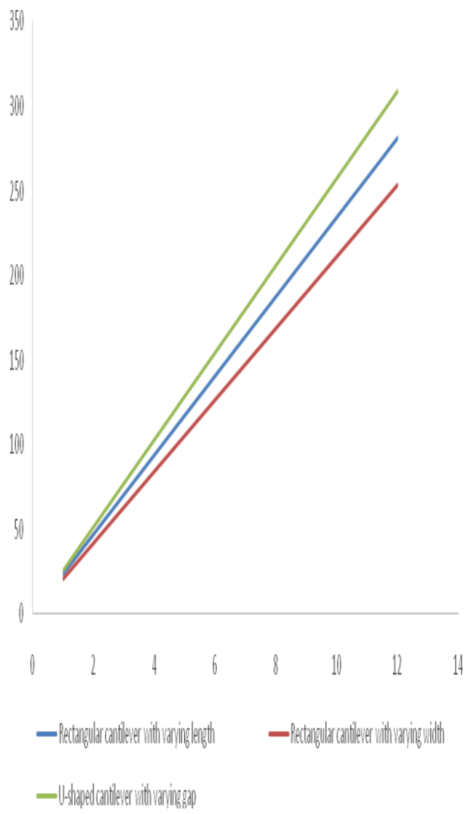


Fig.9.

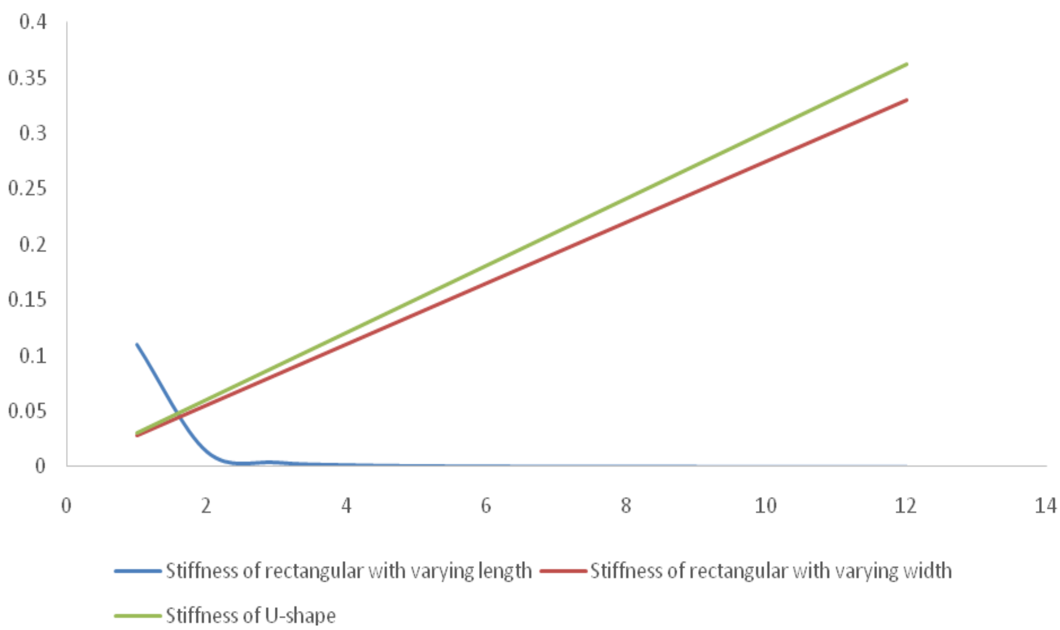


Fig.10.

8. Optimization of Dimension of U shaped cantilever

Table 7

Shape	Length (µm)	Thickness (µm)	Width (µm)	Sensitivity	Stiffness
Rectangular	200	2	100	234.31952	0.00010985
U shape	200	Top layer (sio2)= 0.65 Middle layer (polysi)= 0.70 Bottom layer (sio2)= 0.65	100 (including Air gap)	257.75147	0.3020875

IV. CONCLUSION

Therefore a three layer U shaped cantilever is designed and sensitivity increases by 9% and stiffness increases by 99% when compared with conventional rectangular cantilever. This structure not only helps in absorbing maximum stress but also can be used in conducting environments also.

REFERENCES

[1] Sheng-Jui Chen, Yen-Liang Lin and Chung-Lin Wu,Piezoresistive cantilever for measuring mass of airborne particles‖, doi: 978-1-5090-1493-4/16, IEEE, 2016.

[2] Peng Li and Xinxin Li, ―A single-sided micromachined piezoresistive SiO2 cantilever sensor for ultra-sensitive detection of gaseous chemicals‖, J. Micromech. Microeng. Vol. 16, 2539–2546, 2006.

[3] L.G. Villanueva, G. Rius, F. Pérez-Murano, J. Bausells, Piezoresistive cantilever force sensors based on polycrystalline silicon‖, IEEE, doi:978-1-4799-8108-3/151, IEEE, 2015.

[4] T. Chu Duc, J. F. Creemer, and Pasqualina M. Sarro, Piezoresistive Cantilever Beam for Force Sensing in Two Dimensions‖, IEEE Sensors Journal, Vol. 7, No. 1, January 2007 .

[5] Gholamzadeh, Ebrahim Ghafar-Zadeh, Falah Awwad and Mohamad Sawan, ―Piezoresistive Cantilever Platform for Label-free Detection of Molecules‖, doi: 978-1-4799-2507-0/14, IEEE, 2014.

[6] Liu, Fengli, and Yongping Hao, "Characteristic analysis and simulation for electrostatic micro-cantilever," in Proc. IEEE Int. Conf Information and Automation (ICIA)., pp. 1498-1502, 2008.

[7] Siddaiah N, Koti DR, Sankar YB, Kumar RA, Pakdast H. Modeling and Simulation of Triple Coupled Cantilever Sensor for Mass Sensing Applications. International Journal of Electrical and Computer Engineering. 2015 Jun 1;5(3):403.

[8] Kavitha.K, Design and Simulation of Cantilever Array for Fluid Flow Sensing Applications, COMSOL Conference at Bangalore.2012, Nov 3;75-80.

[9] Pakdast H, Lazzarino M. Triple coupled cantilever systems for mass detection and localization. Sensors and Actuators A: Physical. 2012 Mar 31; 175:127-31.

[10] Goericke FT, King WP. Modeling piezo resistive micro cantilever sensor response to surface stress for biochemical sensors. IEEE Sensors Journal. 2008 Aug;8(8):1404-10.