Design And Analysis of Microcantilevers Type Sensor With Different Shape of Piezoresistive Patch

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Abstract: **This paper presents the design, analysis and simulation of MEMS based piezoresistive microcantilevers of various shapes of piezoresistive patch, to analyse their sensitivity. The analytical simulation of design is done by FEM (COMSOL Multiphysics). The simulation results of applied force and obtained electric potential are given. It is important to note here that the paddle area i.e. the area of actual site of reaction where receptors are placed has been kept constant. This helps in direct comparison of various shapes for the same cantilever. The changes in the sensitivity of a cantilever beam with respect to change in the piezoresistive patch shape for the same applied force are denoted. Further the effect of the change in length of the piezoresistive patch is also shown.**

Keywords: **MEMS, COMSOL Multiphysics, FEM, Piezoresistive, Cantilever.**

I. INTRODUCTION

MEMS cantilever-based sensor is becoming popular in recent years due to its high sensitivity, high Selectivity, easy to fabricate, and can be easily integrated with on-chip electronic circuitry and has grown into the most promising and cost effective measurement tools of the future. They are being developed to meet a vast range of need right from blood glucose level to Missile Guidance systems, Mobile phones to study of genetic and cancerous mutations. Piezoresistive detection is an attractive alternative readout scheme to optical approach. It eliminates the use of lasers and optics, avoiding the problems associated with optical detection and facilitating manipulation and utilization.

Piezoresistive effect describes the changing electrical resistance of a material due to applied mechanical stress. The effect causes a change in resistance value. This effect has been used for semiconductor based sensor such as germanium, silicon and polycrystalline silicon. Silicon offers remarkable piezoresistive effect and it has controllability for electronic circuits and hence is widely used in MEMS.

The bending of the cantilever is related to the applied mass or molecular substance that binds on the surface as shown in figure 1[8]. Upon binding of the analyte (e.g. biological molecules, such as proteins or biological agents) with the receptor, the receptor surface is either tensioned or relieved or the mass of the analyte puts weight on the receptor surface. This causes the microcantilever to deflect, usually in nanometers, which can be measured.

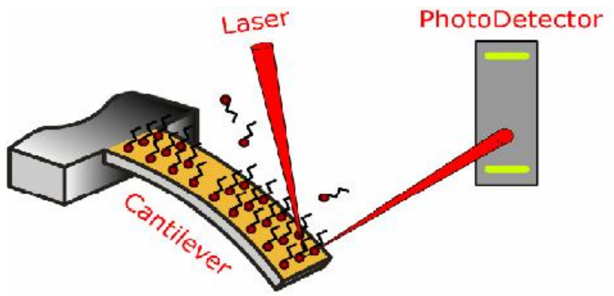


Fig 1: deflection of cantilever due to mass of the analyte and laser based position detection method

The bending produces two effects

1) It changes the orientation of the cantilever surface with respect to the horizontal surface.

2) It produces surface stress and hence strains. This stress could be converted to resistance and then converted to an equivalent voltage using a bridge circuit.

II. THEORY

The theory of piezoresistive effect is closely related to the conductivity of the semiconductor material. Hence, the expression in *E*, Electric field can be expressed as [1]

$$E = \rho . J + \Delta\rho . J$$

where *J* is the current, ρ is the resistivity and $\Delta\rho$ is the relative change in resistivity due to the applied stress. The relative change in resistivity is defined as [1]

$$\Delta\rho = \pi . \sigma$$

Where π is the piezoresistance tensor (units in Pa^{-1}) and σ is the stress. Effectively, the relative change in resistivity is proportional to the relative change in resistance. Hence, the Resistance change for a piezoresistor can be derived as the function of the longitudinal and transverse stresses as below

$$\frac{\Delta\rho}{\rho} = \frac{\Delta R}{R} = \pi_l \sigma_l + \pi_t \sigma_t$$

π_l and π_t are longitudinal and transverse piezoresistive coefficients; σ_l, and σ_t are longitudinal and transverse stress respectively.

Table 1 presents the typical room temperature values of the piezoresistive coefficient for lightly doped silicon. It is obvious that π_{44} is much larger than π_{11} and π_{12}.

Table 1: Room-temperature piezoresistive coefficients for silicon at 10^{-11} Pa^{-1} [1].

ρ	180e-6[ohm*m]	Resistivity of the unstressed material
π_{11}	6.6e-11[Pa^{-1}]	Piezoresistive stress coefficient component
π_{12}	-1.1e-11[Pa^{-1}]	Piezoresistive stress coefficient component
π_{44}	138.1e-11[Pa^{-1}]	Piezoresistive stress coefficient component
g	9.81[m/s^2]	Gravitational acceleration

III. DESIGN PARAMETER FOR CANTILEVER BEAM

The effect of external force acting on a microcantilever is highly dependent on its shape and material properties. Cantilevers having even slight variation in shapes respond differently to the external loads. Moreover, piezoresistive cantilevers work effectively only when the piezoresistive layer is placed close the region of maximum stress. Thus variation in the location of the piezoresistive strip has a large impact on the performance of the structure. This aims at comparing the performance of various microcantilever on the basis of the stress generated in the piezoresistive layer. Effect of the variation of shape of cantilever has been found to have a profound impact on its accuracy and ability to work in different condition.

This paper demonstrates the finite element method to obtain the optimal performance of SiO_2 based microcantilevers sensors by rearranging the dimensions of the cantilever beam to improve the efficiency of the output (sensitivity) of the micro cantilever for the given input (stress applied). A thin beam made up of SiO_2 was integrated with rectangular Si [100] proof mask cantilever as piezo resistive material. The SiO_2 micro cantilever provides relatively higher mechanical displacement as thermally grown SiO_2 film features a lower Young's Modulus at about 57-79 GPa than silicon at 120 GPa .A commercial finite element analysis tool for MEMS, COMSOL Multiphysics software was used to develop a finite element model .

Silicon dioxide and Silicon have properties as shown:

Properties of silicon:

S.No	parameter	value
1.	Young's modulus	120e9 [Pa]
2.	Poisson's ratio	0.4
3.	Density	2330[kg/m^3]

Properties of silicon dioxide:

S.No	parameter	value
1.	Young's modulus	0.7e11[Pa]
2.	Poisson's ratio	0.33
3.	Density	2190[kg/m^3]

In this analysis using COMSOL, 4.4 different cantilever shapes were considered. Each cantilever has the same standard dimensions with the base layer and piezoresistive layers having same fundamental dimensions. The four types of shapes are:

1.Rectangular piezoresistive layer near the fixed end (Basic).
2.C shaped piezoresistive layer at the fixed end.
3.C shaped piezoresistive layer with a slot.
4.Trapezoidal piezoresistive layer close to the fixed end.
5.Trapezoidal piezoresistive layer with a slot.

Table2: Dimension of cantilever.

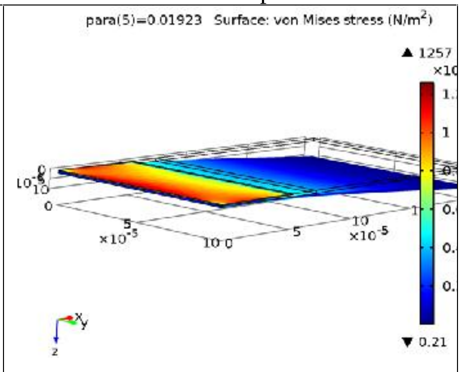
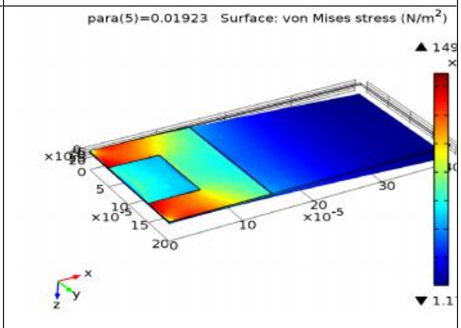
Dimension	**value**
Total Length of the cantilever:	200 «m
Width of the cantilever	100 «m
Thickness of the cantilever:	1.5 «m
Thickness of piezoresistive strip	0.5 «m

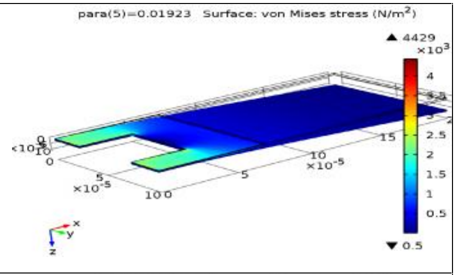
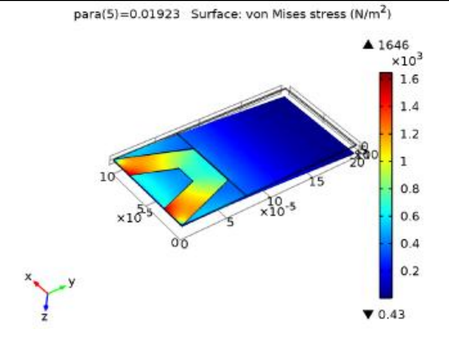
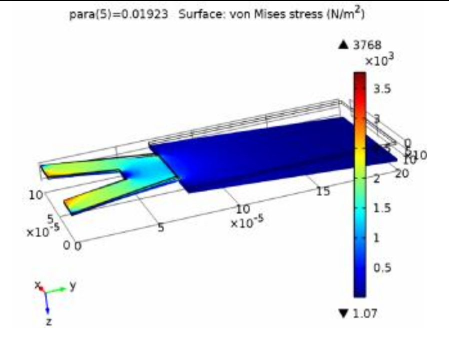
The load has been applied in the form of uniformly distributed force over the paddle area of 130 «m X 100 «m .

IV. SIMULATION RESULT

Figure showing finite element stress analysis on microcantilevers with piezoresistive patch with a clear distinction of different shapes is shown in table 3.

Table 3: Different shapes

Rectangular piezoresistive layer near the fixed end	
C-shaped piezoresistive layer at the fixed end	

C-shaped piezoresistive layer with a slot	
Trapezoidal piezoresistive layer close to the fixed end	
Trapezoidal piezoresistive layer with a slot	

Cantilever surface stress sensitivity is obtained by measuring the change in resistivity when a load is applied on the cantilever with respect to no load condition.

The schematic diagram of electric potential of the rectangular piezoresistive layer near fixed end microcantilevers when force applied= 0.01923N/m2 is shown in figure 2.

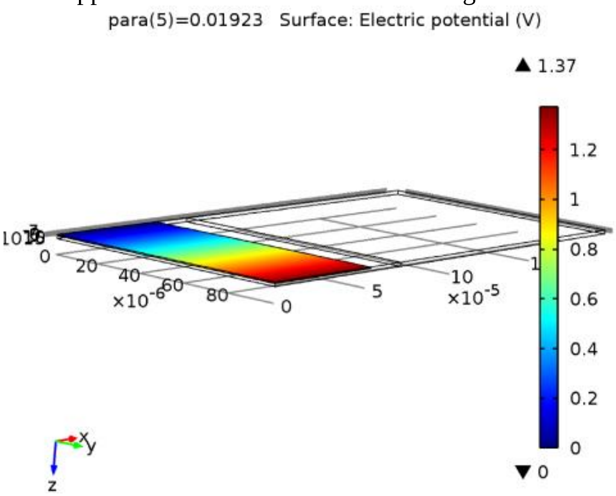


Fig 2: Electric Potential

The schematic diagram of electric potential of the C shape piezoresistive layer at the fixed end microcantilevers is shown in figure 3.

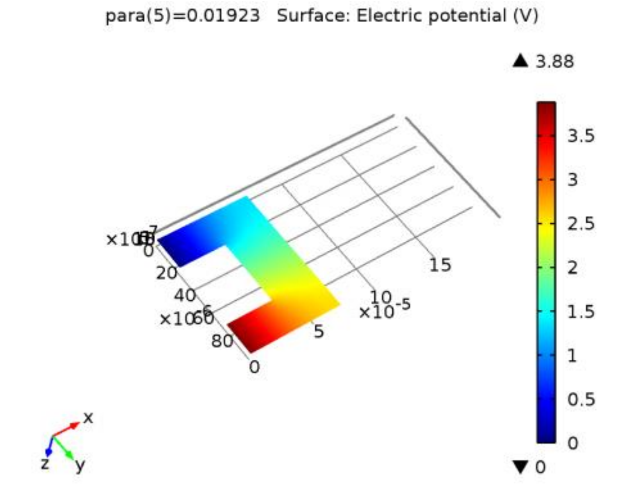


Fig 3: Electric Potential

The schematic diagram of electric potential of the trapezoidal piezoresistive layer with a slot microcantilever is shown in figure 4.

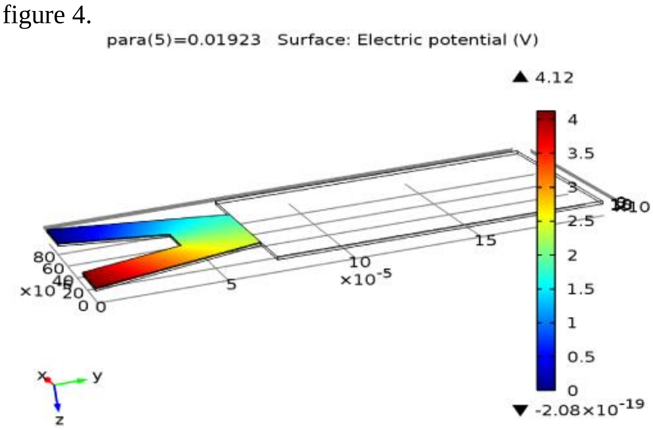


Fig 4: Electric Potential

Table 4 and figure 5 shows sensitivity for different type of cantilever we can clearly see that the *trapezoidal piezoresistive slotted type of cantilever* gives the best results for microcantilevers with identical dimensions. It is also important to note here that the best performance obtained here is with respect to this subset of microcantilevers. It must be clear that for this case the actual best performance would lie at an angle which may be other than that actually taken. Hence, we get best performance at that particular angle with respect to the manufacturability constraints in place.

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Table 4: Comparison of sensitivity of different cantilever

S No.	Type of Cantilever	Maximum Change in Resistance (Ω)	Sensitivity (dR/R)
1	Rectangular Patch type	$4.31*10^{-5}$	$1.542*10^{-8}$
2	C type Unslotted	$3.23*10^{-5}$	$1.668*10^{-8}$

3	C type Slotted	$4.32*10^{-5}$	$2.217*10^{-8}$
4	Trapezoidal Unslotted	$3.23*10^{-5}$	$1.828*10^{-8}$
5	Trapezoidal Slotted	$5.08*10^{-5}$	$2.463 *10^{-8}$

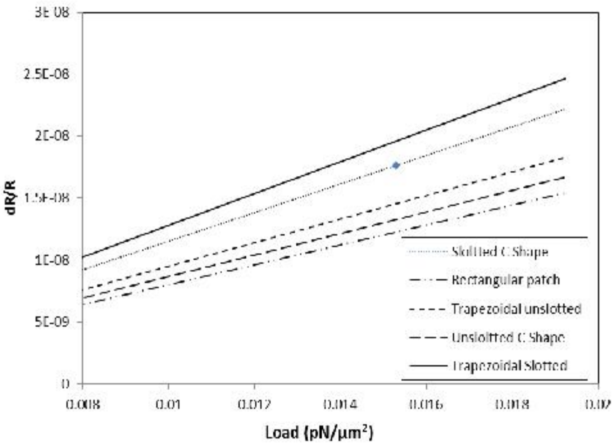

Fig 5: Sensitivity vs load for different microcantilevers

Further the effect of change in length of the piezoresistive patch in the rectangular piezoresistive layer near the fixed end is studied .The length of piezoresistive patch is shown in figure 6.

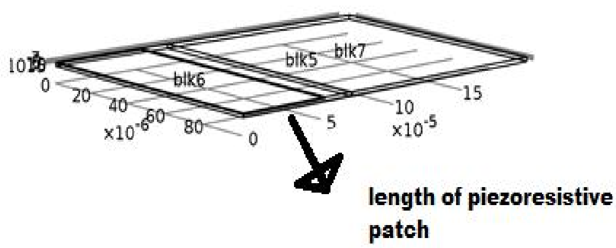

Fig 6: figure showing length of piezoresistive patch Block 6 is the piezoresistive material.

The length of the piezoresistive material was increased, there are two factors taken into account:

- Area of piezoresistive material is increasing which lead to increase in sensitivity.
- Stiffness of the beam is increasing due more stiff piezoresistive length increasing which lead to the decrease in the sensitivity of the beam.

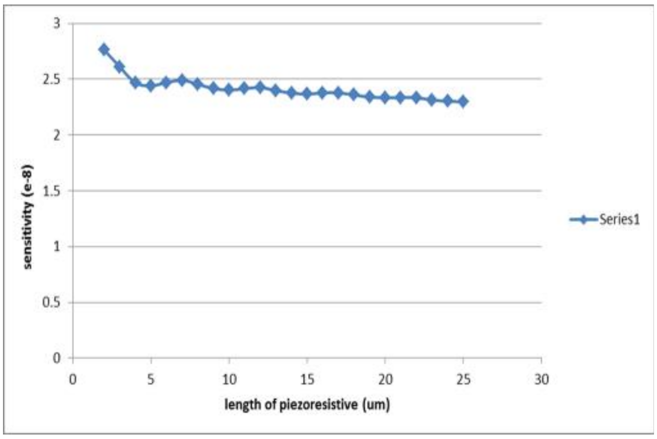

Fig 7: Sensitivity vs length of piezoresistive patch

Local maxima are observed as shown in figure 7 at some length due to the combined effect of the increase in area of the piezoresistive and the increase in stiffness of the beam.

V. CONCLUSION

We have seen that shape of piezoresistive patch has impact on the working of any microcantilever sensor and is a strong function of not only the dimensions of the microcantilever but also the shape of the microcantilever. This has also been proved by the results that we can see from the final shapes and results as in the case above where different shapes were compared and *trapezoidal piezoresistive slotted type of cantilever* was found to give the best results.

All the above analysis was conducted for identical cantilever shapes with the same receptor area. The only differences were only in shapes of piezoresistive patches. Even slight variation in shape of piezoresistor has a direct impact on sensitivity, Johnson noise, Hooge noise, resonant frequency and force resolution of the microcantilever. The above cases represent only a small set of the possible cases that can exist. It must be kept in mind that a large variety of shapes may exist which may have a better performance than those taken into account but have not been studied because either they have not been identified or are difficult to fabricate

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