Sensitivity Enhancement and Optimization of Mems Piezoresistive Microcantilever Sensor for Ultra Mass Detection

N.Siddaiah, A.Pujitha, G.Jairam Sai, U.Gupta, Ch.Chaitanya

Abstract: ***Micro-cantilevers are micro-mechanical structures fixed at one finish and move freely from different finish. In this paper silicon micro-cantilever sensors are designed with variable dimensions. The deserves of MEMS sensors are its sensitivity, simplicity and high speed. This paper proposed a enhanced Piezoresisitive micro-cantilever with square shaped stress concentration regions(SCR's) at the immobile end and on the exterior of the micro-cantilever. The piezoresistor used in this simulation is p-doped semiconducting material (silicon). In this study various structures of Piezoresisitive micro-cantilevers are compared having various number of SCR's by determining the stress and deflection characteristics. Results show that the cantilever with 72 SCR's of dimension 250×100×1µm has greater stress and exhibits more deflection when load is applied.***

Keywords: Piezoresisitive micro-cantilever, SCR's, stress and deflection

I. INTRODUCTION

Micro Electro Mechanical Systems (MEMS) have the benefits of lesser size, low cost, low power consumption and high resolution [5]. Presently MEMS technology is employed wide in medical specialty applications. A micro-cantilever sensing element surface is functionalized to sight molecules, it's referred to as Micro-cantilever biosensor and their sizes vary from micrometers to nanometers. These sensors give low value fabrication, simple use, production, high sensitivity, label free detection and multiprocessing among a microarray format. The higher than properties area unit desired by any sensors, that makes micro-cantilever sensors ideal candidates for sensing applications [2]. Micro-cantilever biosensors utilize a principle that's chemical binding or physical absorption of bio-molecules on the exterior of cantilever, that changes the mechanical properties of the cantilever.

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In these sensors, one surface of cantilever is covered with antibodies, proteins or stimuli – responsive polymers where the different surface of cantilever isn't covered which surface stress enclosed deflections inflicting a downward bending at the free end[2].Piezoresisitive materials provide a variation in resistance of a mechanical stress or pressure when applied. Piezoresistive material is applied on the clamped finish that cause high stress within the cantilever. Once apiezoresistive material like doped semi conductor is strained, its electrical conduction changes and therefore its resistance also changes. Because, once a functionalized piezoresistive micro-cantilever is exposure to focus on molecules, there's a interaction between probe and target molecules. This interaction induces a surface stress that causes cantilever bending and thus piezoresistive material is strained [2]. The advantages of Piezoresisitive micro-cantilever sensors are they're little size, portable, non-hazardous, low cost because of bulk producing, low power consumption, fast response, sensitive and self sensing ability [1].The coupled cantilever sensors are introduced and modelled with different dimensions. They have advantages like mass localization, insensitivity to stress and specific mass adsorption over single cantilever sensors [22].After fabrication of any microstructure it is to be characterized. Optical and dielectric force gradient schemes are used to characterize MEMS devices [23]

II. THEORITICAL ANALYSIS

In the design proposed, three square holes of size 50×20 µm are created on a micro-cantilever at the immobile end, where piezoresistor of width 10µm is placed. 72 square holes of size 8×8µm are created along the surface with 8µm gap between neighboring holes. The Stoney equation for rectangular cantilever is given by

$$\Delta z = \frac{3k(1-\nu)\Delta\sigma l^2}{Et^2}$$

where, Δzis tip deflection, k is the correction factor,ν is the Poisson's ratio; Δσis change in surface stress, E is the elastic modulus, l,t are length and thickness of the cantilever respectively. and poisons ratio=0.28. When force of 0.05N is applied on the cantilever, stress and deformation are are created on the cantilever structure.

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By creating SCRs at the immobile end, the moment of inertia is reduced, resulting in higher deflection. High deflection results in greater stress at the immobile-end of the microcantilever. For length l and cross sectional area A the resistance of the cantilever is given by $R = \rho L/A$, where, ρ is the resistivity. When load is applied there will be change in resistance of the cantilever and the change in resistance is given by:

$$\frac{\Delta R}{R} = \pi_l \sigma_l$$

where, ΔR is the resistance of strained cantilever; R is the resistance of unstrained cantilever; πl is the longitudinal Piezoresisitive co-efficient; and $\sigma l$is the stress induced in piezoresistor due to deflection.

Table 1 . Dimensions of the cantilever and SCR'S

Figure number	Length of the cantilever(µm)	Number of SCR's	Dimensions of SCR's (µm)	Gap between adjacent SCR's (µm)	Dimension of holes at the fixed end(µm)	Length of the piezoresistive material(µm)
2.1	200	40	10×10	10	35×20×1	200
2.2	200	60	8×8	8	35×20×1	200
2.3	250	50	10×10	10	45×20×1	240
2.4	250	72	8×8	8	50×20×1	200

III. DESIGN METHODOLOGY OF PIEZORESISTIVE SENSORS

Piezoresisitive cantilever structures are designed with constant width and thickness of 100um and 1um respectively. the simulations are carried in three steps - increasing the number of stress concentration regions, optimizing the dimensions of the piezoresistive micro-cantilever and, optimizing the dimensions of stress concentration regions and length of piezoresistor material.

Piezoresitive micro-cantilever structures with stress concentration regions:

The piezoresistive material employed in the micro-cantilever sensors is single crystalline silicon semiconductor. By adding the stress concentration regions, the sensitivity of micro-cantilever are greatly improved which makes this a ideal technique to extend the sensitivity of the cantilever. In case of cantilevers length is directly proportional and thickness is inversely proportional to deformation. The micro-cantilever styles planned durinthis study are structured using MEMS Simulation tool.

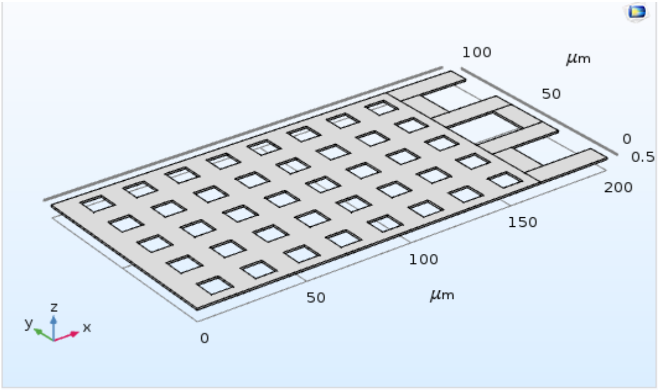

Fig . 1 Cantilever with 40 SCR's

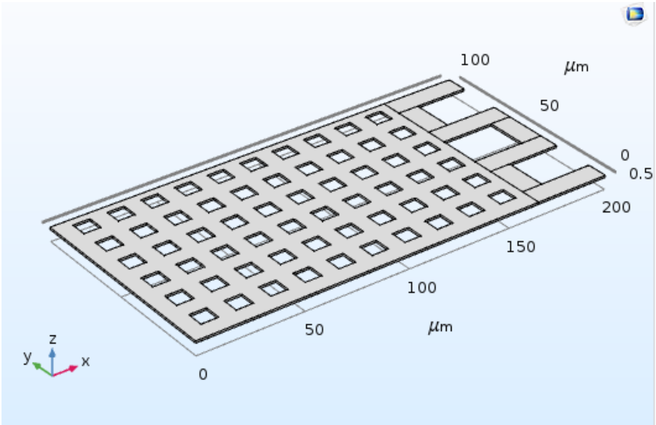

Fig . 2 Cantilever with 60 SCR's

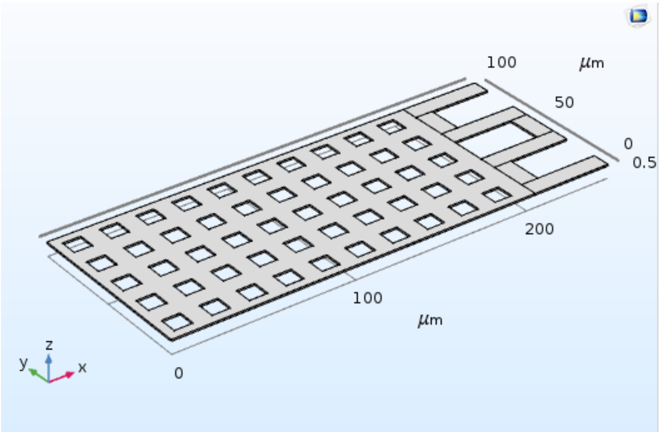

Fig . 3 Cantilever with 50 SCR's

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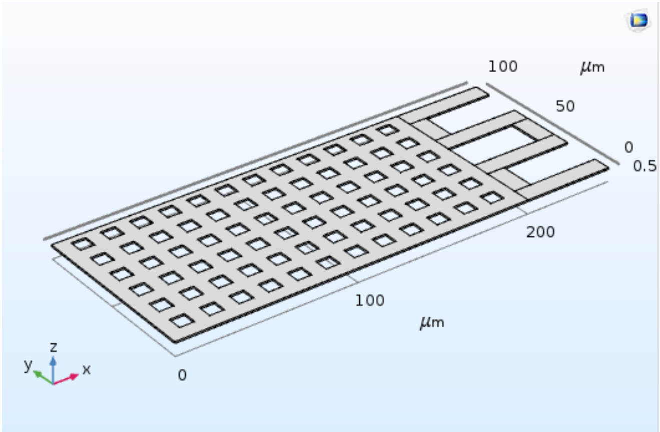

Fig . 4 Cantilever with 72 SCR's

This can be used for obtaining the stress and deflection characteristics, similarly for piezoresistive analysis. The simulations are performed on silicon micro-cantilever of dimensions 200×100×1μm and 250×100×1μm having elastic modulus of 130GPa and poison's ratio of 0.28.

IV. METHODS TO IMPROVE SENSITIVITY

The sensitivity of the cantilever will be exaggerated by the size and location of the piezoresistor. The piezoresistor length is to be short and also the cross-sectional space has to be high to incise back its resistivity. The material with lower modulus of elasticity is to be selected to increase the sensitivity. The sensitivity may be superior by changing the form of cantilever from parallelogram to paddled, stepped etc.[2]

V. RESULTS AND DISCUSSION

In this paper the stress and deflection characteristics of the cantilever are studied. The load is applied at the fixed end of the cantilever, which cause the cantilever to deform. The piezoresistive material is strained by applying load, which cause bending at the fixed end. This stress and deflection values are required for the analysis of sensitivity of the micro-cantilever.

Table 2 . Stress and Deflection Characteristics of cantilever with 40 SCR's

Applied load(N)	Stress(N/m^2)	Deflection(μm)
0.05	1.01×10^{13}	1.34×10^{5}
0.1	2.02×10^{13}	2.68×10^{5}
0.15	3.02×10^{13}	4.02×10^{5}
0.2	4.03×10^{13}	5.36×10^{5}
0.25	5.04×10^{13}	6.7×10^{5}

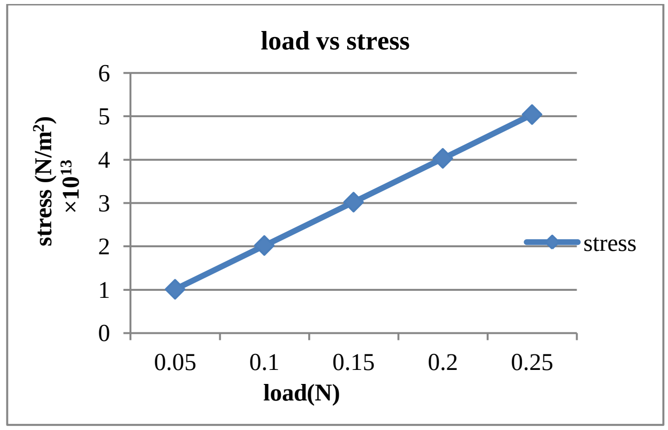

Fig. 5 Stress characteristics for applied load

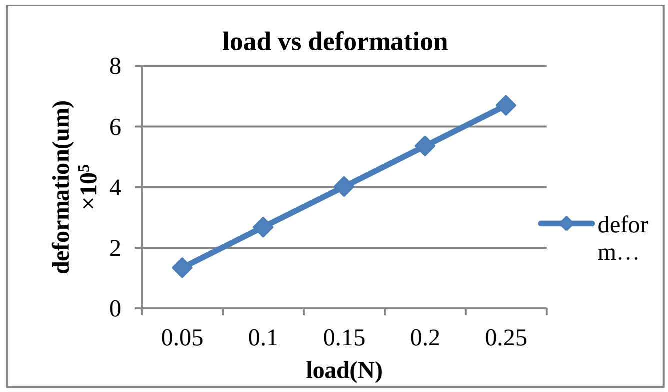

Fig . 6 Deformation characteristics for applied load

Table 3 . Stress And Deflection Characteristics of cantilever with 60 SCR's

Applied load(N)	Stress(N/m^2)	Deflection(μm)
0.05	1.5×10^{13}	2.54×10^{5}
0.1	2.99×10^{13}	5.08×10^{5}
0.15	4.49×10^{13}	7.62×10^{5}
0.2	5.99×10^{13}	1.02×10^{6}
0.25	5.99×10^{13}	1.27×10^{6}

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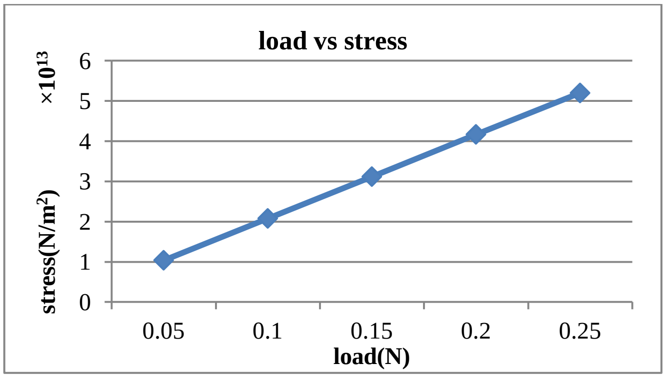

Fig .7 Stress characteristics for applied load

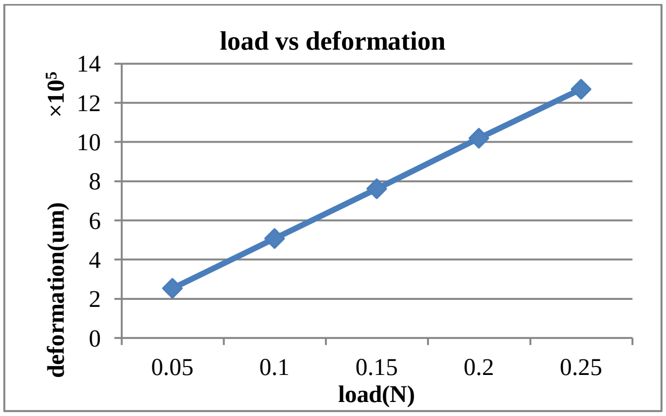

Fig . 8 Deformation characteristics for applied load

Table 4 . Stress and Deflection Characteristics of cantilever with 50 SCR's

Applied load(N)	Stress(N/m^2)	Deflection(μm)
0.05	1.04×10^{13}	5.15×10^{5}
0.1	2.08×10^{13}	1.03×10^{6}
0.15	3.12×10^{13}	1.55×10^{6}
0.2	4.17×10^{13}	2.06×10^{6}
0.25	5.2×10^{13}	2.58×10^{6}

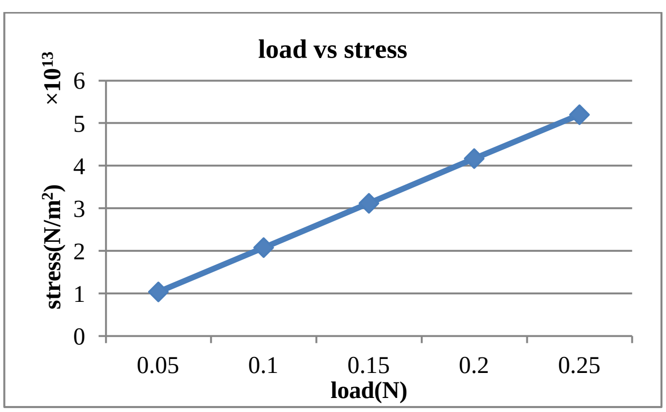

Fig . 9 Stress characteristics for applied load

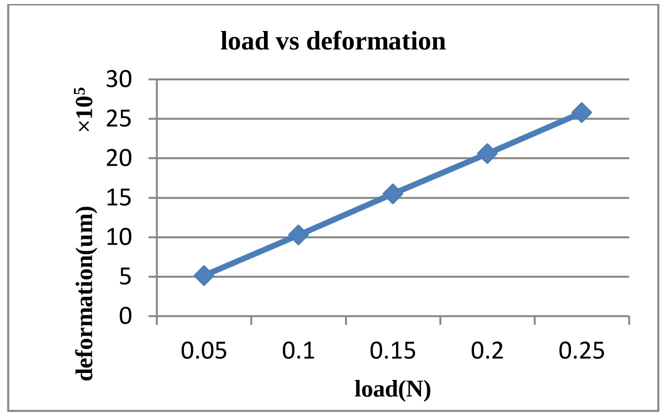

Fig . 10 Stress characteristics for applied load

Table 5 . Stress And Deflection Characteristics of cantilever with 72 SCR's

Applied load(N)	Stress(N/m^2)	Deflection(μm)
0.05	1.67×10^{13}	4.92×10^{5}
0.1	3.34×10^{13}	9.84×10^{5}
0.15	5.01×10^{13}	1.48×10^{6}
0.2	6.68×10^{13}	1.97×10^{6}
0.25	8.42×10^{13}	2.46×10^{6}

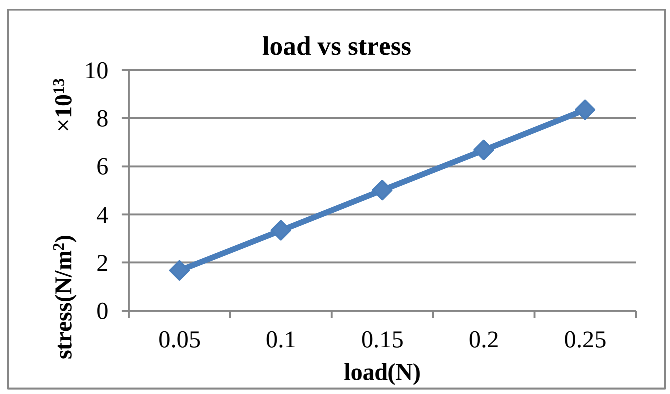

Fig . 11 Stress characteristics for applied load

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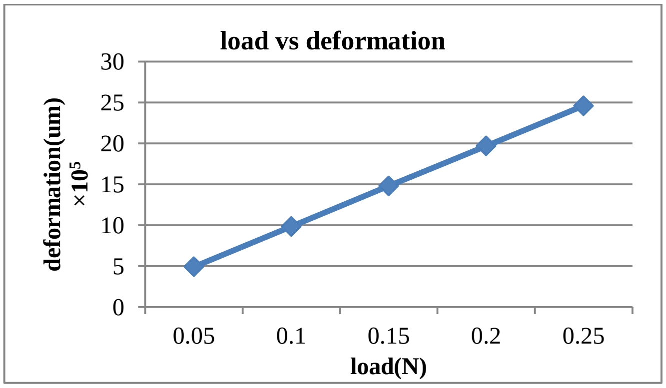

Fig . 12 Deformation characteristics for applied load

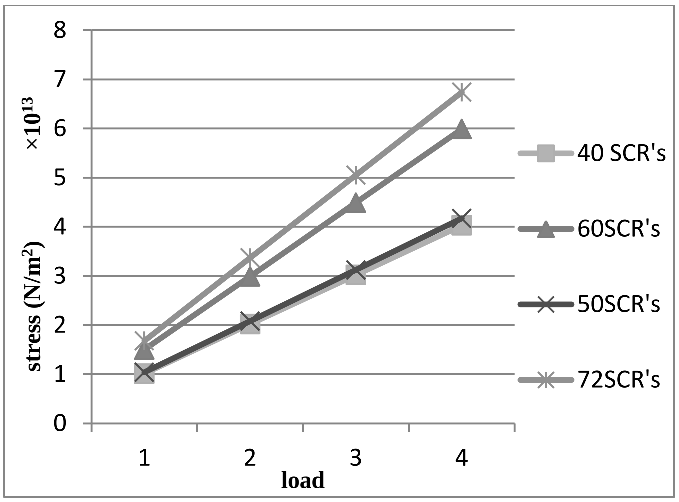

Fig . 13 Comparison of Stress Characteristics under Various Loads

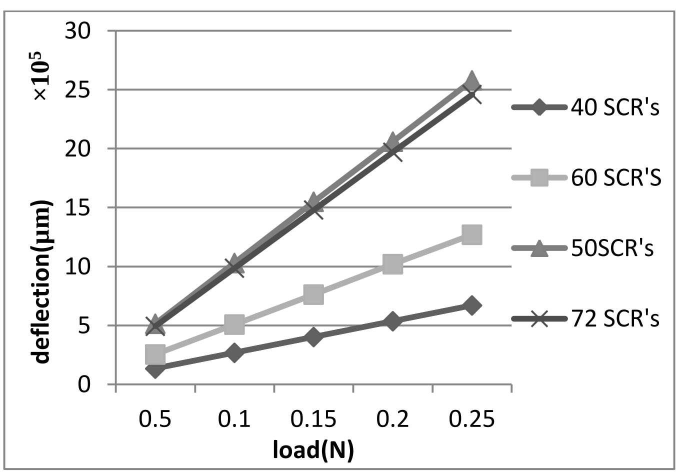

Fig . 14 Comparison of Deflection Characteristics Under Various Loads

Results show that among the microcantilver structures designed, the increase in the number of stress concentration regions resulted in the increase of stress and deformation characteristics. Various structures of Piezoresisitive microcantilvers are compared having various number of SCR's by determining the stress and deflection characteristics. Results show that the cantilever with 72 SCR's of length 250×100×1µm has greater stress and exhibits twice the deflection when load is applied

VI. CONCLUSION

This study projected a highly sensitive piezoresistive microcantilever to examine surface assimilation reactions. The stress and deflection characteristics of the projected style are compared to various microcantilever structures with stress concentration regions and with identical piezoresistor. Thus, the increase in the number of stress concentration regions resulted in the increase of stress and deformation characteristics. The increase in the length of the Piezoresisitive material also lead to increase the sensitivity of the MEMS Piezoresisitive micro-cantilever.

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