SIMULATION APPROACH TO DESIGN HIGH SENSITIVE NEMS BASED SENSOR FOR MOLECULAR BIO-SENSING APPLICATIONS

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ABSTRACT:

This research article utilizes the finite element method of analysis to achieve the finest throughput of piezoresistive nano cantilever sensor by minimizing the dimensions of both physical piezoresistor and cantilever. The 750nmx300nmx15nm-sized cantilever is incorporated with 5nm substantial Si as piezoresistor is used for revision. The proposed cantilever output performance has been calculated based onsurface stress sensitivity and displacement. A maximumresultant displacement value of about 12nm for the load of 100pN has been obtained . The Performance comparison between Polysilicon and SiO_2 cantilever has been found out by applied identical load and measured displacement. Similarly the sensitivity of the cantilever sensor by parametric sweep on thickness is applied for both cantilever and piezoresistor. The parametric sweep results shows that the sensitivity of the cantilever is highest when the thickness of both cantilever and piezoresistoris at the smallest. Poly silicon and SiO_2 based cantilevers with the built-in longitudinal cut at the bottom create stress concentration regions which will greatly improved sensitivity as high as 13.89% and 31.81% in comparison with other Non-SCR cantilevers for the proposed design.

Keywords: MEMS, NEMS, Biosensor, FEM, cantilever

I. INTRODUCTION

MEMS/NEMS based technology has been an extremely reliable and outstanding platform for the development of biological and chemical sensors. These

MEMS/NEMS cantilever based sensors are familiar recently due to better selectivity, sensitivity, ease of fabrication, along with its compactness makes on-chip e-circuitry. The piezoresistive method is often used to detect stress change on the surface cantilever due to biochemical reaction. The piezoresistive coating on the surface of cantilever experiences a strain change existence because of compressive force leads to a change in resistance. The piezoresistive technique offers many advantages like easy calibration, no external detection devices are needed to read, easy to deploy. However, this piezoresistive method has a very low resolution in comparison with the optical-detection system because of the involvement of very low forces and stresses in MEMS-based system development. Therefore, the inevitable solution to solve the existing low-resolution readout method is by improving the cantilever sensitivity. Many researchers reported alternative ways to improve the sensitivity of the cantilever with piezo-resistive cantilevers contain polysilicon based piezoresistor incorporated with doped single-crystalline silicon cantilever [6-8]. Other alternative approaches reported to improve the sensitivity of a sensor were optimizing geometrical dimensions of the cantilever and provided longitudinal cut at bottom of the cantilever as SCR[9- 10]. Reported in [11] as an alternate technique to improve the cantilever sensitivity by the reduction in cantilever noise. All these authors provided a strong base on semiconductor-based piezoresistive microcantilevers.

The recent researchers were reported few SiO_2 based cantilevers, which exhibits relatively higher sensitivity than Si cantilevers[12-14]. The Cantilever made up with SiO_2 provides good mechanical tip displacement as because of lower Young's modulus about 57-79 GPa than silicon at 130GPa. As Geometrical dimensions of the cantilever sensor scaled-down lead to the higher surface to volume ratio results in higher sensitivity and performance. In research, finite element method (FEM) be proposed on the way to investigate mechanical and electrical characteristics of the cantilever which is piezoresistive. Here proposed paper uses FEM analysis to acquire the finest performance of SiO_2 based microcantilever sensor by maintaining a proper trade-off between the dimensional characteristics of piezoresistor and cantilever. The twin-leg slim deposit of Si[100] is incorporated on top of rectangular-shaped SiO_2 cantilever like piezoresistive material. COMSOL simulation software with FEM analysis and fine meshing was used to solve the differential SiO_2 cantilever model.

II. BACKGROUND

According to Stoney's equation [15], differential surface stress creates adisplacement of cantilever and is given as:

$$\delta = \frac{3L^2(1-\nu)}{Et^2}(\sigma_1 - \sigma_2) \qquad (1)$$

where, ν is the Poison's ratio, δ *is the* displacement of the cantilever,E *is*the young's modulus,L and t are thelength and thickness of the cantilever beam, $(\sigma_1 -$

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σ_2)is the differential surface stressrespectively.The stress increases linearly with the distance and is zero. Hence, to attain high sensitivity a piezoresistor should be positioned at the surface of thecantilever beam next to the base. At that point, thestress can be calculated to be:

$$\sigma_{max} = \frac{6L}{Wt^2} \qquad (2)$$

$$F = \frac{3Et}{2L^2}\delta \qquad (3)$$

Where$W$ the width cantilever beam and$F$ is applied force.
The fractional resistance resultant change isgiven by:

$$\frac{\Delta R}{R} = \pi_1 \sigma_{max} = \beta \frac{6L\pi_1}{Wt^2} \qquad (4)$$

$$F = \frac{3Et\pi_1}{2L^2}\delta \qquad (5)$$

where $\pi_1$is piezoresistivecoefficient of Sion the room temperature,at given doping and β- correction factorranges from 0 to 1. By placing (1) in (3), theexpression for partial change in surface stress is given as:

$$\frac{\Delta R}{R} = \beta \frac{3L^2(1-\nu)}{Et^2}(\sigma_1 - \sigma_2) \qquad (6)$$

By making the thickness of the cantilever as thin as possible is the most important to get a major change in resistance, thus leading sensitivity of sensor. Thereby, introducing a longitudinal cut at the bottom fixed end of the cantilever creates most stress concentration region (SCR) of the microcantilever alternately lessening the cantilever resulting in high sensitivity of sensor but leads to poor mechanical strength.

III. Materials and Methods

The simulation is carried out with Comsol Simulation software-domain solver. Figure-1 shows the geometrical dimension of a SiO_2-based piezoresistive cantilever. The material properties are listed in Table-I.

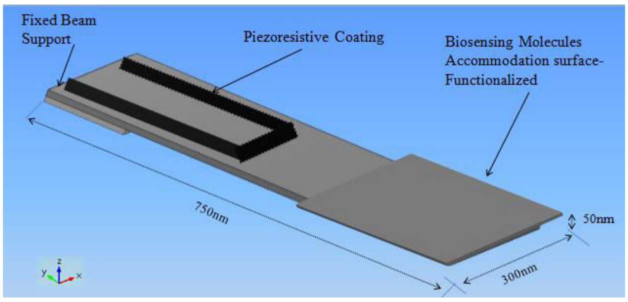


Figure 1: The dimension of a rectangular SiO_2 NEMS Cantilever integrated with a twin-leg Si piezoresistor.

proper super fine mesh is applied to the cantilever structure and unnecessary fixed based part without meshing in order to decrease the computational time and complexity.

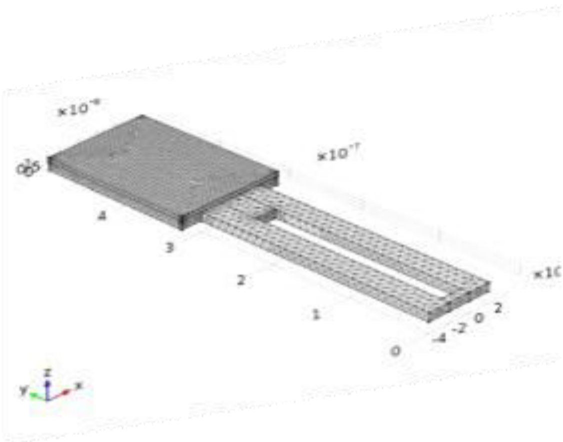


Figure 2: Super Fine Meshing to carry Finite Element Method of Analysis

The Common tensile and compressive forces found in biosensing applications lies in the range of pico Newton's (pN)[16].On the surface of piezoresistive cantilever, if a load of 100pN is applied thenobserve the end value of the lower range.

Table 1: Material Properties [13]

Parameters	Materials	
	Si	SiO_2
Young's Modulus (MPa)	1.30191 x 105	7.0 x 104
Poisson's Ratio 0.278	0.278	0.17
Piezoresistive Coefficients	Π11 : 6.60 x10-5 Π12 : -1.10 x10-5 Π44 : 1.381 x10	--

IV. RESULTS AND DISCUSSION

From the statistical analysis, the sensitivity of cantilever as shown in figure 3 and 4 are found from boundary load conditions and applied force in the order of pN on the surface cantilever. Figure 3 depicts the sensitivity analysis between SiO_2 and PolySilicon with identical geometrical characteristics. From this study, it evidently indicates SiO_2 has relatively significance in providing higher sensitivity than polysilicon and suitable for biosensing applications.

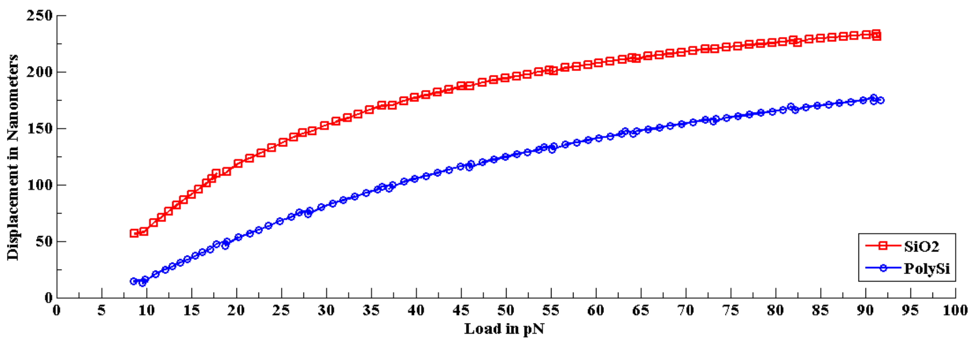


Figure 3: Comparison between Polysilicon and SiO_2 cantilever for the identical load conditions-parametric sweep with Load

With the use of parametric sweep for load from 0-100pN in simulation tool of COMSOL, both cantilever sensitivities over displacement and highest Mises Stress indicates same response. As shown in Fig. 4 and Fig. 5 as thickness increases in the cantilever the displacement decreases due to piezoresistive coating.

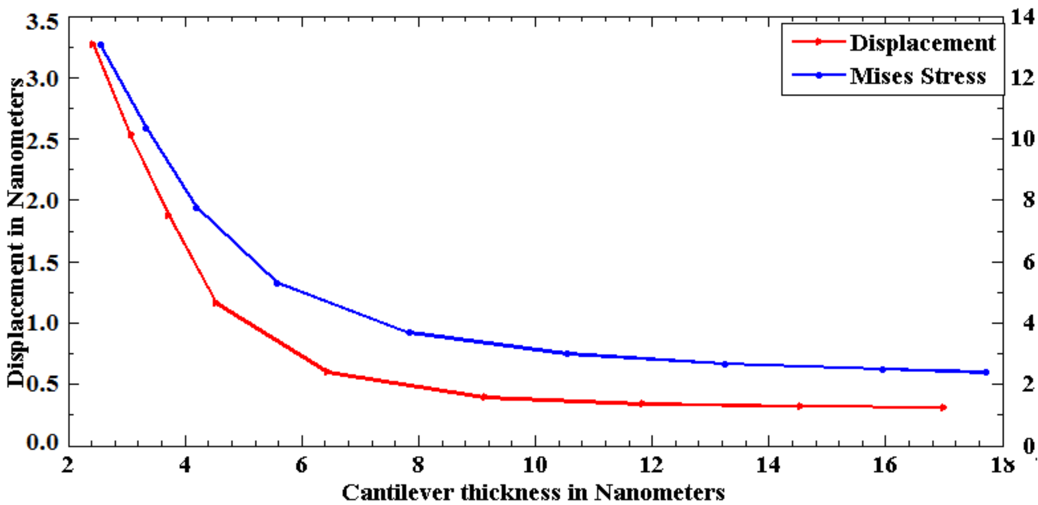


Figure 4: Displacement and Mises Stress values as functions of cantilever thickness Piezoresistor thickness is fixed at 5nm.

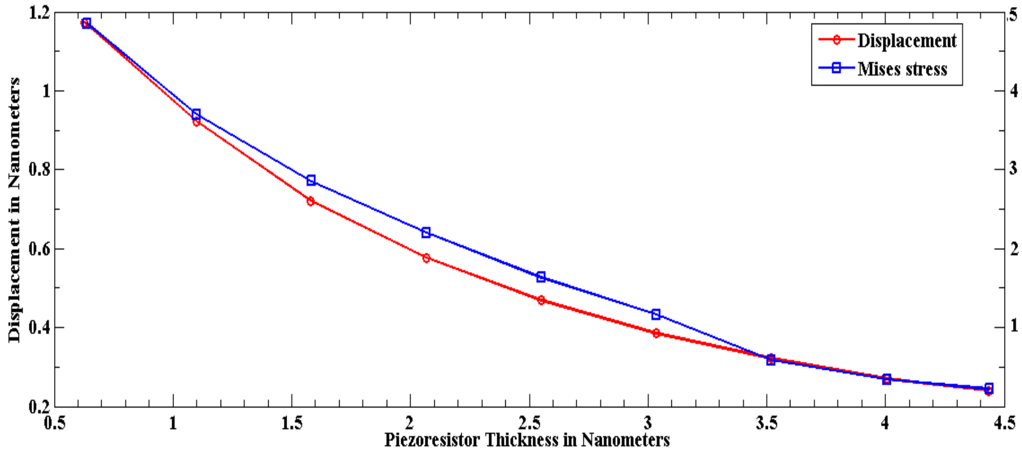


Figure 5: Static displacement and Stress with parametric sweep as function of piezoresistor thickness from 0.5 to 5nm, where cantilever thickness is fixed at 15nm

From the analysis of simulation results, piezoresistive cantilever behaviour in terms of resistance and change in current is estimated. The sensitivity of the cantilever surface is obtained by calculating the change in resistance (ΔR) with the maximum load as 100pN in negative z-axis with no load condition. A potential of 100mV has been applied on piezoresistor. Fig 6, shows the sensitivity of the cantilever when both the piezoresistive coating and physical cantilever thicknesses are minimum.

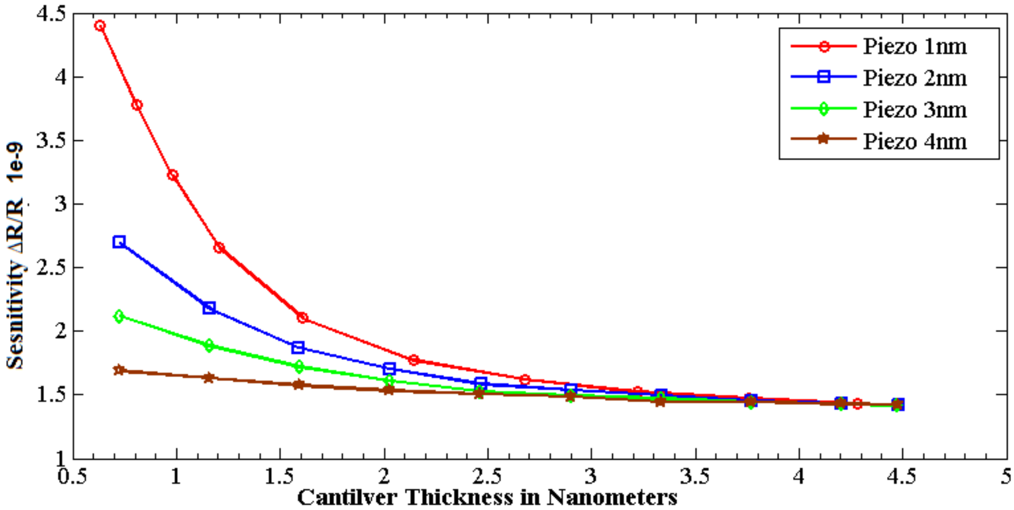
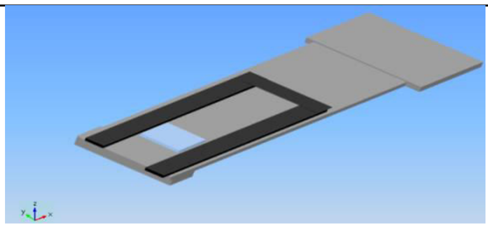
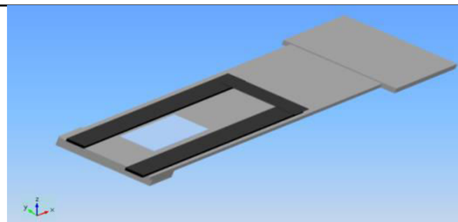


Figure 6: Sensitivity $\Delta R/R$, cantilever as thickness function along with variouspiezoresistor thicknesses

	
SCR-1	SCR-2

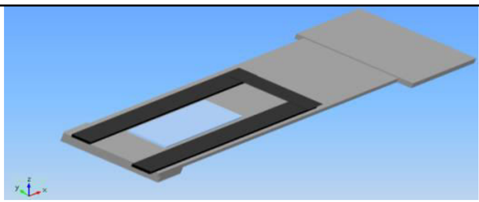
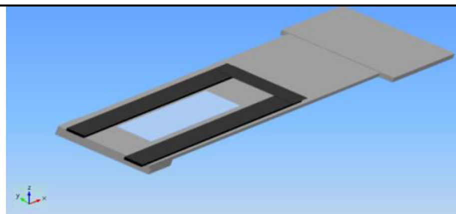
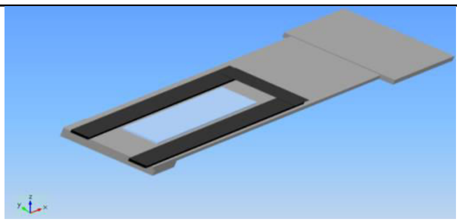
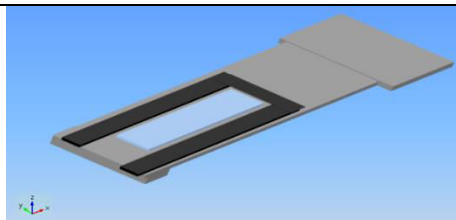
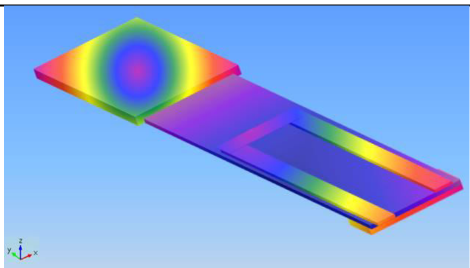
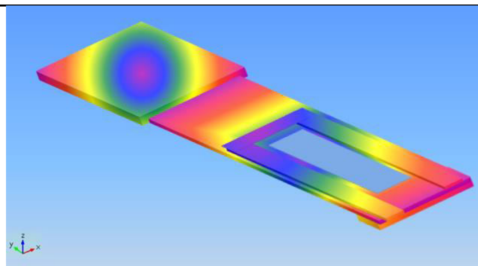
	
SCR-3	SCR-4
	
SCR-5	SCR-6
	
Non-SCR Simulation Model	SCR-Simulation Model

Fig. 7. Variable longitudinal cut to make a different SCRs in cantilever, Cantilever thickness is 15nm, piezoresistor thickness is 5nm

The cantilever sensitivity is studied by incorporating longitudinal cut to make effective stress concentration region or as by removing part of the cantilever segments from the bottom of the SiO_2 as shown in above figure 7. The 15nm deep segments apart of the fixed base is detached along the piezoresistor so as to improve SCR.

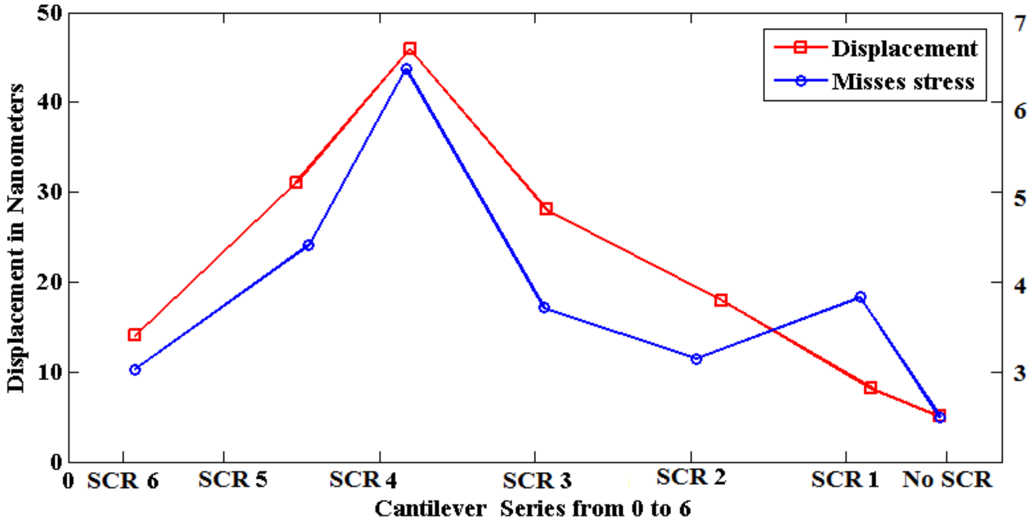


Figure 8: Displacement Sensitivity and Mises stress for cantilevers with different SCR.
Thickness of cantilever is fixed at 15nm, thickness of peziorestistor is 5nm.

Fig. 8 Shows that the cantilever with SCR design 4 shows stress and maximum displacement in comparison with additional designs. According to the above figure ΔR/R indicates an outstanding improvement for design over other designs

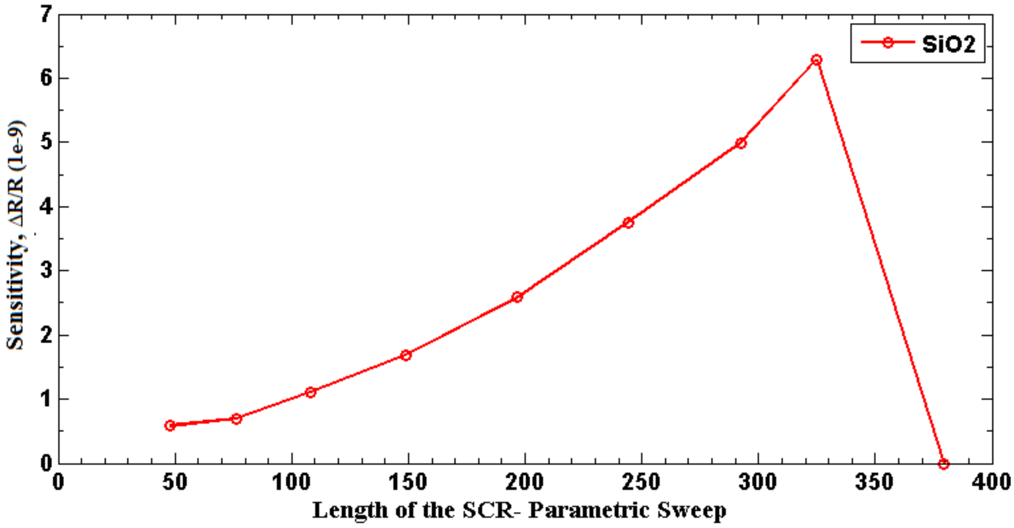


Figure 9: Mechanical Stiffness detection according to length of the longitudinal cut to form SCR

Further simulation and analysis to find the mechanical stiffness of the cantilever for molecular biosensing applications as the parametric sweep are carried out with respect to the length of the longitudinal cut. From Fig-9, it is observed that breakdown occurs at 330nm indicates the maximum possible length of the SCR for given design to obtain maximum sensitivity and stress.

V. CONCLUSION

In this paper, dimensional characteristics of NEMS based cantilever and piezoresistor are clearly with Finite Element Analysis in order to achieve the finest performance in Molecular-level Biosensing. Also, maximum surface stress and displacement with the thickness of piezoresistor and length of the longitudinal cut as highest stress concentration region has been analyzed. Conversely, the best possible length, width and thickness strongly depends on fabrication constraint and ability. From the result analysis, SCR-4 with material SiO_2 and polysilicon piezoresistive cantilevers shows relatively higher sensitivity as 13.89% and 31.81% for the proposed design.

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