A Survey on the Analysis of Diverse Micro Cantilever Shapes for Examining the Sensitivity Level of Biosensor in Biomedical Applications

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Abstract

The real time assessment of bio molecules is becoming more famous and label where the decrease in sensitivity level of micro cantilever reduce the analytes concentration. The sensitivity level of a micro cantilever biosensor is based on the interface among the bio molecule receptor and analytes which leads to deflection. In order to analyze the low concentration analytes, a bio sensor device called cantilever is constructed. The survey is conducted by introducing a device "cantilever" for detecting and measuring analytes which have low concentrations. A cantilever is a device which is placed on one end. Cantilever is the omnipresent beam structure in micro-electromechanical systems (MEMS). MEMS cantilever beams are formulated from various substances such as silicon (Si), poly-silicon and silicon nitride (Si_3N_4). The method of fabrication includes the feature of undercutting the structure of cantilever and it can be released with the aid of dry etching or anisotropic wet technique. The rectangular type of cantilever is introduced by placing the narrow strip at its fixed end by which the pliability of the cantilever gets reduced and the deflections are more at the other end. The ANSYS tool is used to examine and validate the above introduced model. The cantilever bends proposed in this survey are conventionally twice for the similar surface stress areas. This type of highly efficient structure maximizes the sensitivity level and the bio sensor range of cantilever. A widespread micro cantilever can be

premeditated by incorporating proposed and conventional cantilevers on the single chip and also helps to scrutinize the analytes in high concentration range.

Keywords: MEMS, Bio sensors, Micro cantilever, Sensitivity, ANSYS

1. Introduction

Micro-Electro-Mechanical Systems (MEMS) is the assimilation of sensors, actuators, and mechanical substance and electronics on a common substratum by the usage of micro technology. The word MEMS is used for sensing by the group of actuators and micro-sensors which has the facility of responding back to the changes occurred in the environment by the help of microcircuit control [2]. An attempt is made to shrink the sensors and actuators for the use of size and weight reduction, consumption of energy and the cost for fabrication. Assimilating both microelectronics and micro-machines on the single chip is feasible. The micro-sensors prepared by MEMS are utilized for computing the physical parameters. Micro-cantilever beams are the transducer elements by which the physical parameter changes can be computed. The main concept of MEMS is the combination of cantilever beam structure and its deflection [5]. The sensitivity of deflections can be performed by either piezoresistive or capacitive measurement. The main differences among the cantilever and beam are that a cantilever can be placed only at one end whereas the beam is placed at both the ends. The survey shows the effects of MEMS and cantilever using ANSYS tool.

Biosensors devices are well developed devices for transducing the bio recognition events into a quantifiable signal [11]. A biosensor comprises of a bioreceptor components. The component called “bioreceptor” that incorporates to it and identifies the target molecule. The two elements can be united to form a single sensor by biosensor. The basic method of examining and finding the biomolecule and bioreactors must be done for biosensing. This type of identifying is performed by labeling concept. But the concept of labeling turns out to be more costly and the consumption of time is also high. The most important requirements of future generation biosensors are label free detection capability, massive scalable parallelization and detection range sensitivity suitable for vivo difficulties. Hence the label free biosensor models are developed by the researchers. At present, there are types of elements for label free identification i.e. Quartz Crystal Microbalances (QCM), Surface Plasmon Resonance (SPR), Cantilever Array Biosensors (CAB).

One sample can be analyzed at a time by SPR. But limitation of this method is identifying the small molecules. Though the QCM method is highly sensitive than SPR, the scalability level is low since the mass identification capability is strongly based on surface of the sensor [6]. When compared to SPR and QCM the cantilever biosensors are found to be highly sensitive and high level of throughput can be attained by parallelization. One type of cantilever surface is prepared to be biosensitive to perform biorecognition by embedding sensing material in it and it is depicted in figure 1. This type of layer is comprised of boireceptors or covalently bonded materials to it and the method is called as functionalization. The resultant between the bioreceptor molecule and an analyte is distinct. The most usual methods of bioreceptors utilized in biosensing depend on antibody/antigen, proteins or nucleic acid interactions [1].

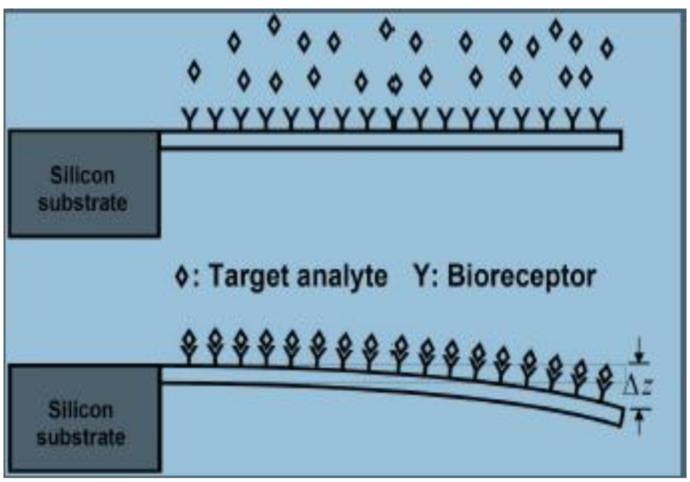


Figure 1: Working of a Cantilever Array Biosensor

The figure 1 tells that the stress caused by the surfaces may twist the cantilever due to the molecules absorbed into the surface of the cantilever which is functionalized. The first dispute was making the label free identification capability combined with massively scalable parallelization identified by cantilever biosensors (array based). The next dispute in cantilever array biosensor method is attaining the sensitivity level that is appropriate in the vivo measurement in identification range [8].

The in vivo identification of analytes in the large range needs a tremendously sensitive cantilever. This survey gives the future cantilever method that can evaluate the enormously low concentration analytes. The comparison is done by considering the deflection generated by stress at the surface level or by applying the concentration level at the other end are similar and this happens nevertheless of the primary mechanism. These two deflections can be compared by equating the level of surface stress to the level of bending stress of the cantilever. The first process is by computing the load by the above comparisons i.e. induced deflection of the surface stress is compared to load deflection [4]. The actual deflection can be attained by placing the load at the free end of the cantilever. This model can be analyzed by introducing the tool called ANSYS model.

2. Related Work

Wu et al. described that the induced deflection is said to be upward or downward based on the type of molecules present [16]. The deflection occurs in the cantilever due to the concentration of molecular variety and it can be determined by measuring the cantilever deflection. The deflection of the cantilever is based on the molar concentration present in the target analyte. McKendry et al. utilized eight types of cantilevers array to identify unlabeled DNA hybridizations at nanomolar concentrations in a minute [12].

Arntz et al. used a same array based method for real-time identification of two cardiac biomarkers proteins called myoglobin and kinase and levels shows the occurrence of heart disease called acute myocardial infarction [17]. They also suggested that protein sensitivity identification can be done by array method of cantilever which has less magnitude level than the DNA hybridization. Zhang et al. utilized micro cantilevers that are quick and label-free detecting the transcripts of biomarker in human RNA in picomolar range [3]. The remaining sections are described as follows: section 3 describes the working principle of cantilever array biosensor, section 4 describes the conclusion and section 5 describes the references.

3. Working Principle of Cantilever Array Biosensor

The beam of cantilever contains a fixed end and next is freely moving end for the provided load deflection. The length of cantilever is more compared to thickness and its width. The load is not provided when the cantilever is kept at the rest state and hence it is said to be horizontal as well as straight initially. The horizontal frame of the beam is warped into a curve like structure when the force is applied. The cantilever's beam is always based on the parameters like material type, length and the cross sectional shape of the beam [9]. The deflection level of cantilever also depends on the factors like applied load and the methods utilized for the beam. A Micro-cantilever is a type of device that can be utilized as chemical, biological or chemical sensors by identifying the alterations in bend of the cantilever or resonant frequency.

Resonant frequency is termed as the system frequency where the maximum level of amplitude gets oscillated. This type of frequency is equivalent to the natural frequency of the system while performing little damping. The system is said to be resonant when the resonant frequency is attained. The system mass is changed by attaining the resonant frequency. It is described by the natural frequency,

$$\omega^0 = \sqrt{k/m} \qquad \text{------- (1)}$$

Here,

- ω^0 → Circular frequency
- k → spring constant
- m → mass

The spring constant is assumed to be $k = Et^3w/4t^2$ -------- (2)

The spring constant k is the function of various parameters like,

- The elasticity property of a material is given as Young's modulus →E
- The beam width is denoted as →w
- The beam length is denoted as →l
- The beam thickness is denoted as →t

The functioning of the cantilever can be performed by embedding the bioreceptor layer on the top of the surface and inducing the surface level of stress by binding the deflection between bioreceptor and target analytes at the bottom. Even though the label free identification ability and level of scalability to permit the access for massive parallelization is attained by cantilever method based biosensors, the another dispute in cantilever biosensor is attaining the level of sensitivity for detecting the range applied to in vivo analysis. The cantilever must be very sensitive enough for analyte in vivo detection in extremely high dynamic range [18]. The survey introduces the new design of cantilever that can analyze analytes which have low concentrations. The mechanisms are used to identify the level of deflection generated by either a concentrated load or by a surface stress that is applied at one end are similar and the methods can be compared. The two deflection level can be compared by equating this to cantilever's bending stress. First, the load is calculated by considering the level of surface stress which has induced deflection equivalent to induced deflection of concentrated load [10]. The original deflection level is attained by applying the load at the free end of the cantilever. A method of finite element analysis software ANSYS tool is employed to examine the proposed model.

3.1 Theory

The concept of functionalization theory is applied in Bio-MEMS cantilever sensor. Here, the micro cantilever is said to be biosensitive by coating the bioreceptors above it. The bend of the micro cantilever is noticed by applying the biochemical reaction between the bioreceptor and applied analyte. This warp occurrence is due to internal stress produced by the beam and it occurs in the terms of upward or downward deflection [7]. The deflection gets increased in the beam of the rectangular micro cantilever by maximizing the length of the beam and minimizing the thickness of the beam. The design of the micro cantilever also produces the free end deflection and this free end deflection is based on the materials used. The more deflection gets produced at the free end of the micro cantilever by using elastic material. The Hook's law tells that, "the deflection occurring at the free end of micro cantilever is directly proportional to the applied load".

$$\delta \propto F \qquad \text{……… (3)}$$

$$\delta = aF \qquad \text{……… (4)}$$

Where,

- F → Force
- a → 1/k
- δ → cantilever free end deflection and t is the force generated by applying biochemical reaction between the bioreceptor and analyte.

- K → spring constant and it always depends on flexural rigidity.

The sensitivity mode of the micro cantilever beam is described in the static mode as the modifications in the deflection at the free end for the modification in mass loading on the surface of the micro cantilever. The sensitivity expression can be described as;

Sensitivity = change in deflection /change in molecular pressure …….. (5)

When the biosensors transforms the small changes in the unit of pressure into quantifiable deflection at the free end, then the biosensor is said to be highly sensitive. The method can be combined and the formula for conventional rectangular micro cantilever beam of free end deflection is given by,

UDL Force, $$\delta = \frac{qwl^4}{8EI} \qquad \text{………. (6)}$$

Point Load, $$\delta = \frac{Pl^3}{3EI} \qquad \text{………. (7)}$$

Where,

- q and P → uniformly distributed point load.
- E and I → Young's modulus and moment of inertia (rectangular beam).

The correlation between point load and induced surface stress is given as;

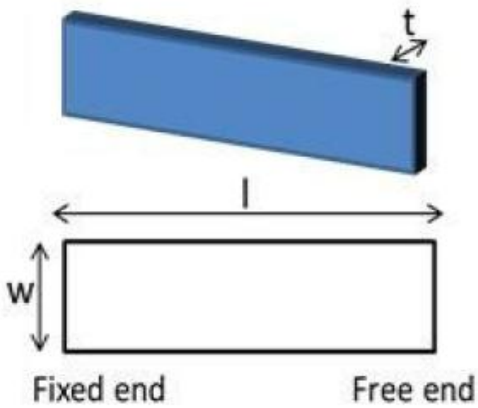
$$P = \frac{\sigma wt(1-v)}{l} \qquad \text{……… (8)}$$

The pressure equation can be written by taking the equations (7) and (8) and the free end deflection statement of predictable rectangular micro cantilever beam is given as,

$$\delta = \frac{3pl^4}{2Et^3} \qquad \text{………. (9)}$$

Where,

- p → biomolecules generated pressure on the micro cantilever surface.
- 'σ' and 'γ' → the stress and Poisson ratio for the beam.



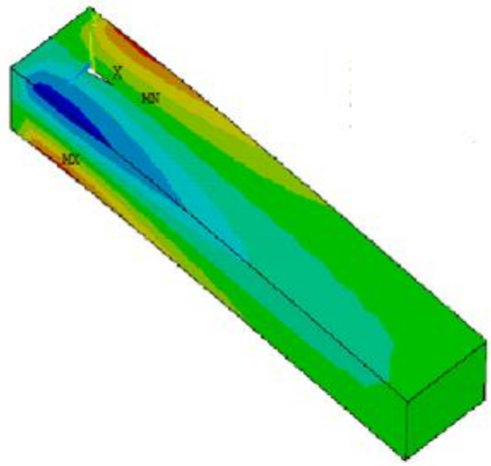


Figure 2a: Design of Micro Cantilever Beam **Figure 2b: Free End Deflection**

By inoculation of myoglobin protein the maximum level of surface stress is produced on eight cantilever array is 0.05 N/m and this case is shown in Figure. 2(a) for the conventional rectangular micro cantilever beam, and when the value of length (l), width (w) and thickness (t) are given as 500 µm, 100 µm and 50 µm and then the pressure generated by the stress at the surface level (0.05 N/m) is 19.2 Pa. The pressure for the free end deflection of the rectangular cantilever beam is 0.11×10-9 m and that is illustrated in Figure. 2(b).

3.2 Proposed Cantilever Shape Structure

The three types of micro cantilever beam designs are proposed for the biomolecules detection and they are effectual used in 'in vivo analysis' and the loading of the cantilever mass surface is quite low [15]. The proposed design may generate freer end deflection at the micro cantilever beam and the finite element method tool ANSYS is used for detecting and measuring analytes which have low concentrations and this type of highly efficient structure maximizes the sensitivity level and the bio sensor range of cantilever. The survey discusses the three types of micro cantilevers and they are noted below.

- Rectangular Beam
- Center Fixed Beam
- Tapered V – Shaped Beam

Figure 3: Rectangular Beam

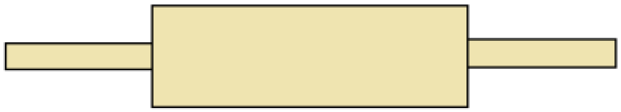


Figure 4: Center Fixed Beam

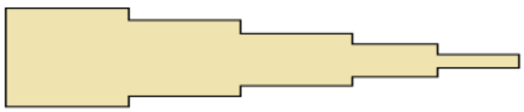


Figure 5: Tapered V – Shaped Beam

The designing the shapes and orientations are based on the concept of Miller indices. The Miller Indices features are effectively used to construct the materials in cubic crystal families [14]. The comparative study of the material change of the cantilevers is implemented and the variations in stress, strain, and total warp of cantilevers are generated. Table 1 shows the change in resultant stress, strain and total warp with change in material of cantilevers.

Material Properties	**Material Names**		
	SiO_2	**Si_3N_4**	**Poly-si**
Young's Modulus(Pa)	70E9	250E9	160E9
Density(Kg/ m^3)	2220	2400	2320
Poisson's Ratio	0.17	0.23	0.22
Length(μm)	110	110	110
Width(μm)	30	30	30
Height(μm)	3	3	3
Force(N/ m^2)	1	1	1
Equivalent Stress (Max.)	2.54E12	2.59E12	2.58E12
Equivalent Strain(Max)	34.936	9.9967	15.553
Total Deformation(Max)	0.09324	0.02594	0.04058

Table No: 1 Change in resultant stress, strain and total warp with change in material of cantilevers

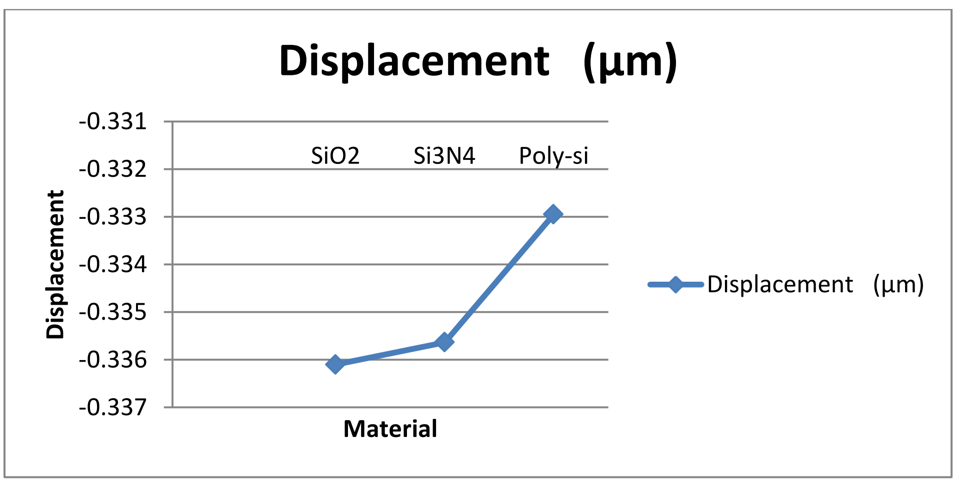
These above described structures are examined by considering the parameters:

- Materials
- Dimensions of the structures

The shape's dimensions of the structures can be different with respect to the length, gap the plates, width, thickness, etc.

Material	**Displacement (µm)**	**Reaction Force (10^{-6})N**
SiO_2	-0.336102	19.6426
Si_3N_4	-0.335635	24.7171
Poly-si	-0.332950	14.2899

Table No: 2 Rectangular Beam with l=35 µm



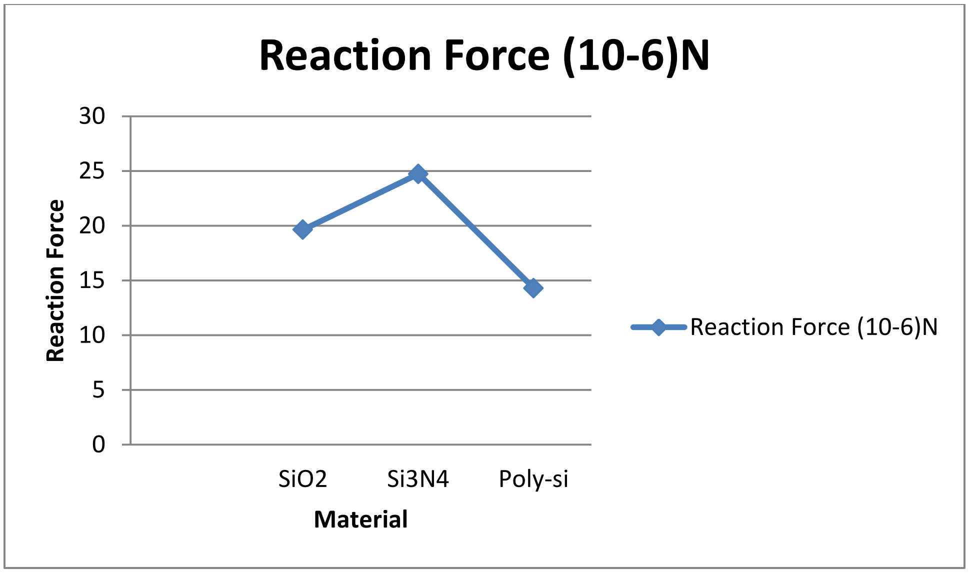
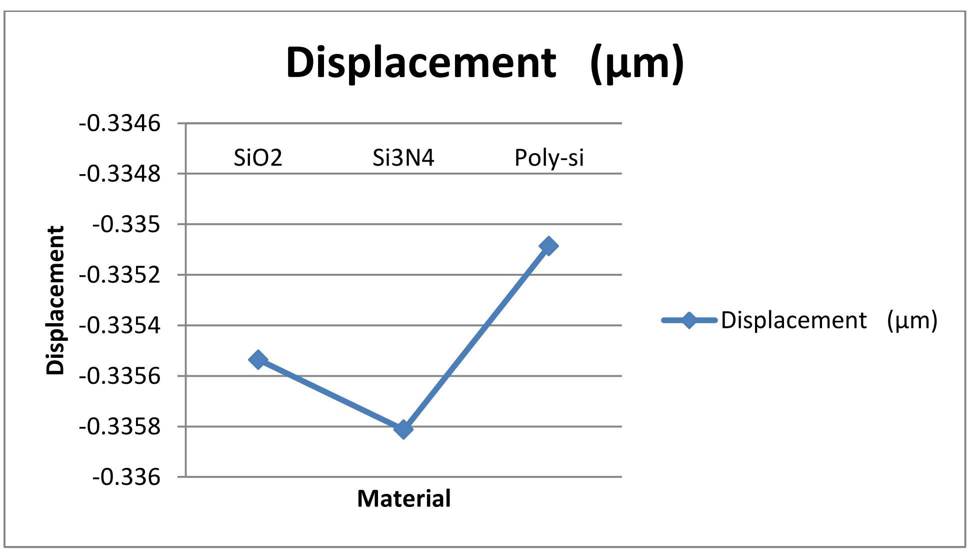


Figure 6: Rectangular Beam with l=35 µm

Material	Displacement (µm)	Reaction Force (10^{-6})N
SiO_2	-0.335536	1637.91
Si_3N_4	-0.335813	3272.92
Poly-si	-0.335086	2545.13

Table No: 3 Center Fixed Beam with l=35 µm



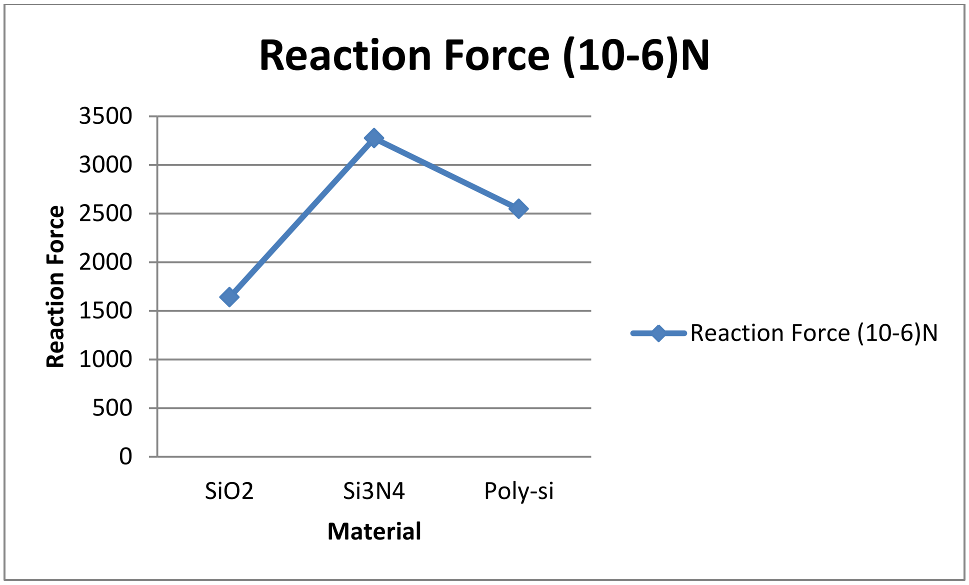
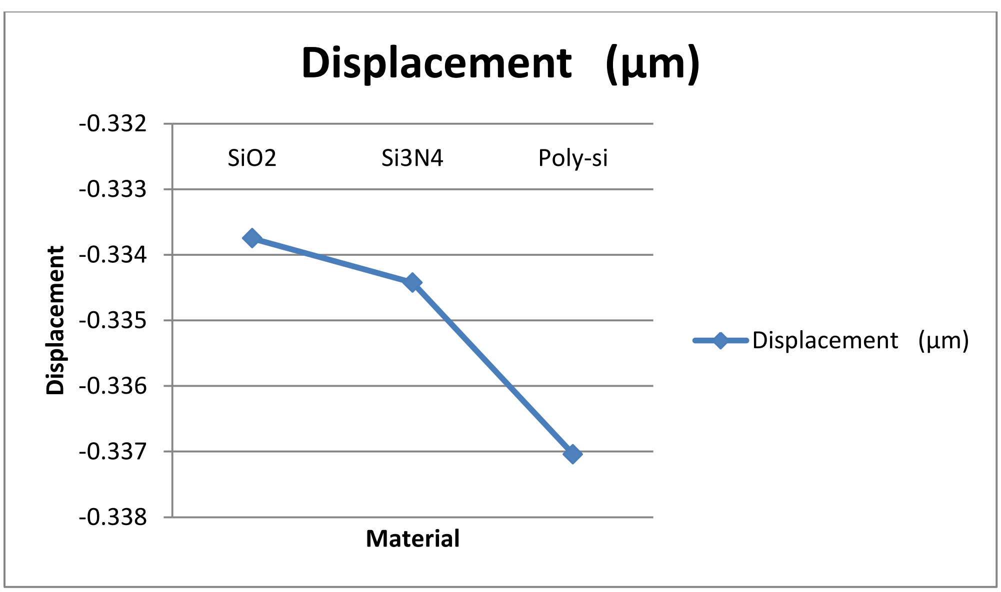


Figure 7: Center Fixed Beam with l=35 µm

Material	Displacement (µm)	Reaction Force (10^{-6})N
SiO_2	-0.33375	10.1923
Si_3N_4	-0.334425	13.084
Poly-si	-0.337042	7.67437

Table No: 4 Tapered V Shaped Beam with l=35 µm



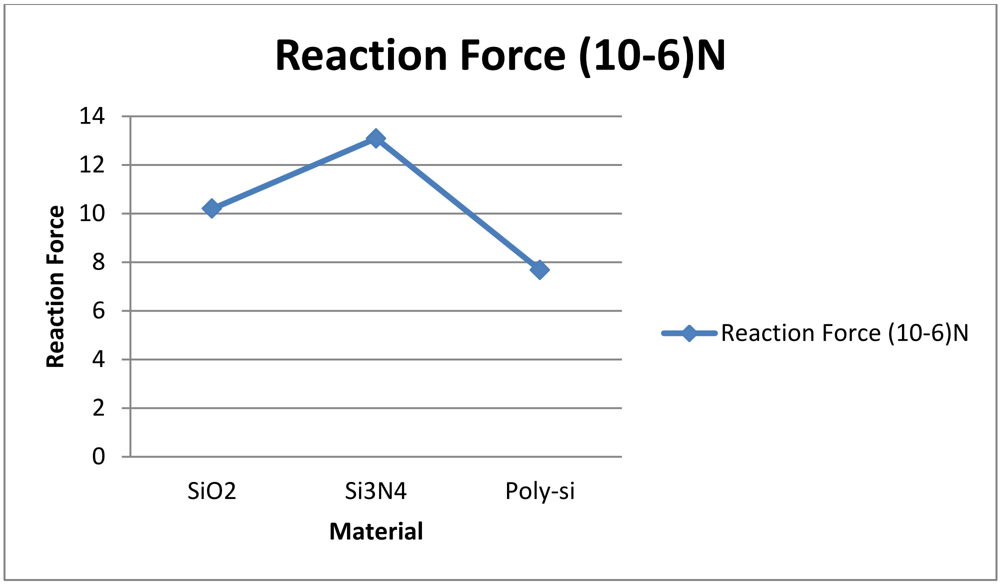


Figure 8: Tapered V Shaped Beam with l=35 µm

The table 2 and figure 6 depicts the displacement and reaction force of the various materials of the rectangular shaped beam whose value is l=35 µm, The table 3 and figure 7 depicts the displacement and reaction force of the various materials of the center fixed shaped beam whose value is l=35 µm, The table 4 and figure 8 depicts the displacement and reaction force of the various materials of the tapered V shaped beam whose value is l=35 µm. The above projected method increases the rate of deflection at the free end of the micro cantilever while comparing with the fixed beams due to the large surface area. The bioreceptors fixed at the micro cantilever surface are maximum at the free end and connect about all analyte molecules at the beam's free end [13]. The biochemical reaction is very high because of the more number of connections at the free end of the micro cantilever that displays the high level of deflection at the free end when compared to conventional rectangular micro cantilever beam.

4. Conclusion

The performance analysis is achieved on the small cell rather than the entire structure in 'in vivo analysis' and the more sensitive biosensors are needed. These type high sensitivity sensors are utilized to exchange the low level activities of biomolecules into a reckonable quantity. Hence the various micro cantilever beam structures are examined for the attainment of better deflection. The survey projected three types of beam structures that afford free end deflection. From the above parameters, different things existing in micro cantilever are analyzed. The outcomes assist for scrutinizing the sensitivity level of cantilever that is utilized for different types of biosensing applications like glucose detection, colorectal cancer stage detection, etc and also for the potential extent.

5. References

[1] Anchit J.Kaneria, D.S.Sharma, R.R.Trivedi. Static Analysis of Electrostatically Actuated Micro Cantilever Beam, Procedia Engineering 51, 2013, pp.776-780.

[2] Huan Hu(Alan), Ben Murphy, and Sylvester Ogletree, Prof. Horacio D. Espinosa, Microcantilever based Biodetection, (2007).

[3] J. Zhang, H.P. Lang, F. Huber, A. Bietsch, W. Grange, U. Certa, R. McKendry, H.-J.Guntherodt, M. Hegner and CH. Gerber, “Rapid and label-free nanomechanical detection of biomarker transcripts in human RNA”, Nature Nanotechnology, vol. 1, 2006, pp. 214-220.

[4] M. Calleja, M. Nordstrom, M. Alvarez, 1. Tamayo, L. M. Lechuga, and A. Boisen, "Highly sensitive polymer-based cantilever-sensors for DNA detection,"Ultramicroscopy, vol. 105, pp. 215-222, 2005.

[5] Maziar Norouzi, Alireza K, “Design of Piezoelectric microcantilever Chemical Sensor in Comsol Multiphysics Area”, Electrical and Electronics, Vol.2, issue 1, No.184, 2009.

[6] Mohd. Zahid Ansari and Chongdu Cho* ”Design and Analysis of a high sensitive Microcantilever Biosensor for Biomedical Applications”IEEE conf.IEEEIEEE 2008.

[7] Monika Chaudhary and Amita Gupta, Microcantilever-based Sensors, (2009).

[8] N. I. Abu-Lail, M. Kaholek, B. LaMattina, R. L. Clark, and S.Zauscher, ”Micro-cantilevers with end-grafted stimulus-responsive polymer brushes for actuation and sensing,” Sensors and Actuators B: chemical, vol. 114, pp. 371-378, 2006.

[9] N.MuruguNachippan, V. Balaji, SallaVenkataSubba Reddy, K. Logesh, Enhancement of deflection of micro cantilever beam for improving the sensitivity of biosensor, 0974-4290(2015).

[10] Nitin S.Kale, V.Ramgopal Rao,”Design and Fabrication Issues in Affinity Cantilevers for bioMEMS Applications”,Micro Electro Mechanical Systems,VOL.15,NO.6,2006 .

[11] R. Edwin Fernandez, S. Stolyarova, A. Chadha, E. Bhattacharya, and Y. Nemirovsky, Fellow, IEEE ”MEMS Composite Porous Silicon/ Polysilicon Cantilever Sensor for Enhanced Triglycerides Biosensing” IEEE SENSORS JOURNAL, VOL. 9, NO. 12, december 2009.

[12] R. McKendry, J. Zhang, Y. Arntz, T. Strunz, M. Hegner, H.P. Lang, M.K. Baller, U. Certa, E. Meyer, H-J Guntherodt, and C. Gerber, "Multiple label-free biodetection and quantitative DNA-binding assays on a nanomechanical cantilever array", Proc. Natl Acad. Sci., USA, vol. 99, 2002, pp. 9783- 9788.

[13] R. Raiteri, M. Grattarola, H. J. Butt,Micromechanical cantilever based Biosensor, Sensors and Actuators B, vol.79, 2001, pp.115-126

[14] Robert Littrell et.al. : Modelling and Characterization of cantilever based MEMS piezoelectricsensors and actuators, JournalofMicroelectromechanical Systems Vol.21 No.2 pp.406-413 (2012).

[15] Suryansh Arora, Sumati, Arti Arora, P.J George, "Design of MEMS based Microcantilever using Comsol Multiphysics", Applied Engineering Research, Vol.7 No.11, 2012.

[16] Wu, H. Ji, K. Hansen, T. Thundat, R. Datar, R. Cote, M.F. Hagan, A.K. Chakraborty, and A. Majumdar, "Origin of nanomechanical cantilever motion generated from biomolecular interactions", *Proc. Natl. Acad. Sci.*, USA, vol. 98, 2001a, pp. 1560-1564.

[17] Y. Arntz, J.D. Seelig, H.P. Lang, J. Zhang, P. Hunziker, J.P. Ramseyer, E. Meyer, M. Hegner, and C. Gerber, "Labelfree protein assay based on a nanomechanical cantilever array", Nanotechnology, vol. 14, 2003, pp. 86-90.

[18] Yang-Choon Lim, Abbas Z. Kouzani, Wei Duan, and AkifKaynak "Effects of Design Parameters on Sensitivity of Microcantilever Biosensors" IEEE ICME Conf. 2010,July 13-15, 2010.