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Design and Analysis of MEMS Piezoresistive Three layers Microcantilever-based Sensor for Biosensing Applications

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Abstract. ***The field of Microtechnology and Micro-Electro-Mechanical Systems (MEMS) has grown exponentially during the previous two decades .This work is dedicated to finite element (FE) 3Dstructural modeling of three layers micromechanical sensors in ANSYS 13.0 gives 3D model which are close to reality mathematical models. Material used in cantilever for different layers are silicon-dioxide, poly-silicon and nitride. . The emphasis of the analysis is put on tile effects of the angle of inclination of the concentrated force upon the deformed shape, the load-deflection relationship stresses and strain for further analysis with a greater degree of accuracy. The model we made is three layers microcantilever where the centre layer i.e. second layer, is piezoresistive layer that helps to calculate Characteristics i.e. deflection, deformation, stress and strain in the cantilever for the given applied force that can we used for future analysis for the detection of biomolecules in various biosensing application.***

Keywords- Microcantilever, Piezoresistive, Young modulus and Elasticity.

I. INTRODUCTION

Microelectromechanical System (MEMS) is a rapidly growing technology with a broad range of commercial applications, mainly in sensors and actuators fields. Micro cantilever sensors have emerged as a universal, very powerful and highly sensitive tool to study various physical, chemical, and biological phenomena. As biosensors, they are found to display label-free, real-time and rapid assaying features. Microcantilevers detect bending or vibrational frequency. Hence it is suitable as a physical, chemical or biological sensor. Microcantilever mechanism is similar to diving board moving up or down at regular interval.

One side of the cantilever can be shown to deflect due to stress and as a result detect the molecular adsorption. Chemical bonding of the molecule decides upward or downward deflections. Mechanical detection systems in Biochip use Microcantilever dual material (e.g. Au-Si). These beams are used as sensing elements. Receptor coating of material belonging to Au is done. Receptor surface gets into a state of tension or release depending on analyte binding (e.g. biological molecules, such as proteins or biological agents). Cantilever deflections are proportional to analyte concentration and in the range of nanometers are further measured using optical techniques. . This idea has been utilized in screening certain diseases such as cancer. Chemical and biological warfare agents' detection is also based on this concept [7]. For the electrical detection of surface stresses observed in Biosensing applications, composite piezoresistive cantilever structures are used as the sensing elements. In such a cantilever structure, it is necessary to understand how the variations in material type, thickness, and piezolayer placement within the cantilever stack affect the cantilever response to surface stresses [1].

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II. PIEZORESISTIVE DEFLECTION DETECTION METHOD

T he surface of the cantilever is embedded with peizoresistive material to account for stress change at the surface. This is known as piezoresistive method. Deflection of cantilever due to stress change will create strain to the piezoresistor. This strain in piezoresistor will change its resistance ''1,''and will be recorded and measured electronically. The merits of the piezoresistive method can be seen as it whole readout system can co-exist on the same chip [3]. It is known that application of strain changes resistance of the peizoresistive material. The two physical quantities are related as follows ''1,''

$$\Delta R / R = K_l \, \delta_l \, K_t \, \delta_t \qquad (1)$$

"K" is the material dependent gauge factor. The gauge Factor has longitudinal and transverse components denoted by subscripts "l" and "t" respectively. The deflection of the free end of the beam depends on the type of loading to which the beam is subjected. If a concentrated load, *F*, is applied to the free end of a rectangular beam, then the deflection of the free end of the beam, δ, is given as ''2,''

$$\delta = FL^3 / 3EI \qquad (2)$$

III. MECHANICAL PROPERTIES OF CANTILEVERS

Cantilever is characterized by two basic mechanical quantities, the spring constant and the resonance frequency [5]. The applied force F is directly proportional to the bending of cantilever "z" and the spring constant k is the proportionality factor. This is the well known relation knows as Hooke's law. It is mathematically written as ''3,''

$$F = -k.z \qquad (3)$$

Stiffness of the cantilever is produced due to the spring constant. Spring constant for a rectangular cantilever of length l is given by ''4,''

$$K = 3.E.I / l^3 \qquad (4)$$

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Where *'E'* is the Young's modulus and *'I'* is the moment of inertia.
For a cantilever made up of several layers, i.e., a composite Structure, *'EI'* is given by ''5,''

$$EI = w\sum (E_i(h_i^3/12 + h_i(z_i - z_N)^2)) \qquad (5)$$

Where *Ei* is the Young's modulus of the *i*th layer, *hi* is the thickness of the *i*th layer, z_i is the distance of the layer from the neutral axis, and z_N is the neutral axis and is given by ''6,''

$$z_N = \sum_i E_i z_i h_i / \sum_i z_i h \qquad (6)$$

The neutral axis signifies a plane in the structure having zero stress [1].
Silicon, nitride, or silicon oxide cantilevers are widely used in commercial applications. They come in a wide variety of different shapes, dimensions, and force sensitivities. CMOS VLSI development featuring nanometer dimensions of transistors and latest ICs have made it feasible to get an array of smart and intelligent cantilevers [4].

IV. MICROCANTILEVER DESIGN

ANSYS design is shown in Fig.1
It is the three layer microcantilever of different material.

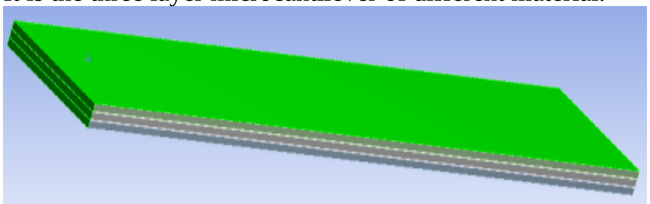

Fig 1.Microcantilever beam Design in ANSYS 13.0

IV. I. Design Step

A. Problem Description:

We have microcantilever beam and calculating different parameters i.e.

- Deflection of the beam
- Deformation of the beam
- Maximum bending stress along the beam.
- Bending moment along the beam

B. Build Geometry:

Here we define the length, breadth and depth of microcantlever in micrometers. In this, by using Extrude function, to generate a rectangular model of three layer microcantilever. The Geometer parameters of cantilever are:
Length: 100 um
Width: 30 um
Depth/Height: 4.5 um

C. Define Material

Material that we use to make a cantilever i.e. silicon dioxide, poly-silicon and nitride with their different elastic properties like Young Modulus, Poisson's ratio and density .

D. Generate Mesh

In order to achieve results that are reliable when using the finite element method one has to use an acceptable element mesh with respect to the shape and size of the elements. Free meshing is not easier to control as opposed to mapped meshes which are more accurate. Mapped meshes are customizable as it gives user control over size and shape of the mesh in local regions. 2D and 3D elements of mapped meshing is as shown in Fig.

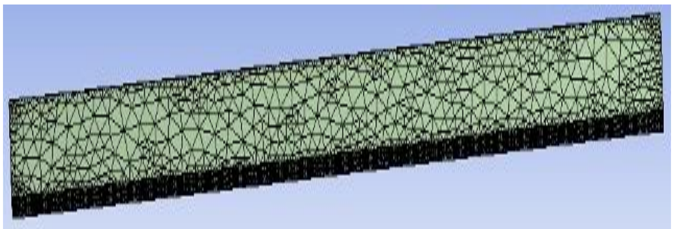

Fig.2 Meshing of cantilever

E. Apply Load

Boundary conditions are another important consideration in MEMs. There are displacement, support and force boundary conditions for solids and structures. Here, the force of 5 uN is applied at the edge of the cantilever is fixed as shown in Fig.3.

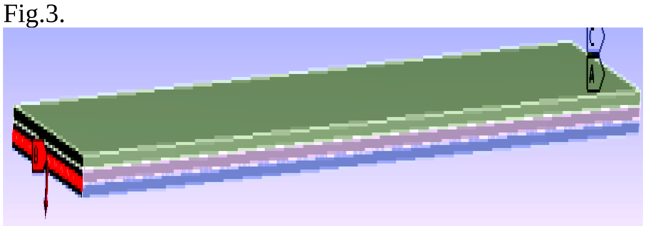

Fig.3 Force applied at point with fixed edge

F. Obtain Solution & review results

After all deciding the parameters cantilever we obtained the various result as given as;

1. Stress
2. Strain
3. Total deformation
4. Directional deformation (Deflection)

V. MICROCANTILEVER SENSORS APPLICATION

Generally, biosensing is a more demanding task than physical or chemical sensing because of the complexity of the biochemical processes involved and the nature of the operation environment. In biosensing applications, detection is usually carried out in a liquid (aqueous) environment. Flow and mixing of the solution cause turbulence which directly affects cantilever deflection. Additional drifts in deflection have been observed. They can be due to both slow electrochemical processes on either side of the cantilever and to rearrangements of the sensing surface, which is usually composed by multilayers of complex molecules like proteins. Various application of microcantilever in different field is illustrated as below:

1. Detection of DNA, Enzymes & proteins.
2. To count number of bacteria in air.
3. Detection of humidity.
4. Explosive vapour detection.
5. Diagnosis of Tuberculosis
6. Detection of Explosive.

VI. RESULTS AND OBSERVATION

The MicroCantilever is designed of three layers with different material i.e. Silicon dioxide, Poly-Silicon and Nitride. All these material have different properties, like Young Modulus, Poisson Ratio and densities etc. that is shown in Table.1.

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Table.1 Elastic Properties of different materials.

S. No	Materials	Elastic Young Modulus (MPa)	Poisson Ratio
1	SiO_2	70000	0.3
2	Polysilicon	75000	0.22
3	Nitride	4500	0.44

The force-deflection curves for microcantilever were obtained by fixing the one end of the cantilever and applying force of 5 uN to the "Load" end (*DOF is in Z-axis) [1]. *DOF- Degree of Freedom.

The simulated model in ANSYS 13.0 is shown in Fig.4. Here the Blue color end is fixed and opposite side is free to move. So the effect of force applied at the free end has the maximum deflection as shown by Red color in Fig.4 and the blue color end has the minimum deflection of cantilever.

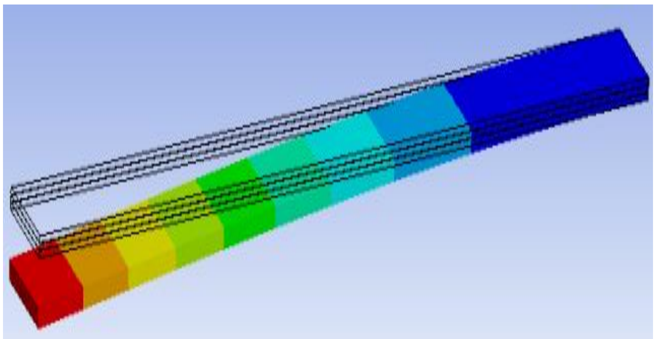

Fig.4 Deflection contour of microcantilever by applied force.

Here we shown the strain obtained in different areas of cantilever of applied force.

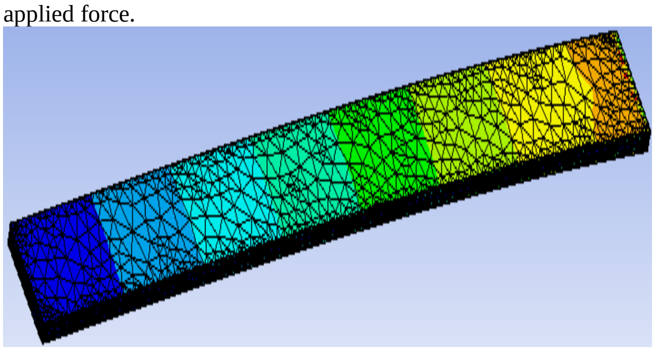

Fig.5 strain contour band after simulation in ANSYS 13.0

We obtained all the values for stress, strain, directional deformation (deflection) and total deformation in cantilever by using ANSYS 13.0.

The graph obtained for Force applied vs. Deflection in microcantilever. This shows the deflection of cantilever in both the direction positive as well as negative as shown Fig.6.

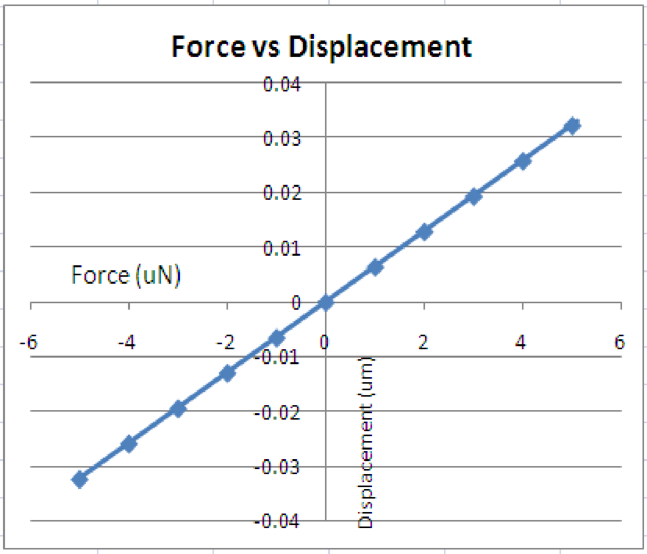

Fig.6: Deflection component v/s Force component

Fig.6 shows the deflection component varies linearly along with force component. As the force increases the deflection of the microcantilever increases. The values obtained are almost near to the real theoretical values of model.

Also the deformation in the microcantilever is calculated that is shown in fig.7. Here also the deformation is increases with the increase in the force applied at the edge of microcantilever.

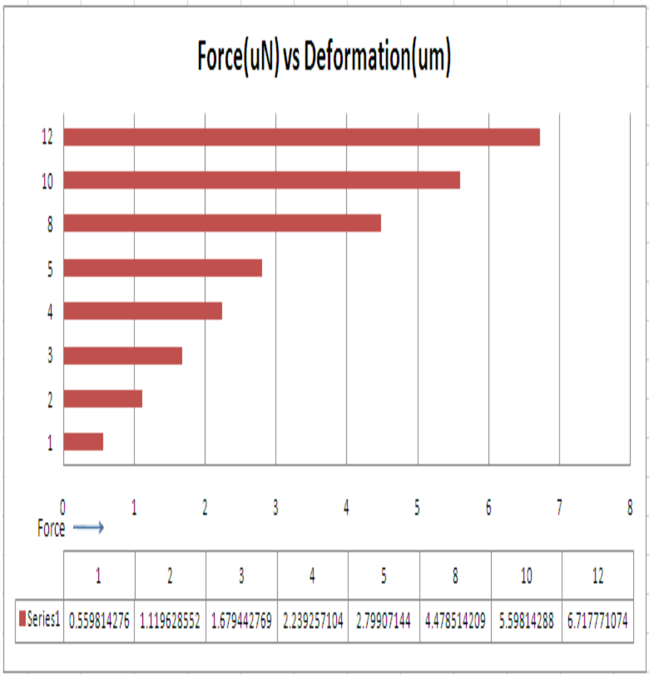

Fig .7: Effect of force component v/s Deformation

The graph obtained between the stress v/s strain in shown below in fig [8].

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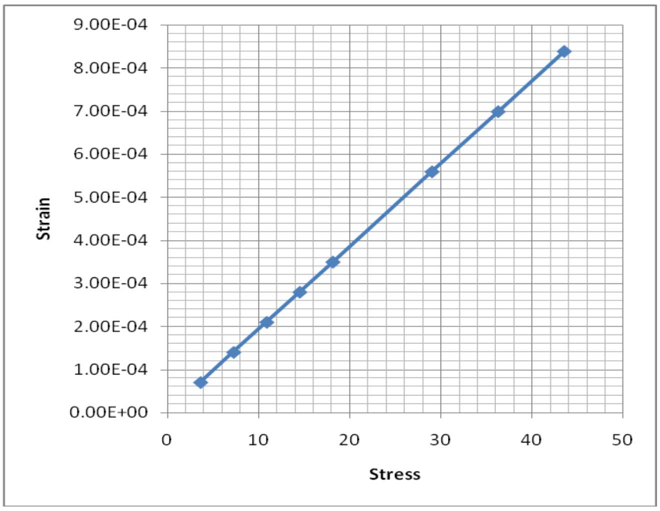

Fig.8: Graph of Stress v/s strain

Final result obtained is summarized in Table.2. , where the value of all four components that we have calculated i.e. deflection , deformation , stress and strain for given applied force as shown in Table.2.

Table.2: Values obtained for particular amount of force.

Force [uN]	Deflection [um]	Deformation [um]	Stress []	Strain
5	0.0323	2.7990	18.1448	0.000349
10	0.06463	5.5981	36.289	0.00069

VII. CONCLUSION

From the above observations, we have analyzed and calculated the different types of parameters that are induced in microcantilever which nearly equal to theoretical model values. These all results help us to observe the sensitivity of the cantilever that is used for various types of biosensing application and for future scope.

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