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MEMS Bio-sensor with capacitive read out for Tuberculosis Detection

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Abstract:— The Micro-electronics mechanical system is a popular ever growing domain in microscopic devices. The size of the micro devices varies in the range of 0.001 to 0.1mm i.e., 1 to 100 micrometers. This paper focus on the detection of tuberculosis using micro devices. Here the simulation of unique and novel designs of micro-cantilever, polysilicon as a material. The simulated results are Eigen frequency, deflection, stress, strain, C-V characteristics, and capacitance of the cantilever.In this a microcantilever based sensing system is designed using COMSOL Multiphysics. The surface of the cantilever is coated with antbody layer. As the antigens of TB disease come in contact with the antibody layer of the microcantilever , deflection takes place. The amount of deflection is measured and read out capacitive.

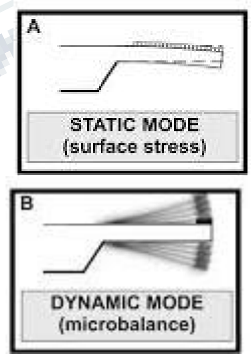
Index terms-MEMS, C-V, SU8, Silica, E (Modulus elasticity).

I. INTRODUCTION

Micro-cantilever are the devices which belong to the MEMS devices. MEMS devices are well known for their unique property i.e., smaller in size. They have various application domain which have rapid scope and growth. MEMS devices well known application is sensors and actuators. The application field like sensor should have the quality of good sensitivity in physical, chemical and biological sensing areas.

Micro cantilevers gives the advantage like easy to fabricate, flexibility and high sensitivity. The biological application of the micro-cantilever have many demand, there are used in the detection of various diseases like swine flu, liver cancer, hepatitis and so on. Not onlyin medical field also in the physical domain like temperature sensor. Cantilever has two mode of operation namely static mode and dynamic mode. Static mode of operation is where the deflection is in only one direction whereas in dynamic mode the deflection happens in both directions vertically. this deflection is upon the force applied by the bio-molecules applied on the beam.

TB is a contagious and fatal disease produced by single etiological mycobacterium tuberculosis. Recent survey of TB shows that more than one third of the population has been infected with TB and every one second the infections are occurring. TB is the second most infectious disease. So the best choice to detect TB at an early stage is by cantilevers.



A biosensor is a chemical sensing device that converts specific biological input to a quantified output that process able to electrical signal and possesses unique features like compact size, simplicity of use and absence of any radioactive elements for the diagnostics. Comparing with traditional biochemical apparatus's, micro-scale biosensors are more consistent, low cast and very fast. Micro-cantilevers have been recognized to be an exceptional platform for the biochemical sensors.
This paper is mainly focusing on the design andsimulation of unique designs of micro-cantilever. The micro-cantilever have three main structure, they are (i) substrate, (ii) anchor

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and (iii) beam. The substrate is a first element in the micro-cantilever, which is fixed and acts as the base of the device which hold other two element on it, here the entire substrate is fixed. An anchor creates a finite gap between substrate and beam, to allow the beam to deflect. The gap is filled with vacuum which acts as the dielectric between ground and a potential. The beam is the main element which is only fixed at one end and free at the other. On this the bio-chemical antigen layer is formed depending on the biological application.

Due to the stress on non-fixed end of the beam is deflects upwards, downwards, right or left side accordingly. Whole cantilever structure is similar to the capacitor, which as two plates one is fixed, another is variable and an dielectric between the two plates. Here in the micro-cantilever the substrate is fixed and beam is variable.

II. DESIGN

The dimension parameters of the design are length, width and thickness. To decide these values we have to consider the parameters like young's modulus, poison's ratio, spring constant, stress, frequency, sensitivity.

Properties	Poly silic on	Silica	Silicon Nitrade	SU8
E (Modulus elasticity)	160	73	315	4.4
Poisson's ratio	0.22	0.17	0.27	0.22
Density	2230	2200	3184	1190
K (Spring constant)	0.02	7.85e-3	0.03	4.32e-4

Table-1: properties of different materials.

The equations of the parameters are given below:

1. Frequency,

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where., K= spring constant, m= effective mass of micro-cantilever beam.

2. Surface stress $\Delta\sigma$differential, $\Delta\sigma = \frac{Et^2}{3(1-\gamma)l^2}\Delta z$ ……………..(2)

Where., E=young's modulus, t=thickness, γ=poisons ratio, l=length of cantilever

3. Spring constant

$k = \frac{E\omega t^3}{4l^3}$ ……………..(3)

Where., E=young's modulus, t=thickness, l=length of cantilever, ω=width of cantilever

4. K for (500*50*5) um =1.25m N/m ……………..(4)

5. $m\frac{d^2}{dt^2}x(t) + kx(t) = 0$……………..(5)

Soln:

$x(t) = A_1 \sin\sqrt{\frac{k}{m}}t +$

$A_2 \cos\sqrt{\frac{k}{m}}t$……………..(6)

6. $d = \frac{FL^3}{3EI}$……………..(6)

Where., d= small deflection, F=force applied, l=length of cantilever, E=young's modulus, I=second movement of area

7. Sensitivity,

$$s = \frac{\text{displacement}}{\text{spring constant}}$$

……………..(7)

As per the above mentioned parameters the dimension of the micro-cantilever are length=500 micro meters, width=50 micro meters and the thickness= 5 micro meters. The anchor thickness is 4 micro meters, as it should be less than the substrate and beam thickness. The substrate upper part is made as groundand the beam lower is set as the electric potential of 2 volts. The material polysilicon is selected in this paper. Depending on the analyte placed on the beam the young's modulus, poison's ratio and the stress is changed and depending on the length and width of the beam the deflection is change.

The simulation of the micro-cantilever designs is done in the COMSOL multi-physics software. In the sensor designing process the simulation of the sensor plays an great role. The COMSOL multi-physics simulation tool gives the

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enormous advantages of simulating the various physical domain in it. The COMSOL tool has different physics, study, materials, geometry, results and meshing.

Steps involved in designing and simulation:
1) Select the 3D model

2) Select physics(solid mechanics)

3) Select the study(Eigen frequency)

4) Draw the design in the geometry according to the dimensions calculated

5) Unite the entire geometry

6) Fix the faces of the object

7) Add the material(Polysilicon)

8) Add the mesh(Tetrahedral)

9) Study and compute the Eigen frequeny

10) If needed can add the frequency solver to the study

11) Plot the results in the 1D-plot and line graph(stress, displacement, strain)

12) To get the capacitance add the electrostatic physics to the component

13) Add the stationary

14) Apply the voltage and select the domains for potential and ground

15) The capacitance is calculated by giving proper equation in the multislice

16) The force of 100 Newton is applied to the component by converting it to the Delton(1.6284336 e-21)

III. DESIGN 1

Figure-1.1 shows the simple structure of the beam which have the length of 500 micro meters and width is 50micrometers and 5 micro meters of thickness. The entire structure is simulated in the COMSOL multi-physics simulator with the material as Polysilicon.

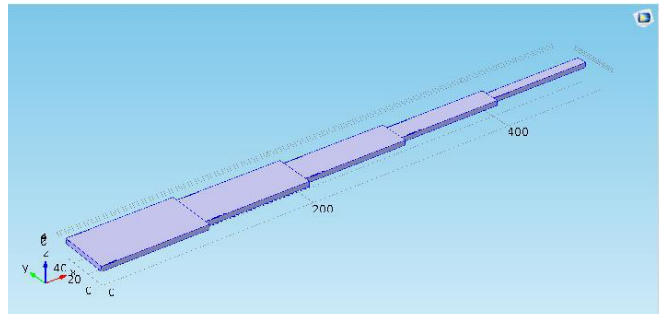

Figure-1.1 Beam with the Polysilicon material.

Figure-1.2 shows the beam with the mesh, here we have used Free Tetrahedral mesh with normal in size.

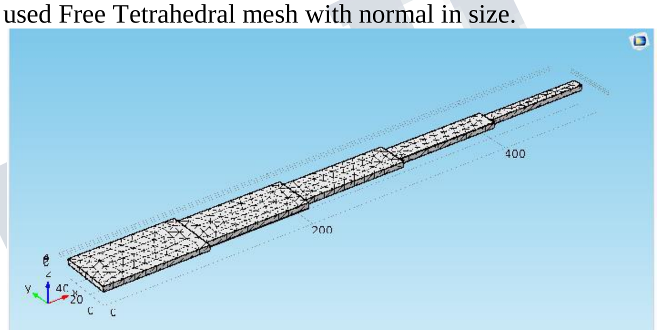

Figure-1.2: Beam with free tetrahedral mesh

Figure-1.3 shows the complete structure of the design with Beam, anchor and substrate. All three elements are geometrically united and the fixed and the free ends are defined also the Polysilicon as the material.

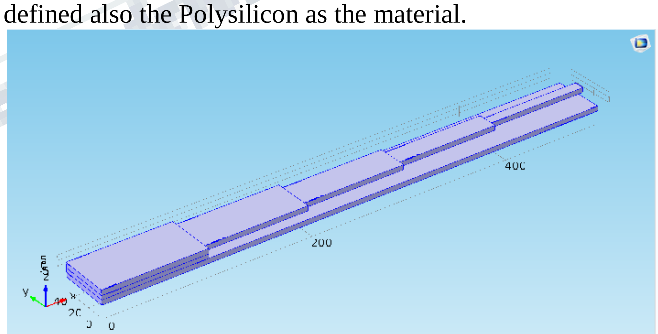

Figure-1.3: Entire structure with anchor and substrate.

Figure-1.4 shows the entire design with the mesh, here we have used Free Tetrahedral mesh with normal in size. The applying of the mesh to the design is to have nodal and functional representation of the geometry. The mesh allows us to apply the force on each junction point the design, because when the device comes in the area of micro-meters the force enacted on the device must be even in all junction point.

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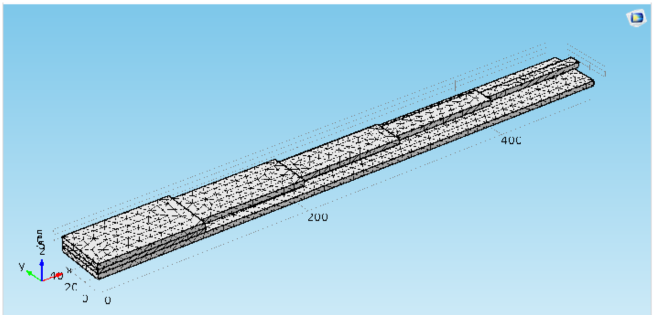

Figure-1.4: Mesh(free tetrahedral)

III. DESIGN 2

Figure-2.1 shows the another unique design which has the two rectangles in the beam each of 100micro-meters and one end of the beam is fixed. And another is deflecting end.

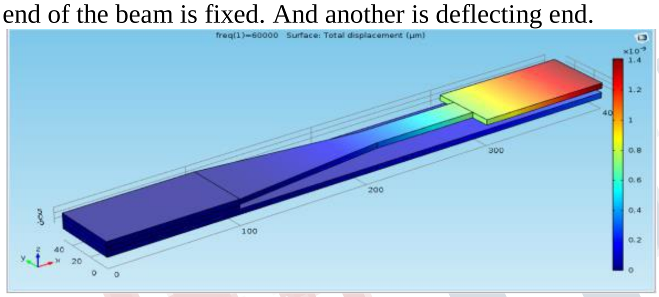

figure-2.1: Design-2

IV. RESULTS

Results for design-1:
Figure-1.5 shows the displacement for frequency of 60K hz, where the Beam is deflected with respect to the frequency. For each frequency the direction of the deflection of the beam changes.

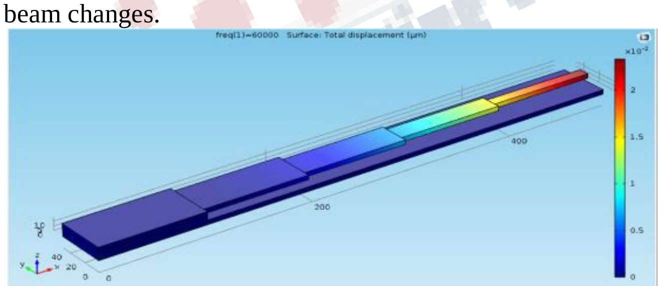

Figure-1.5: Displacement for frequency of 60K hz

Figure-1.6 shows the capacitance of the structure for the applied Electric potential and the ground substrate the structure the capacitance is simulated, the capacitance is 3.33 Femto Farads.

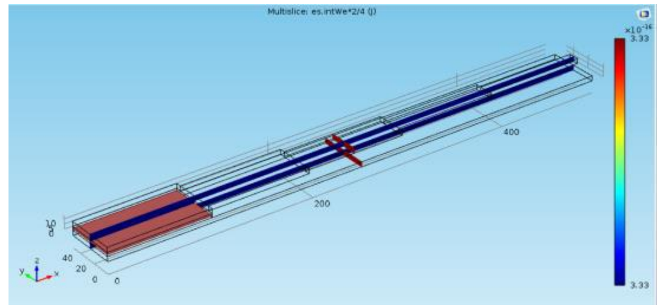

Figure-1.6: capacitance of the structure

Figure-1.7 shows the Capacitance vs Voltage graph, where capacitance varies with respect to the voltage.

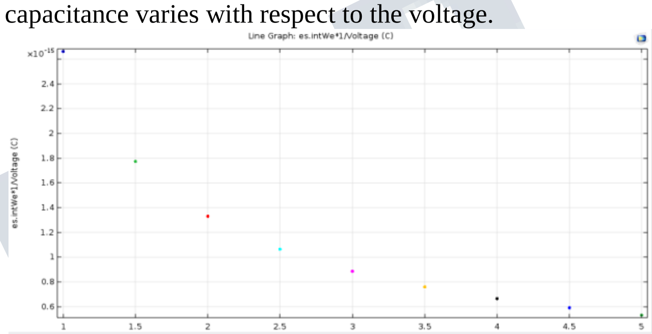

Figure-1.7: C vs V curve

Results for design-2:
Figure-2.2 shows the displacement for frequency of 60Khz, where the Beam is deflected with respect to the frequency. For each frequency the direction of the deflection of the beam changes.

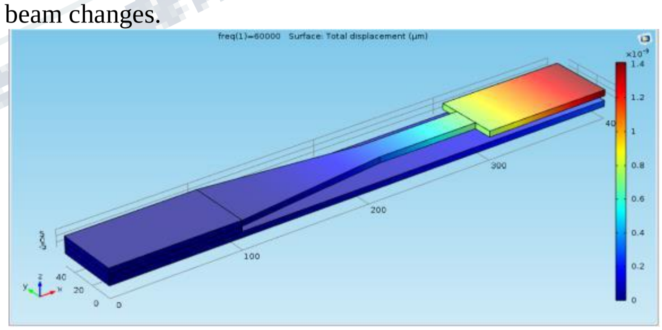

Figure-2.2: displacement for frequency of 60K hz

Figure-2.3 shows the capacitance of the structure for the applied Electric potential and the ground substrate the structure the capacitanceis simulated, the capacitance is 1.42 Femto Farads.

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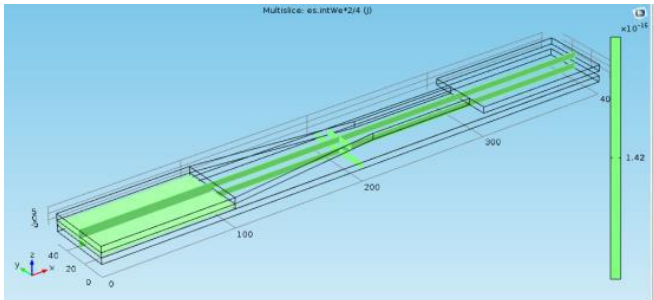

Figure-2.3: Capacitance

Figure-2.4 shows the Capacitance vs Voltage graph, where capacitance varies with respect to the voltage.

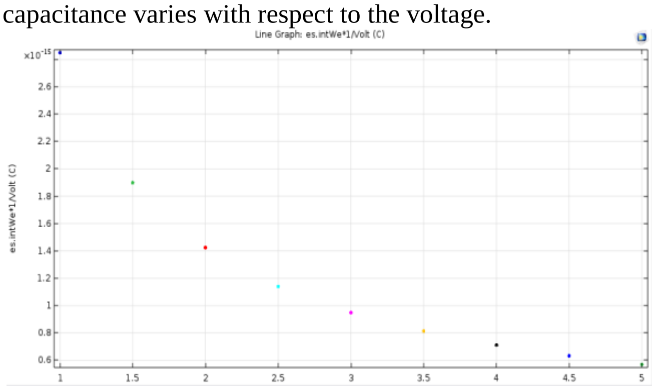

Figure-2.4C vc V curve

V. CONCLUSION

The MEMS based cantilevers here are designed and simulated with the thickness of 5 micro-meter and total length of 500micro-meter. The capacitance is in the range of femto farads and the design have the displacement of maximum 20nm and 0.14fm. The capacitance curve is linearly varying with respect to voltage. Displacement for frequency of 60K hz of the design-1 is 0-20nm and design-2 is 0-014fm, whereas capacitance of design-1 is 0.33femto farads and design-2 is 1.43 femto farads.Out of the two designs the good capacitance is given by design-2 which have 1.4 femto farads. Therefore from the above results the design-1is the best design. As mentioned above that the designs can be used for the detection of Tuberculosis, the application of the bio-material antigen is grown on the beam, the spittoon can be applied. Due to the biological reaction of the antigen and spittoon deflects the beam. By trialand error method the decision can be made whether the person have TB or Not.

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