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Comparative Study of Cantilever Biosensor for Detection of Tuberculosis

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Abstract: Now everywhere in the world sensors are used to solve daily human problem. In the medical field sensors are used to diagnose various diseases. In this article for detection of tuberculosis, micro cantilever biosensor has been design and simulate. Rectangular shape cantilever biosensors with silicon, poly-silicon and aluminium material were designed and analysed the displacement. The displacements of this biosensor are compared with the other available models. The MEMS based micro cantilever biosensor were design in COMSOL Multiphysics. 10N to 100N load force are applied on the surface of cantilever for deliberate the interaction of antigen antibody. Stress generated on the surface of cantilever when antigen antibody binds together and it get deflects. This deflection is measured for 10N to 100N load force which is compare with other modules. The displacement generated by cantilever was 1.71 x 10^{28} µm for 100N force which is higher than all the other models, thus the proposed cantilever model is the best model for detection of tuberculosis.

Keywords: Tuberculosis, Cantilever, Biosensor, MEMS, Antigen, Antibody.

I. INTRODUCTION

Globally various diseases are surviving, which affects the functions of an organism. Diseases are referring to as dysfunction, pain, social problems, and distress or person death. Diseases are classified as deficiency, psychological, hereditary and infectious disease. The most severe diseases are infectious diseases such as Covid-19, tuberculosis and so on. The bacteria or viruses of these types of diseases can affect to person from affected person's mouth or nose when they cough, sneeze, speak or breathe. Diseases not only affect people physically, but also psychologically, because being sick and having a disease change the patient's outlook on life.

Tuberculosis is one of the leading causes of death for children, youngsters and old age peoples. Every year millions of people were suffered from tuberculosis. In the Covid-19 pandemic situation the death rate of tuberculosis as compare with last decade is increase. The bacteria such as Mycobacterium tuberculosis is a source of tuberculosis. Generally it affects to lung organs which is called as pulmonary tuberculosis. When person suffering from pulmonary tuberculosis with the general symptoms may also experience coughing up blood, chest pain, shortness of breath and so on [1, 2]. The bacterial of tuberculosis also affect to other organs which is called as extra pulmonary tuberculosis. The general symptoms of extra pulmonary tuberculosis are swelling, bone deformities, weight loss, fever, night sweats and so on [1, 3, 4, 5]. Due to the complex structure of mycobacterium tuberculosis, it gets difficult to diagnose easily and at an early stage. From last few decades many researchers has been developed various detection techniques to diagnose tuberculosis. Some detection techniques are based on skin, blood, sputum smear microscopy, radiography, image based, culture based and so on. But no full proof techniques were designed which diagnose tuberculosis easily and quickly [6, 7]. To fulfil the goal of government to completely eliminate tuberculosis from the world, there is urgent need to developed effective and quick diagnostic technique.

The purpose of this article is to designed and simulates the micro cantilever biosensor for easily and quickly diagnose tuberculosis. For this purpose rectangular biosensor were designed and analysed the displacement of cantilever and compare the displacement of our model with other available models.

II. MICRO CANTILEVER BASED BIOSENSOR

Biosensors are sensors that use biomolecular interactions as sensor responses. For sensing the biological elements biosensor used antigen antibody. Tuberculosis causes by ESAT-6 and CFP-10 antigens. 6KDa are the molecular weight of antigen ESAT-6 and the molecular weight of anti ESAT-6 antibody is 11KDa. The value of 1KDa is 1.661 x 10^{-24} kg. Thus the total molecular weight of antigen and antibody of tuberculosis is 28.228 x 10^{-24} kg [8, 9, 10].

These biomolecular interactions collaborate with micro cantilever platforms, can create influential biosensor designs. The structure of cantilever has low resistance to bending and is mechanically responsive to change the surface tension on its surface. The biochemical reaction which occurs at the cantilever surface can be observed as a bending of the cantilever, due to a change in the surface tension. For bio-recognition, the cantilever surface is made bio-sensitive by applying a sensor layer on it [11].

The structure of micro cantilever which is based on micromechanical and electromechanical sensor has fixed on one end and other end of it is free for displacement [12, 13]. The displacement generated on the sensitive surface of cantilever due to the collaboration of antigen antibody that means biochemical reaction. For observing the biochemical reaction, antibodies are placed on the top surface of cantilever and sample drop to the surface and if sample contain specific antigen it get interact with antibodies, due to this interaction cantilever get deflects. When antigen antibody interacts with each other the mass get added and the cantilever gets deflects. Due to the better sensitivity of Micro cantilever it used in various fields. In medical field for detection of diseases various types of sensors are used.

III. METHODOLOGY

Rectangular shape cantilever are constructed for detection of tuberculosis. The structure of cantilever is divided in three sections. First section is cantilever beam with width 5 µm, depth 80 µm and height 1 µm. Second is sample compartment with width 20 µm, depth 40 µm and height 2 µm. Third is fixed end with width 40 µm, depth 10 µm and height 5 µm are the dimensions of all three sections of micro cantilever. The surface of all these three sections are made by different materials such as first section is made with silicon material, second with poly-silicon and third with aluminium. Fig 1 shows the design of rectangular shape cantilever using above dimensions.

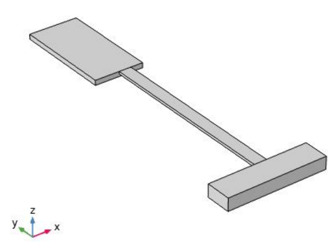

Fig. 1 Design of Rectangular Shape Cantilever

In COMSOL Multiphysics, 3D design is used to design the MEMS module of cantilever sensor where fixed constraint is applied at one side and other side is free for deflection. On the surface of cantilever 10N to 100N load force are applied for considering the interaction of antigen antibody.

To calculate the force following equation is used:

$FA = Ftot / A$ ------ [1]

Where, FA = Force per unit area

Ftot = Total force

A = Area of the surface

When the force illustrate to the sample, the value for Young's modulus = 170Pa and Poisson's ratio =0.44 was considered. Therefore, due to the interaction of antibody antigen the surface of cantilever generates stress which forms the deflection [14, 15].

To calculate the deflection of cantilever beam:

$D = pl^3 / 3ei$ ------ [2]

Where, p = load force

l = length

e = young's modulus

i = moment of inertia.

Where, moment of inertia for rectangular shape is:

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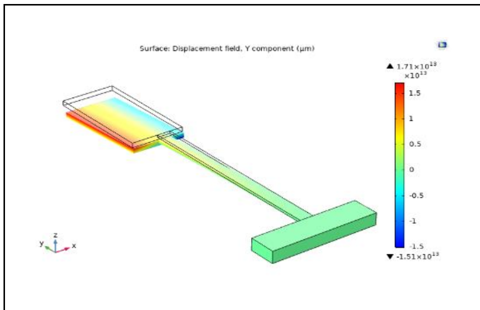
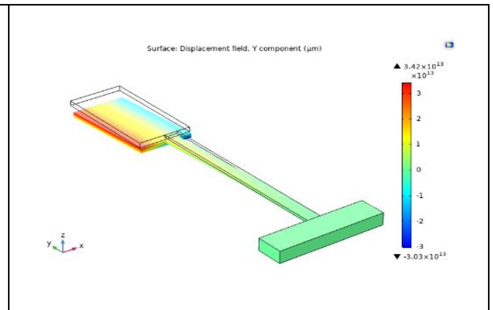
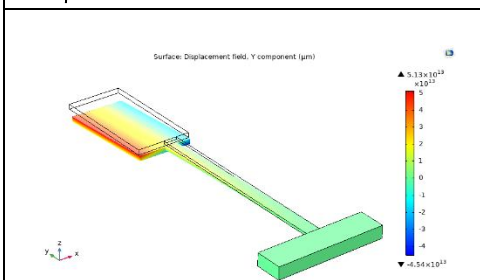
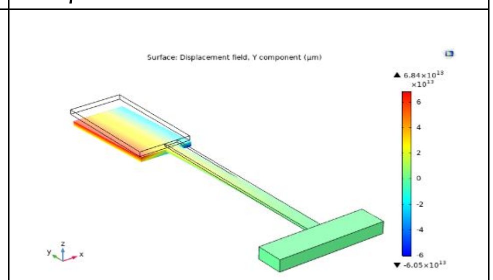
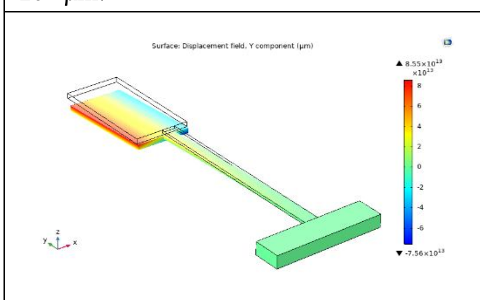
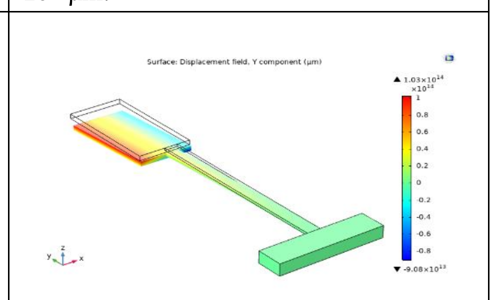
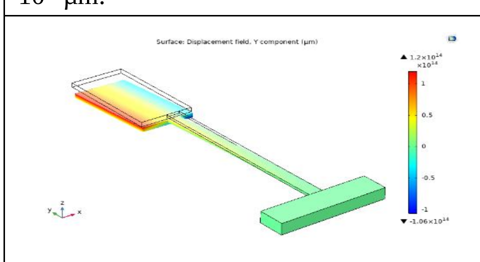
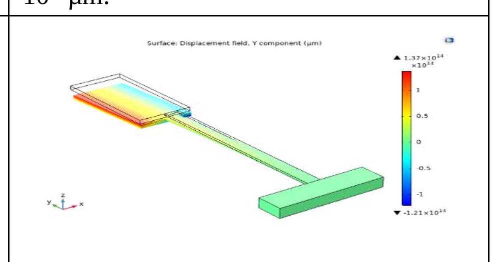
$i = bd^3 / 12$ ------ [3]

Where, b = breadth

d = thickness

To analyse the deflection, COMSOL Multiphysics is used and simulate the rectangular shape cantilever with load force 10N to 100N. Figure 2 shows rectangle shape model with load force 10N to 100N.

	
For 10N load force the cantilever displacement was obtained as 1.71 x 10^{26}µm.	For 20N load force the cantilever displacement was obtained as 3.42 x 10^{26}µm.
	
For 30N load force the cantilever displacement was obtained as 5.13 x 10^{26}µm.	For 40N load force the cantilever displacement was obtained as 6.84 x 10^{26}µm.
	
For 50N load force the cantilever displacement was obtained as 8.55 x 10^{26}µm.	For 60N load force the cantilever displacement was obtained as 1.03 x 10^{28}µm.
	
For 70N load force the cantilever displacement was obtained as 1.2 x 10^{28}µm.	For 80N load force the cantilever displacement was obtained as 1.37 x 10^{28}µm.

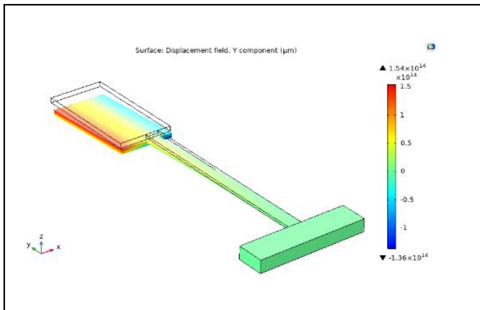
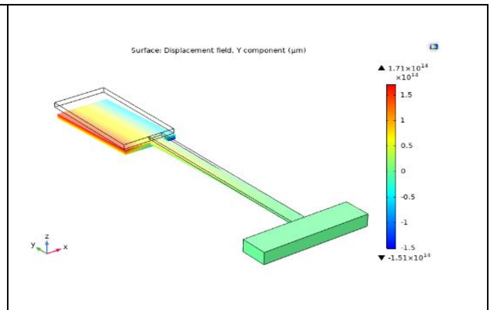
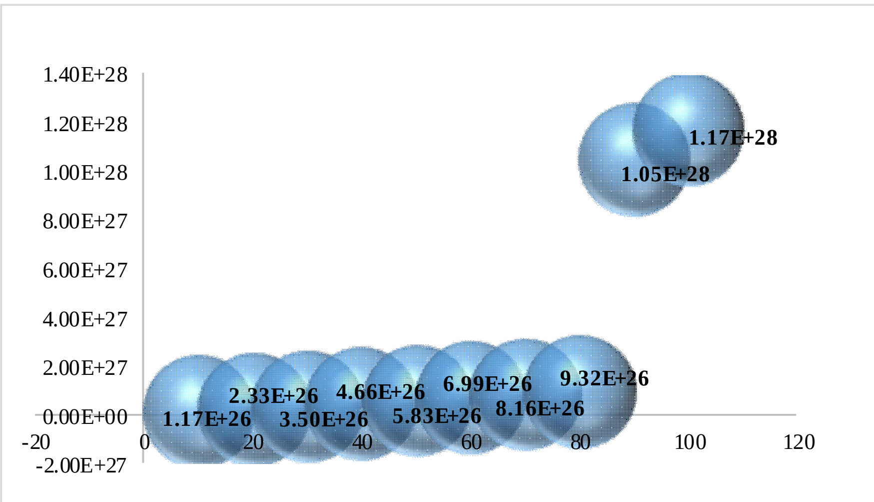
	
For 90N load force the cantilever displacement was obtained as 1.54 x 10^{28}µm.	For 100N load force the cantilever displacement was obtained as 1.71 x 10^{28}µm.

Fig. 2 Model of Rectangular Shape Cantilever Biosensor with 10N to 100N load force

IV. RESULT

As shown in figure, due to interaction of antigen antibody, stress generated on the surface of cantilever and it produced displacement for 10N to 100N load force. The displacements generated by cantilever for 10N to 100N load are recorded as shown in graph 1.



Graph 1: The displacement generated by cantilever for 10N to 100N load

For 10N load force, 1.71 x 10^{26}µm displacement was generated, for 20N it generated 3.42 x 10^{26}µm displacement, for 30N load force 5.13 x 10^{26}µm, for 40N it generated 6.84 x 10^{26}µm, for 50N load force it generated 8.55 x 10^{26}µm, for 60N it generated 1.03 x 10^{28}µm, for 70N load force 1.2 x 10^{28}µm, for 80N it generated 1.37 x 10^{28}µm displacement, for 90N load force 1.54 x 10^{28}µm and for 100N load force cantilever generated 1.71 x 10^{28}µm displacement. From these displacement it was observed that for 100N load force cantilever generated highest displacement as 1.71 x 10^{28}µm.

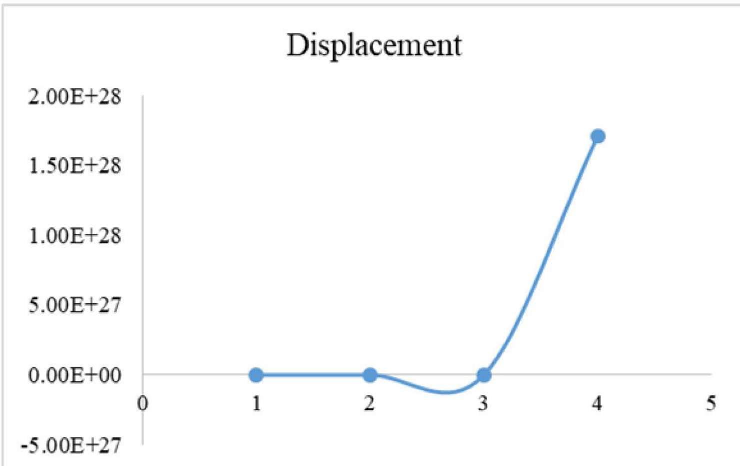
V. COMPARISON OF EXISTING SYSTEM WITH PROPOSED SYSTEM

The displacement of our proposed system was compare with other researchers system. Existing system-I (N. Murthy et al) has been designed rectangular shape model with poly-silicon material and generated 3.440 µm displacement for 100N load force. Existing system-II (Yashaswini B.M et al) has been designed rectangular shape model with gold material and obtained the displacement as 8.5194 x 10^{5} µm for 100N load force. Existing system-III (Srinivasa Rao K et al) has been designed rectangular shape model with silicon material which generated displacement as 5.63 x 10^{6} µm for 100N load force. It has been observed that the performance of our proposed system is higher than the others system. As our proposed system generated 1.71 x 10^{28}µm displacements which are higher as compare to others system.

Thus we can propose that our proposed rectangular cantilever shape model is the best model for detection of tuberculosis which has higher sensitivity and generate higher displacement. Table shows the displacement of existing system and our proposed system. Graph shows the ratio of the displacement of existing system and our proposed system.

TABLE I
THE DISPLACEMENTS OF EXISTING AND PROPOSED SYSTEM

Displacement (µm)			
Existing System-I	Existing System-II	Existing System-III	Proposed System
5.63×10^{6}	8.5194×10^{5}	3.440	1.71×10^{28}



Graph 2: The displacement of existing and proposed system

VI. CONCLUSIONS

Mycobacterium tuberculosis is a hazardous disease which is leading cause of death. No simple diagnosis methods are available to diagnose this dangerous disease due to which patient not gets proper treatment in time. In this research work we have design rectangular shape model of cantilever biosensor with silicon, poly-silicon and aluminum material, on the surface of cantilever considering the antigen antibody we have applied 10N to 100N load force and analyzed the displacement. For 100N load force 1.71×10^{28} µm displacement was generated. When stress generated on the surface due to the binding of antigen antibody it get deflected and this deflection is measured. This displacement is compare with the existing research model. After analysis it has been noted that our proposed model get highest displacement, thus it is the best model for detection of tuberculosis

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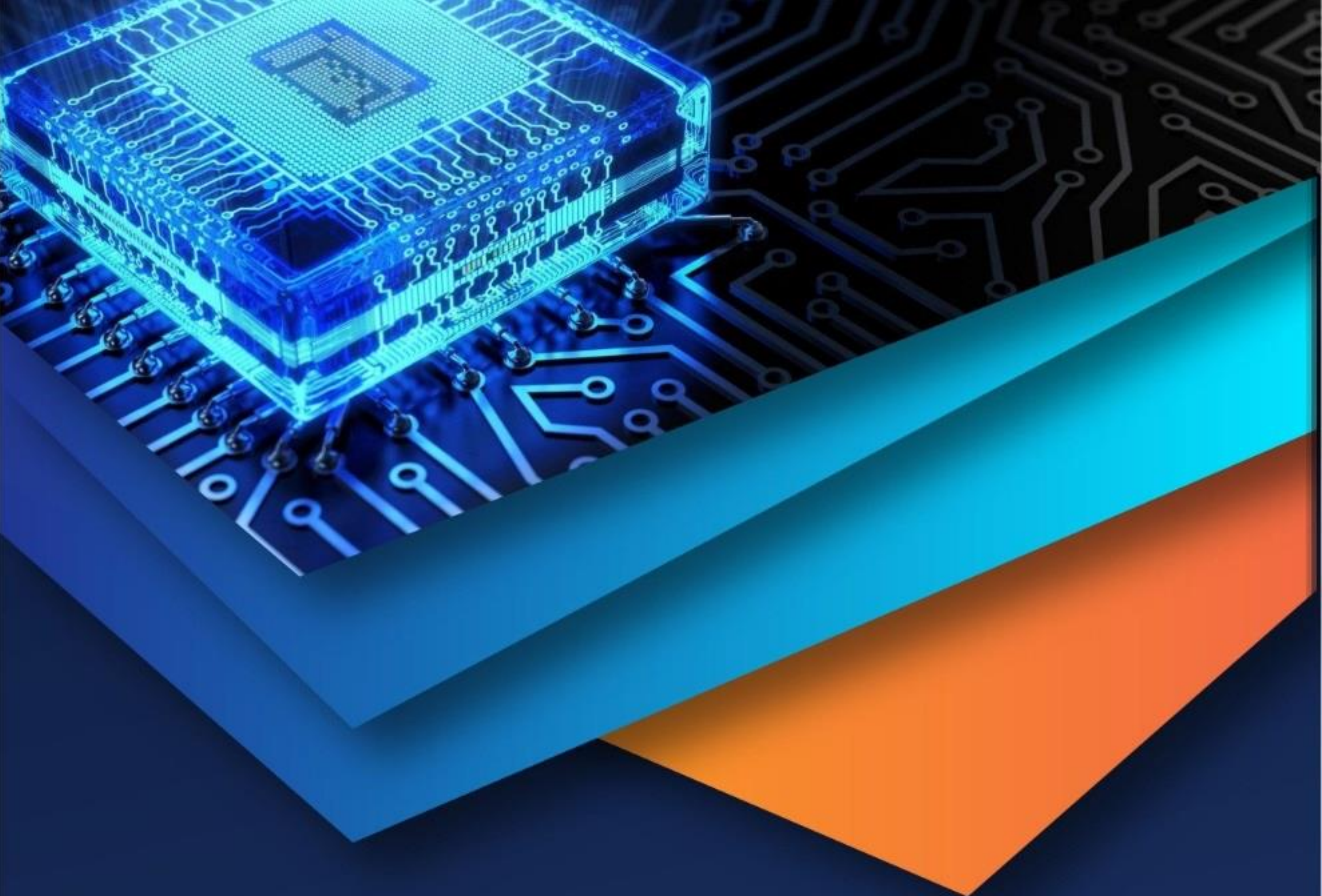

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