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Simulation of Cantilever Biosensor for Detection of Tuberculosis

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Abstract: Worldwide Mycobacterium Tuberculosis comes under top ten diseases, which affect to millions of people every year. Due to its complicated structure, it is very difficult job to diagnose this infectious disease in time. In this research article, first the complications of tuberculosis and some detection techniques are studied. After that, for fast and within time detection of tuberculosis, Cantilever Biosensor with various shapes are simulated. The Cantilever is design with Poly-Silicon material and its surface coated with ESAT-6 antigen antibody. For stress generation a load forces are apply from 10N to 100N and displacement of all the models are analyze. After analysis it has been recorded that Rectangular shape generates maximum displacement as compare with other shapes. Rectangular shape cantilever biosensor achieved 1.71 x 10^{28} µm displacement with 100N load force.

Keywords: Cantilever, Mycobacterium Tuberculosis, Biosensor, COMSOL, Displacement, Rectangle, Simulation.

I. INTRODUCTION

Health is a capital of human being, as per the world health organization; to enjoy more aspects of our life we must maintain our health. To maintain health, it should be disease free. However, it is not possible every time, unintentionally some diseases attack to human health, which disturbs our life. Therefore, it is very important that if some diseases attack our body, it should be diagnosed properly and timely. So that infectious people get proper treatment before it damage or convert in serious mode. Many researchers developed various advance techniques to diagnose the diseases. Still some diseases are not get diagnose within time. Tuberculosis is one of the infectious diseases [1]. Most of the techniques are available to detect this disease, but all techniques are at developing stage [2, 3]. Tuberculosis caused by gram-positive mycobacterium tuberculosis [1]. It generally affect to lung organ, when it affect to lung it refers as pulmonary tuberculosis and when it affect to other body parts it refers as extra pulmonary tuberculosis [4, 5]. There are two types of tuberculosis active and latent. When person suspected with tuberculosis, bacteria of tuberculosis are in inactive stage, and person have no symptoms then it called as latent disease. When bacteria of tuberculosis enhance in body and developed the symptoms of tuberculosis then it called as active disease. Tuberculosis is an airborne disease, it spread through sneeze and cough from one person to another [6]. Due to its spread-ability feature, every year millions of people suffering from tuberculosis [7, 8]. The sufferers from this hazardous disease have enormous social and financial burden, mostly in developing countries such as India and Sub-Saharan Africa [9]. It is very dangerous and widespread diseases, which affect to all age groups. Thus, there is necessity to detect and prevent disease in time, for that purpose it is important to design and developed a technique, which can detect disease easily and timely.

II. TRADITIONAL DETECTION TECHNIQUES

For detection of tuberculosis, some traditional detection techniques are available such as Tuberculin Skin Test, Smear Microscopy and Radiography. Each detection technique has some advantages and disadvantages.

A. Tuberculin Skin Test

From 1907, Mantoux or Tuberculin Skin Test used for detection of tuberculosis; various improvements were made in this method. Protein purified derivative are injected into the skin on the lower part of the arm. The response on the skin generated after 48-72 hours. If immune system is low, then Mantoux test unable to generate proper response, therefore it gives false negative result and patients who injected Bacille Calmette-Guerin vaccine it shows 8.5% false positive result [3, 10].

B. Smear Microscopy

Smear microscopy has been used for detection of pulmonary tuberculosis. Smear microscopy is simple method for detection of acid-fast bacterium. In Ziehl-Neelsen staining method, minimum 1 x 10^4 bacterium per ml of sputum is essential. However, when bacterial load is less than 1 x 10^4 organisms per ml in sputum sample then it will not get proper output. This is the limitations of Sputum Smear Microscopy [11, 12].

C. Radiography

In the 20th century for tuberculosis detection the used of radiography were started especially in the developing countries. To visualize the internal structure of patient X-rays are used by radiography. The system used by X-rays is electro-magnetic radiation manufactured by an X-ray tube. To identify the lung abnormalities chest X-ray is used which is a rapid imaging technique. However, the abnormalities of TB are not perfect. Therefore, X-ray is not a perfect system, special apparatus and trained staffs are required to handle the equipment and generate the output [13, 14].

III. BIOSENSOR BASED DETECTION TECHNIQUES

Considering the fact of traditional diagnosing technique there is an urgent need to developed substitute method, which should be easy and cost effective. In view of this most of the researcher has developed some biosensors to recognize this hazardous disease. A biosensor for the detection of tuberculosis is usually distinct as a compressed analytical device containing a bio-sensing constituent with a physicochemical sensor. Based on the biological elements, nucleic acid and antibody biosensors have been developed [15, 16].

A. Piezoelectric Quartz Crystal Biosensor

Piezoelectric quartz crystal shows changes in frequency of the crystal, which is associated to the changes in the mass placed over the electrodes. Based on the distinct resonant frequency characteristics of quartz crystals, any variation in resonating mass by the binding with specific bio-molecules and bacteria like mycobacterium tuberculosis can be detected. However, the major problem with this system is that sample pre-treatment is needed to remove contagion with other bacteria thus; it is time consuming [17, 18, 19].

B. Electrochemical and Electrical Biosensor

The recognition method of electrochemical and electrical based on changes in electrical signals at a surface working electrode by either chemical or physical connections. Due to Mycobacterium tuberculosis cell wall mechanism can be immobilized onto an electrode surface exposed to a suspension of M.tb, this method detect the interaction between the bacteria of tuberculosis and its antibodies by a change of conductance. This sensor is highly sensitive, but a constant pH and ion absorption of the reaction is very critical [20].

Thus, all the studied biosensors are at developing stage. Considering the advantages and disadvantages of biosensors, there is an urgent need to develop easy and timely diagnosed technique. Therefore, in this research Cantilever Biosensor was design.

IV. CANTILEVER BIOSENSOR

Cantilever Biosensor used a special structure for sensing the bio-molecules, the structure based on micromechanical and electromechanical sensor [21, 22]. The outcome of cantilever sensor based on its displacement. The displacement generated at one end of cantilever sensor, thus the one side of cantilever is fixed and other side is free for displacement. The performance of this sensor is superior and sensitivity is high to detect bio-elements. The main advantage of cantilever sensor over traditional methods sample purification is not required. The deflection of cantilever based on the interaction of antigen-antibody. Mass on the surface of cantilever increases when antigen-antibody interacts with each other and free side of it get deflects. Deflection demonstrates when sample contain some precise elements and antigen-antibody binds together. The top surface of cantilever is design as bio-sensitive based on precise antibody. When sample placed on this surface its antigen-antibody interact with each other and it gets deflects.

Antigen ESAT-6 and CFP-10 are the sources of tuberculosis. The molecular load of antigen ESAT-6 and its antibody are 6KDa and 11KDa respectively. The value of 1KDa is 1.661 x 10^{-24} kg, therefore the combined weight of ESAT-6 antigen and antibody is 28.228 x 10^{-24} kg [23]. The range of interactions of antigen-antibody for the cantilever surface is 10N to 100N [24]. The intermolecular force of interaction of 10 antigen-antibody is projected which is functional on the surface of cantilever for articulate the deformation value. Thus, the load of 10 antigens is 28.228 x 10^{-24} kg [25].

V. EXPERIMENTAL DETAILS

To design the sensor, simulation plays an important role; it helps to explore the features of the sensor. COMSOL Multiphysics has been used to design and simulate the cantilever biosensor. Micro-cantilever used a simple mechanical structure, which fixed at one end and free at another end. The top surface of cantilever is varnish by precise sensing element, based on this mechanism cantilever work as a sensor. For result of simulation we have applied, the force from 10N to 100N for obtained the displacement. To design the model under structural mechanics the solid mechanics model implemented.

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Cantilever sensor has been designed with different shapes and different dimensions with poly-silicon material. Rectangular, Pi, Triangular and Cylindrical shapes were used for simulate the cantilever biosensor. Young's modulus as 170Pa and Poisson's ratio as 0.44 was acquired while load force functional to the sample. Dimensions of all models are shown in Table 1.

TABLE I
DIMENSIONS OF ALL THE MODELS

Dimensions	Rectangular	Pi	Triangular	Cylindrical
Width	20	10	-	-
Depth	40	10	-	-
Height	2	0.2	-	1
Radius	-	-	-	1
X-axis	-	-	0, 10, 5	-
Y-axis	-	-	1, 1, 20	-

After designing the models load force corresponds to the weight of ESAT-6 antigen applied to the surface of cantilever. Due to this on the cantilever surface stress generated and it gets deflects. After deflection the sensitivity were analysed for all the models. The load forces of 10N to 100N were applied with poly-silicon material for analysing the sensitivity of all the models. Fig 1 to Fig 4 shows all the models simulated with load force 10N to 100N.

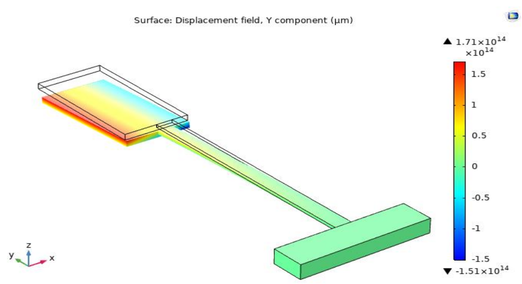

Fig. 1 Displacement with Rectangular Shape for 100N load force = 1.71 x 10^{24} µm

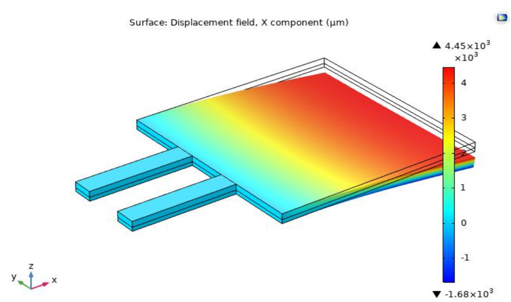

Fig. 2 Displacement with Pi Shape for 100N load force = 4.45 x 10^{6} µm

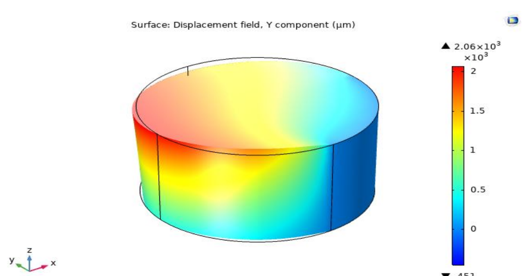

Fig. 3 Displacement with Cylindrical Shape for 100N load force = 2.06 x 10^{6} µm

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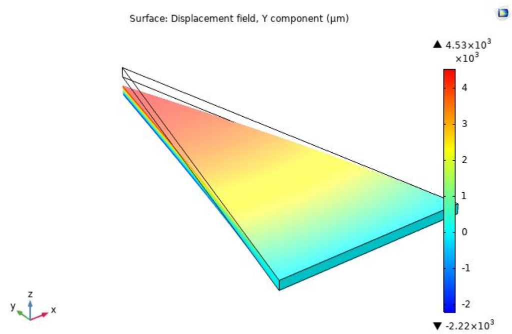
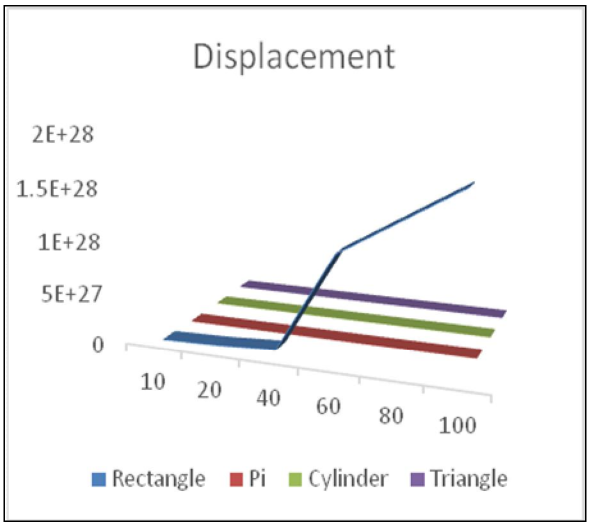


Fig. 4 Displacement with Triangular Shape for 100N load force = 4.53 x 10^6 µm

As shown in Fig 1 to Fig 4, after simulation all the models generated displacement. The displacement varies with different shapes for load force of 10N to 100N. These displacements were analysed as shown in Graph 1.



Graph. 1 Analysis of Displacement with all models from 10N to 100N load force

As per the Graph 1, the displacement of all the models of shapes Rectangle, Pi, Cylinder and Triangle for load force 10N to 100N were explore. It has been noted that all the models for 100N load force produced maximum displacement. For load force of 100N Rectangular shape produced 1.71 x 10^{28} µm, Pi shape produced 4.45 x 10^6 µm, Cylindrical shape produced 2.06 x 10^6 µm and Triangular shape produced 4.53 x 10^6 µm. After analysing all the models, Rectangular model generate maximum displacement. Thus, Rectangle model considered as the best model for detection of tuberculosis.

VI. CONCLUSIONS

Tuberculosis is a very perilous disease, until date it is an unsettled global health problem, because detection technique are not so powerful which can detect disease easily and within time. Traditional detection techniques take long time to detect and most of the time generates false negative results. Biosensors, which are developed, by most of researchers are at developing stage. Thus, there is an urgent need to design an easy technique, which can detect the disease within time. In this research, Cantilever Biosensor was design with various shapes and simulated in COMSOL Multiphysics. Simulation helps us to explore the features of sensor. Four different models were design with Rectangle, Pi, Cylinder and Triangle shape with poly-silicon material. 10N to 100N load force were applied to the top surface of cantilever were antigen-antibody interact with each other for generating the stress. After simulation displacements were analysed of all the models, result shows that maximum displacements as 1.71 x 10^{28} µm were generated by rectangular shape cantilever biosensor. Thus, Rectangular model considered as the best model for detection of tuberculosis.

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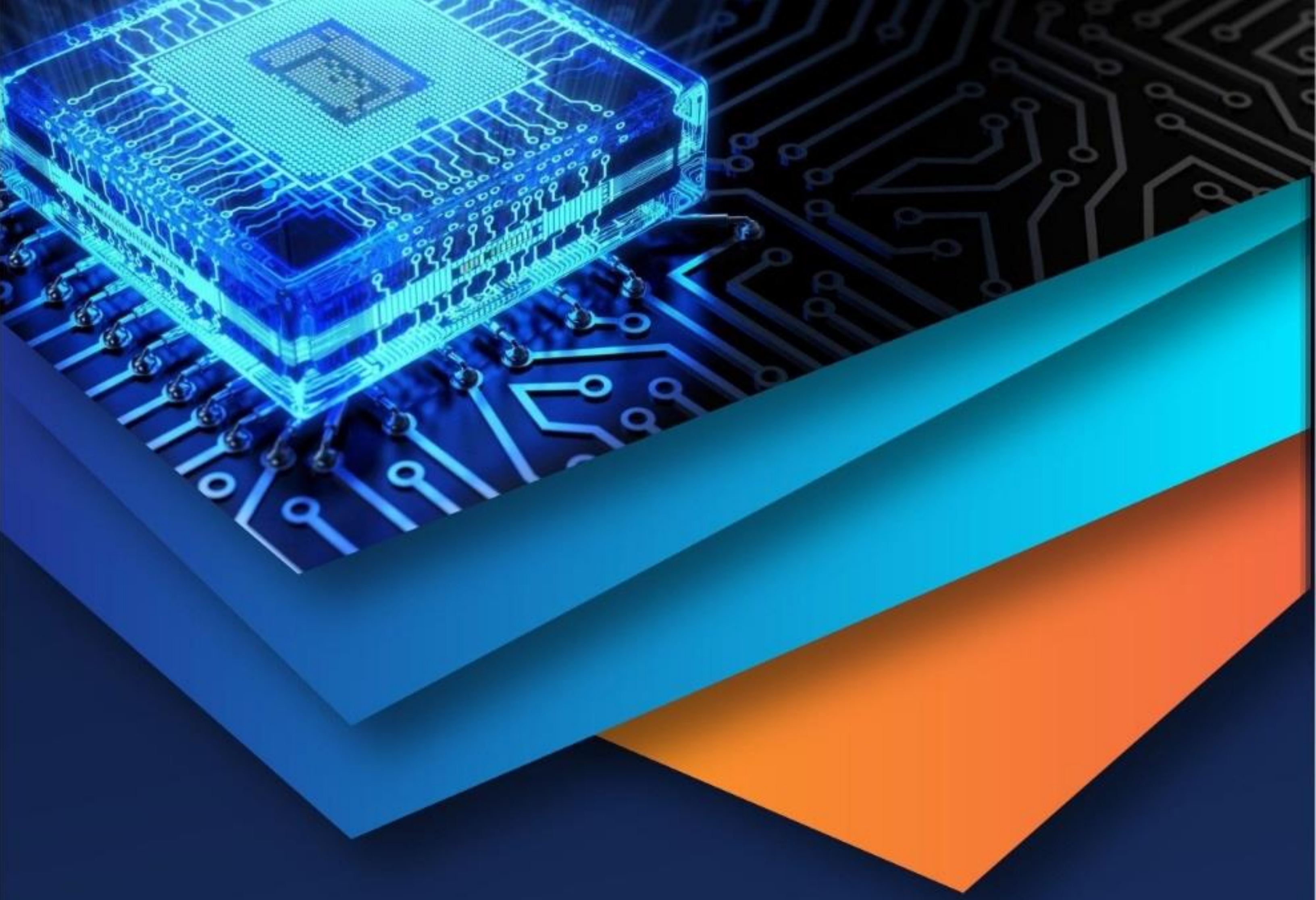

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