DESIGN AND CHARACTERIZATION OF VARIOUS SHAPES OF MICROCANTILEVER FOR HUMAN IMMUNODEFICIENCY VIRUS DETECTION

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Abstract

The ability to detect pathogenic relevant molecules in the human body with high sensitivity and specificity has a powerful opportunity in early diagnosis and treatment of diseases. This paper presents the design, analysis and simulation of MEMS microcantilevers with various shapes like rectangular, triangular, V-shape and T-shape (Paddle) for one HIV detection with mass 10^{-18} Kg which produces force of 9.81x 10^{-18} Newton, To analyze the sensitivity of microcantilever , SiO2 material is used. The simulation of these designs is performed by Comsol Multiphysics. The change in total displacement of a microcantilever with respect to change in its shape for the same applied force is observed. From the analysis performed T-shape (Paddle) cantilever with length 1000µm, width 100 µm, thickness 0.5 µm with paddle length 500 µm, width 100 µm and thickness 0.5 µm produces maximum displacement of 3.24 x10^{-07} µm. By this obtained deflection, using recent advanced read out systems the disease can be identified easily at early stages.

Key Words: *Microcantilever, Biosensor, Different shapes, HIV detection*

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1. INTRODUCTION

The cantilever structure has been widely used in variety of sensors in the applications of optics, electromagnetics, ambient temperature, and biology[1,2]. Microcantilevers possess an extremely high force sensitivity ranges in the piconewton (pN) range as the cantilevers made by Atomic Force Microscopy [3] The recent developments of atomic force microscopy enabled the mass fabrication of micrometer sized cantilevers with different geometrical shapes. Recently, this variety of AFM cantilevers is used as highly sensitive sensors operating essentially for biological detections[4]. By coating the cantilever with sensing layer, it can be detect a wide range of analyte concentrations. In static mode of operation, the static deflection of the cantilever on exposure of analyte is measured and bending caused due to interaction of analyte with the sensor coating in the cantilever[5]. Microcantilevers operating in static mode, which undergo static bending caused by external force or molecular specific binding on the surface, are of the most studied, mainly due to the booming research interest in biomedical applications such as genomics [6]–[8], proteomics [9]–[11], and analytical chemistry [12]–[15].The main advantages of microcantilever based sensors are their small size, high sensitivity and fast response time[16]

2. MICROCANTILEVER FOR HIV DETECTION

Modern biosensors based on MEMS techniques have greater potential to enhance for detecting foreign and potentially dangerous toxins and it is cheaper, faster, and easier-to-use these analytical tools. The principle of microcantilever based sensors are divided into two modes namely static mode sensing and dynamic or vibration mode sensing. In static mode sensing, microcantilevers are usually deposited with a any thin film which is further coated with a certain receptor. Depending upon the binding the specific analyte, stress or Force is generated which resulting in bending of the microcantilever. Piezo-resistive, Optical, Piezo-capacitive methods are used to read out the deflection and convert into the corresponding electrical signal for further signal processing. and thus detect the targeting bioparticles. Microcantilever can be used to detect bimolecules by deflection which depends upon the interaction of target molecule with a probe coating on the surface of the microcantilever. By measuring the amount of total deflection of cantilever, the amount of target can be quantified. The human immunodeficiency virus (HIV) remains one of the most important communicable diseases. It is an infection associated with serious disease, persistently high costs of treatment and care, significant number of deaths and shortened life expectancy.HIV is a virus, which attacks the immune system and causes a lifelong severe illness with a long incubation period[17].

HIV is different in structure from other retroviruses. It is roughly spherical with a diameter of about 126 nm[18] with a diameter of about 126 nm. The total force to be applied on the surface of cantilever can be made by calculating the volume and substituting the density value. By Newton's law, Total Force produced by one HIV is F= 9.8x10^{-18} Newton.

3. DIFFERENT SHAPES OF MICROCANTILEVER & SIMULATION

In this paper the analysis is performed for rectangular, triangular, V-shape, T-Shape(Long paddle) and T-Shape(Short paddle). The total displacement of a microcantilever can be modelled by applying a total force on the top of the microcantilever. The simulations are carried out by considering the cantilevers made up of silicon, and have an elastic modulus of 70 GPa and a Poisson's ratio of 0.17, respectively. Table 1 shows the properties of SiO_2. Here cantilevers are subject to a total force of $9.8\text{x}10^{-18}$ Newton on the top surfaces.

Table 1 SiO2 Properties

S.No.	Parameter	Value
1	Young's modulus	70 GPA
2	Poisson's ratio	0.17
3	Density	2200 Kg/m3

3.1 Rectangular Microcantilever

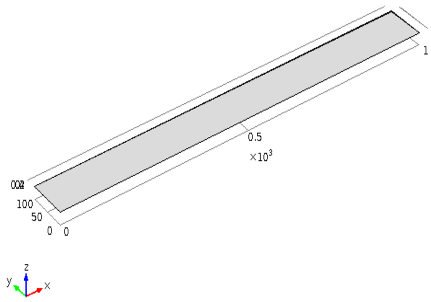

Fig-1: Design of Rectangular Shape Microcantilever

Fig-1 shows the design of rectangular shape microcantilever. To detect one HIV virus to obtain maximum deflection, the length of the rectangular cantilever L=1000 μm, width w= 100 μm and thickness t=0.5 μm and 1 μm is performed and total displacement of microcantilever simulated by using Comsol Multiphysics software. Fig. 2(a)&(b) shows the total displacement for thickness 1 μm and 0.5 μm. As the length of the cantilever increases, total deflection increases and maximum displacement is obtained when length is 1000 μm, width 100 μm and thickness 0.5 μm produces maximum deflection of $1.6351\text{ x}10^{-8}$ μm with respect to the force applied due to one HIV.

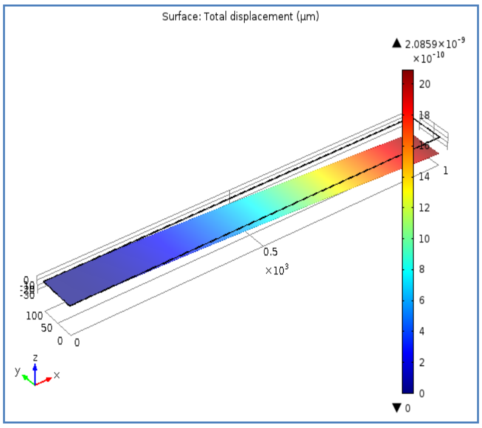

Fig.2(a)

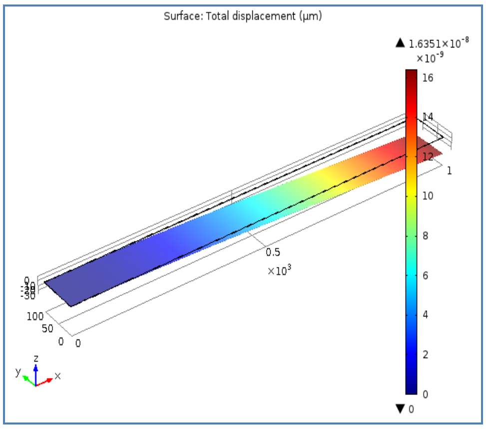

Fig.2(b)

Fig. 2 (a) & (b) Total Deflection for thickness t=1 μm and t=0.5 μm for Rectangular Shape Cantilever With L=1000 μm and W=100 μm

3.2 Triangular Microcantilever

Fig. 3 shows the design of triangular shape microcantilever. To detect one HIV virus to obtain maximum deflection, the height of the triangular cantilever H=1000 μm, base b= 100 μm and thickness t=0.5 μm and 1 μm is performed and total displacement of microcantilever simulated by using Comsol Multiphysics software. Fig. 4 (a) and (b) shows the total displacement with thickness 1 μm and 0.5 μm. As the height of the cantilever increases, total deflection increases and maximum displacement is obtained when height is 1000 μm, base is 100 μm and thickness 0.5 μm produces maximum deflection of $1.1171\text{ x }10^{-8}$ μm with respect to the force applied due to one HIV.

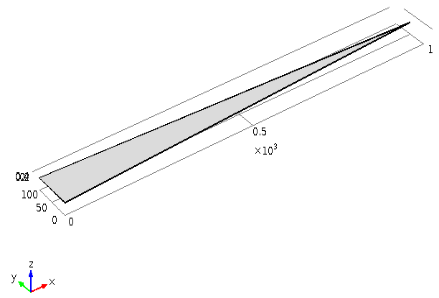

Fig. 3 Design of Triangular Shape Microcantilever

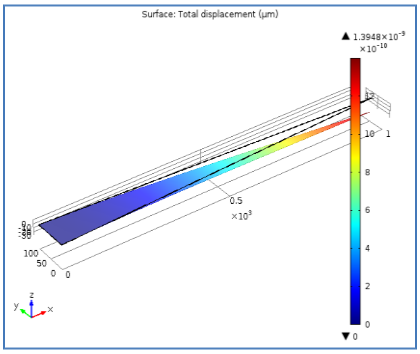

Fig.4 (a)

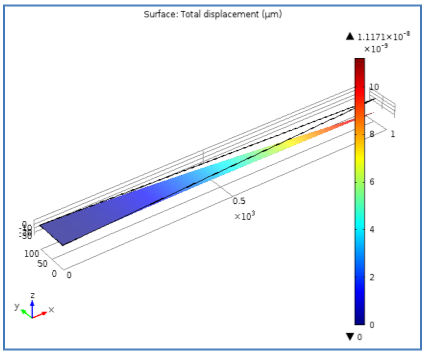

Fig.4 (b)

Fig.4(a) & (b) Total Deflection for thickness t=1 μm and t=0.5 μm for Triangular Shape Cantilever With Height H=1000 μm and base B=100 μm

3.3 V shape Microcantilever

Fig. 5shows the design of V- shape microcantilever. To detect one HIV virus to obtain maximum deflection, the height of the V Shape cantilever H=1000 μm, base length b= 100 μm and thickness t=0.5 μm and 1 μm is performed and total displacement of microcantilever simulated by using Comsol Multiphysics software. Fig. 6 (a) and (b) shows the total displacement with thickness 1 μm and 0.5 μm. As the height of the cantilever increases, total deflection increases and maximum displacement is obtained when height is 1000 μm, base length is 100 μm and thickness 0.5 μm produces maximum deflection of 2.5627 x 10^{-8} μm with respect to the force applied due to one HIV.

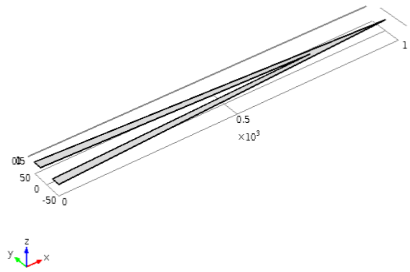

Fig.5 Design of V-Shape Microcantilever

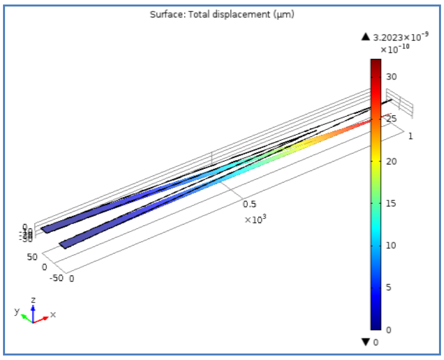

Fig. 6(a)

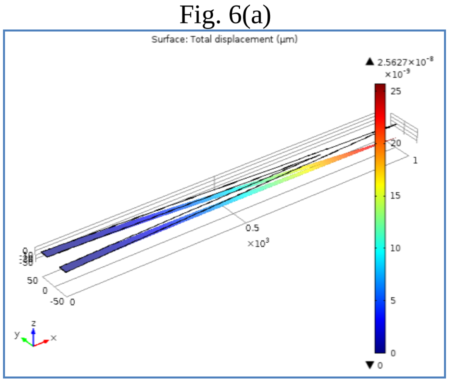

Fig. 6(b)

Fig.6 (a) & (b) Total Deflection for thickness t=1 μm and t=0.5 μm V shape cantilever with base B=100 μm and height H=1000 μm

3.4 T shape Microcantilever(Long Paddle)

Fig. 7 shows the design of Long paddle T- shape microcantilever .To detect one HIV virus to obtain maximum deflection, the height of the T SHAPE (Long Rectangular Paddle) cantilever with width W=100 μm and length L=1000 μm for Paddle length L=1000 μm and width W=100 μm is performed and total displacement of microcantilever simulated by using Comsol Multiphysics software. Fig. 8 (a) and (b) shows the total displacement with thickness 1 μm and 0.5 μm. As the length of the cantilever increases, total deflection increases and maximum displacement is obtained when length is 1000 μm, base length is 100 μm and thickness 0.5 μm produces maximum deflection of 2.7384 x 10^{-8} μm with respect to the force applied due to one HIV.

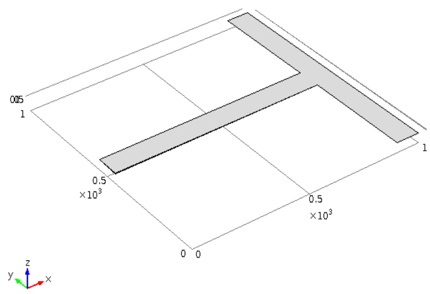

Fig. 7 Design of Long Paddle(T-shape) Shape Microcantilever

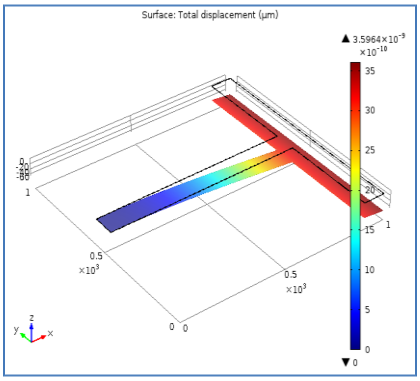

Fig. 8(a)

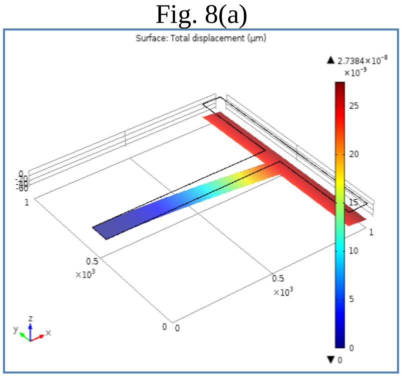

Fig.8(b)

Fig. 8 (a) & (b) Total Deflection for thickness t=1 μm and t=0.5 um T SHAPE (Long Rectangular Paddle) cantilever with base width W=100 μm and length L=1000 μm for Paddle length L=1000 μm and width W=100 μm

3.5 T shape Microcantilever(Short Paddle)

Fig. 9 shows the design of short paddle T- shape microcantilever To detect one HIV virus to obtain maximum deflection, the height of the T SHAPE (Short Rectangular Paddle) cantilever with width W=100 μm and length L=1000 μm for Paddle length L=500 μm and width W=100 μm is performed and total displacement of microcantilever simulated by using Comsol Multiphysics software. Fig. 10 (a) and (b) shows the total displacement with thickness 1 μm and 0.5 μm. As the length of the cantilever increases, total deflection increases and maximum displacement is obtained when length is 1000 μm, breadth is 100 μm and thickness 0.5 μm produces maximum deflection of 3.2348 x 10^{-7} μm with respect to the force applied due to one HIV.

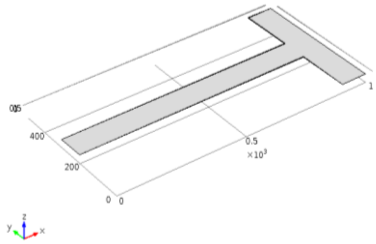

Fig. 9 Design of Short Paddle(T-shape) Shape Microcantilever

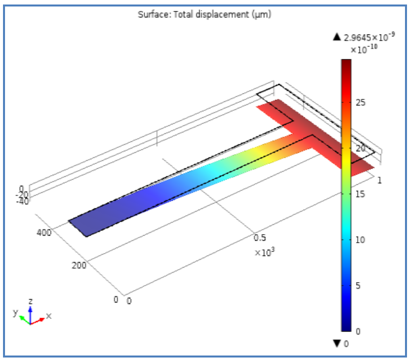

Fig. 10(a)

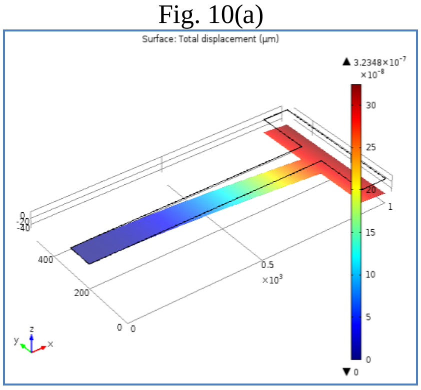

Fig. 10(b)

Fig.10 (a) & (b) Total Deflection for thickness t=1 μm and t=0.5 μm T SHAPE (Short Rectangular Paddle) cantilever with base width W=100 μm and length L=1000 μm for Paddle length L=500 μm and width W=100 μm

4. RESULTS & DISCUSSION

As per the analysis performed for different shapes of microcantilever for the identification of one HIV, table 2 gives variation of displacement value for different shapes like rectangular, triangular,V shape and T shape(Long and Short paddle). Fig.11 shows the total displacement with respect to different shapes of cantilevers, out of which T shape(500 µm paddle) produces maximum total displacement of 3.24 x 10^{-07} µm which can be easily measured using simple read out systems.

Table 2 Variation of Total Displacement of cantilever with respect to different dimensions

S.No.	Shape of the Micro Cantilever	Total Displacement (µm) for T=1 µm	Total Displacement (µm) for T=0.5 µm
1	Triangular	1.39 x 10^{-09}	1.12 x 10^{-08}
2	Rectangular	2.09 x 10^{-09}	1.63 x 10^{-08}
3	V-Shape	3.20 x 10^{-09}	2.56 x 10^{-08}
4	Long Paddle T shape (1000 µm Paddle)	3.60 x 10^{-09}	2.74 x 10^{-08}
5	Short Paddle T shape (500 µm Paddle)	2.97 x 10^{-09}	**3.24 x 10^{-07}**

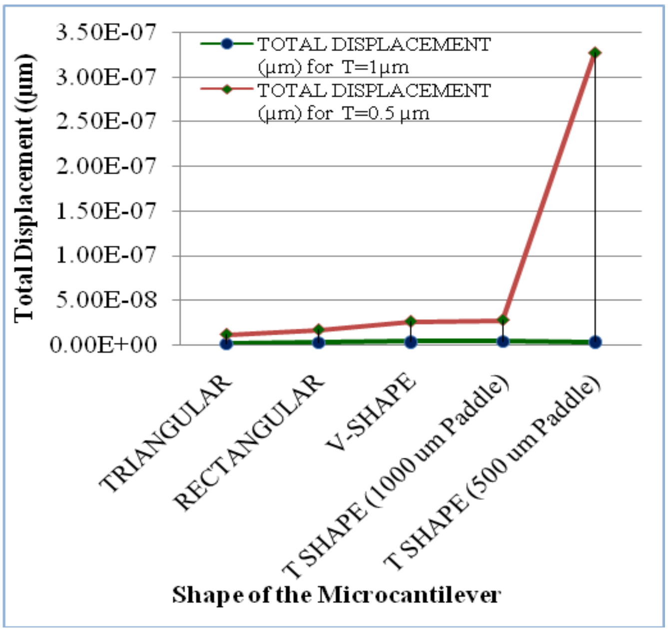

Fig.11 Total Displacement with respect to shape of the cantilever with thickness t=0.5 µm and t=1 µm

5. CONCLUSION

As microcantilevers based sensor are mostly used as physical, biological, and chemical sensors in various applications. In this paper, T SHAPE (Short Rectangular Paddle) cantilever with base width W=100 µm and length L=1000 µm and thickness 0.5 µm, for short paddle length L=500 µm and width W=100 µm with thickness 0.5 µm produces total displacement of 3.24 x 10^{-7}µm for one HIV. As HIV detection is complex, the proposed T SHAPE (short rectangular paddle) microcantilever gives inferences that it produces maximum measurable displacement for identification of HIV. The simulation is performed using Comsol multiphysics software and the variation of total displacement for rectangular, Triangular, V shape and T shape (Paddle) microcantilevers studied by considering SiO_2 as material. In Future more sensitivity and displacement can be obtained by introducing stress control region by making slots in the microcantilever with different shapes and by choosing the appropriate cantilever material to produce maximum displacement.

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Fig. 2 (b)
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BIOGRAPIES

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