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RESEARCH ARTICLE

OPTIMUM DESIGN AND ANALYSIS OF RECTANGULAR MICROCANTILEVER FOR HUMAN IMMUNODEFICIENCY VIRUS DETECTION

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ABSTRACT

Microcantilever based sensors is a promising platform for sensors in various chemical and biological applications. Rectangular microcantilever is commonly used biosensing device for the detection of various disease detection target in biomedical applications .HIV is a virus which producing life threatening diseases which attacks the immune system. In this paper to detect HIV, various analyses performed on rectangular cantilever for optimum design to produces maximum total displacement due to attachment of HIV virus on the surface of the microcantilever. This study proposes a rectangular cantilever for the detection of HIV under static mode of operation. The analysis is performed by varying the length, width, thickness of the rectangular cantilever for getting maximum displacement for one HIV detection. The simulation results show the displacement of cantilever with number of HIV targeted on the cantilever. From this analysis rectangular cantilever with length 1000 µm, width 100 µm and thickness 0.5 µm produces maximum deflection of 1.632 $x10^{-8}$ µm with respect to the force applied due to one virus of HIV. Hence it may be possible to detect the HIV virus in human by using proposed rectangular microcantilever sensor as it produces measurable deflection using recent read out methods.

Key words: Rectangular Microcantilever, Static mode of operation, HIV detection, Simulation

I. INTRODUCTION:

Microcantilever based biosensors becomes an attracted interest for the recognition of target analytes because of their fast, compact read-out systems, and high sensitivity.[1-2]. A biosensor is a sensing device which can be divided into three main component namely, a detector which recognizes the signal of interest (analyte), a transducer which converts the signal into a more useful output, typically an electronic signal, and a read-out system which filters, amplifies, displays, records, or transmits the transduced signal[3]. Micro cantilever-based sensors have two types of application modes widely used in sensing applications, static mode, where the cantilever bends due to an attached mass or force acting upon it and dynamic mode, where the resonant frequency is monitored which shifts due to the mass getting attached to the structure.

Micro cantilever sensors can be operated in air, vacuum or in liquid[4]. When the sensor operates in a static mode, the sensitivity is mainly determined by the microcantilever deflection, where, the deflection of the microcantilever depends on thickness coating of the sensitive layer [5]. The ability of scalable, label free detection to allow massive parallelization and sensitivity of the detection range applicable to in vivo problems is some of the important requirements for a future generation of biosensors, Although generally used in the topological investigations of surfaces such as in atomic force microscopy, arrays of microcantilevers are attracting much interest as sensors in a variety of applications. Microcantilever sensors have emerged as a universal, very powerful and highly sensitive tool to study various physical, chemical, and biological phenomena [6-12]. The human immunodeficiency virus (HIV) is a slowly replicating retrovirus that causes the acquired immunodeficiency syndrome (AIDS)[15][16]. Due to HIV in humans makes progressive failure of the immune system which allows life-threatening opportunistic infections and cancers to thrive. Without treatment, average survival time after infection with HIV is estimated

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to be 9 to 11 years, depending on the HIV subtype [17]. Infection with HIV occurs by the transfer of blood, semen, vaginal fluid, pre-ejaculate, or breast milk. Within these bodily fluids, HIV is present as both free virus particles and virus within infected immune cells.

II. Microcantilever Based Human Immunodeficiency Virus Detection:

A cantilever is a simple mechanical structure, which is fixed at one end and free at the other end. Micro cantilever is a micro fabricated structure in which length is longer as compared to width, and has a thickness much smaller than its length or width. To operate cantilever as a sensor, it has to be coated with a sensing layer which should be specific to recognise target molecules in key-lock processes. Microcantilever sensors can be operated in air, vacuum or in a liquid. Two commonly used principle of operation of microcantilever for sensing applications are the adsorption-induced deflection and the resonant frequency shift. [4]. By using micro cantilever HIV may also be detected by operating under static mode.[19]. In HIV, H – Human – This particular virus can only infect human beings. I – Immunodeficiency – HIV weakens your immune system by destroying important cells that fight disease and infection. A "deficient" immune system can't protect. V – Virus – A virus can only reproduce itself by taking over a cell in the body of its host

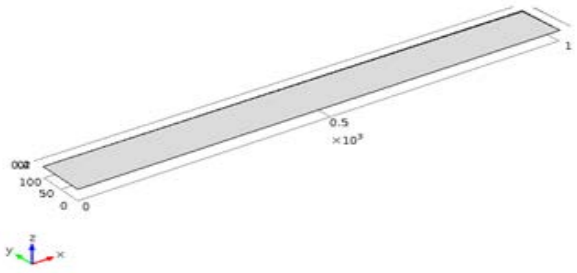

Figure 1: Typical Structure of microcantilever

Fig.1 show the typical structure of microcantilever and The stoney equation is used to calculate the deflection and it is given by equation (1), which is commonly used for relating substrate curvature to film stress.

$$\Delta z = \frac{4(1-v)\Delta\sigma l^2}{Et^2} \quad \text{-- (1)}$$

From the equation, the deflection (Δz) induced by surface stress can be estimated. Here, v is Poisson's ratio, E is Young's modules, l and t are respectively the length and thickness of microcantilever. It is noted that this equation does not contain any parameters relating with a coating film inducing the surface stress. In order to detect a specific analyte by cantilever, the microcantilever is provided with probe coating on the surface depends upon the nature of the analyte. The probe coating is a sensitive layer which provides specificity for analyte recognition. This principle relies on transduction of chemical or physical processes into mechanical deflection. The analyte molecules diffuse into cantilever coating, which begins to bend, jointly with the mass increase, a change of interfacial stress between coating and cantilever occurs resulting in a bending of cantilevers due to increase in force.

III. Force Calculation For Hiv Detection:

HIV is different in structure from other retroviruses. It is roughly spherical[18] with a diameter of about 126 nm
Calculation of total force to be applied on the surface of cantilever can be made by calculating the volume and substituting the density value

Vol. of sphere= $\frac{4}{3} \times \pi \times (\frac{126e^{-9}\ m}{2})^3 = 1.05x10^{-21}\ m^3$ -- (2)

Assume density of HIV = 1 g/cm³
Therefore, Mass = $1.05x10^{-21}\ m^3 \times 1e^3\ kg/m^3 \cong 1x10^{-18}$ kg
Therefore By Newton's law, Total Force produced by one HIV is **$F = ma = 1x10^{-18}x9.8 = 9.8x10^{-18}$ Newton**; m is mass of virus and g is centre of gravity(9.81 m/s^2)

IV. Modeling and Simulation:

The deflection of a microcantilever can be modeled by applying a force of $9.8x10^{-18}$ Newton at the top surface of the cantilever. The simulations are performed by modeling the cantilevers by the material SiO2 having characteristics as shown below.

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

The cantilevers are subject to a total force of $9.81\ x10^{-18}$ N on their top surfaces ie., the force due to one HIV virus attached on the top of the microcantilever.

(i) Analysis 1(Variation of Total displacement with length):

To detect one HIV virus to obtain maximum deflection, the length of the rectangular cantilever is varied for width w= 100 µm and 150 µm with thickness t=0.5 µm and t=1 µm performed and total displacement of microcantilever

simulated by using Comsol Multiphysics software. Fig. 2 shows the variation of total displacement with respect to length of the cantilever. This shows that when 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 1.632 $x10^{-8}$ µm with respect to the force applied due to one virus of HIV

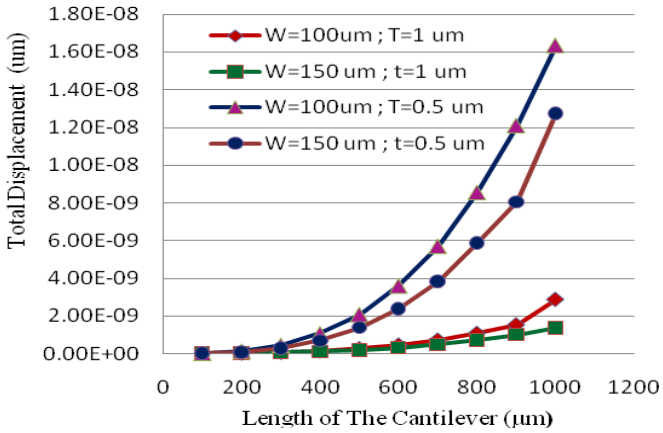

Figure 2: Variation of Total displacement of cantilever with respect to length of the microcantilever with different width and thickness

(ii) Analysis 2(Variation of Total displacement with width):

To detect one HIV virus to obtain maximum deflection, the width of the rectangular cantilever is varied for length= 1000 µm and 500 µm with thickness t=0.5 µm and t=1 µm performed and total displacement of microcantilever simulated by using Comsol Multiphysics software. Fig. 3 shows the variation of total displacement with respect to width of the cantilever. This shows that when the width of the cantilever decreases, total deflection increases and optimum displacement is obtained when width is 100 µm, length 1000 µm and thickness 0.5 µm produces maximum deflection of 1.632 $x10^{-8}$ µm with respect to the force applied due to one virus of HIV. Here important criteria to be satisfied is when width of cantilever decreases the area gets reduced hence the width should not be as small but it should have optimum. By this analysis performed the optimum width is 100 µm.

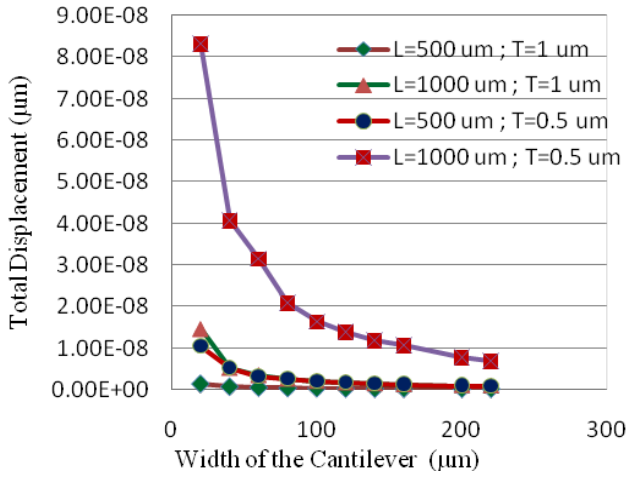

Figure 3: Variation of Total displacement of cantilever with respect to width of the microcantilever with different length and thickness

(iii)Analysis 3(Variation of Total displacement with Thickness):

To detect one HIV virus to obtain maximum deflection, the thickness of the rectangular cantilever is varied for length= 1000 µm and 500 µm with width w=100 µm performed and total displacement of microcantilever simulated by using Comsol Multiphysics software. Fig. 4 shows the variation of total displacement with respect to thickness of the cantilever. This shows that when the thickness of the cantilever decreases, total deflection increases and optimum displacement is obtained when thickness 0.5 µm, length 1000 µm and width is 100 µm produces maximum deflection of 1.632 $x10^{-8}$ µm with respect to the force applied due to one virus of HIV. Here important criteria to be satisfied is when thickness of cantilever decreases the fabrication become complex hence the optimum thickness for the rectangular cantilever for easy fabrication and analysis is 0.5 µm.

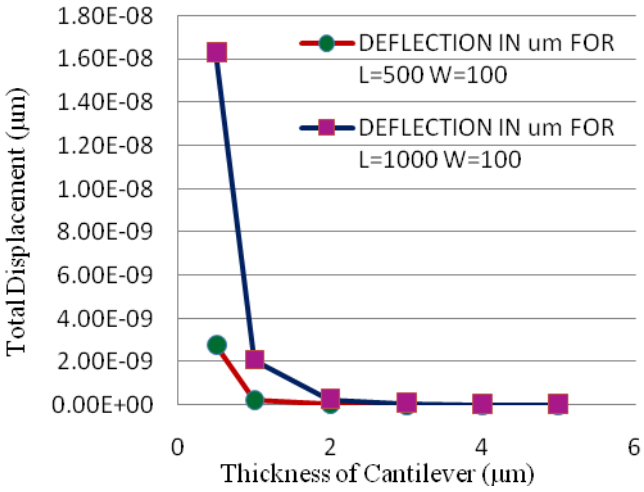

Figure 4: Variation of Total displacement of cantilever with respect to thickness of the microcantilever with different length and width

(iv) Analysis 4(Variation of Total displacement with number of virus in cantilever):

To obtain maximum deflection for number of HIV virus interacted on the surface of the cantilever, the length = 1000 µm and 500 µm, width w=100 µm, thickness = 1 µm and 0.5 µm performed and total displacement of microcantilever simulated by using Comsol Multiphysics software. Fig. 5 shows the variation of total displacement with respect to number of HIV virus interacted on the surface of the cantilever. This shows that when the no. of HIV virus target increases, total deflection increases. Fig.6 shows the total displacement of 1.6332x10^{-8} µm obtained with Length 1000 µm and Width 100 µm with thickness 0.5 µm for the detection of one HIV.

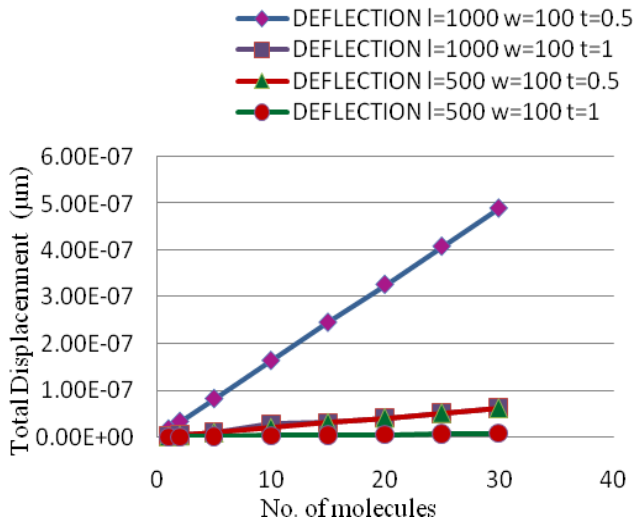

Figure 5: Variation of Total displacement of cantilever with Number of HIV virus interacted on the surface of cantilever with different dimensions of cantilever

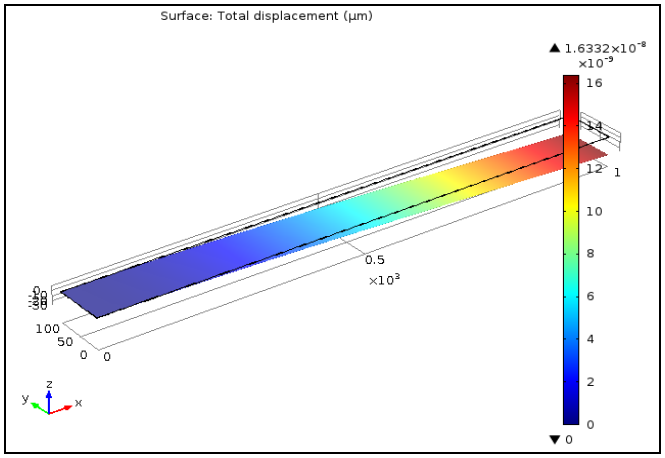

Figure 6: Total displacement of 1.6332 x10^{-8} µm obtained with Length 1000 µm and Width 100 µm with thickness 0.5 µm

Fig.6 shows the total displacement of 1.6332 x10^{-8} µm obtained with Length 1000 µm and Width 100 µm with thickness 0.5 µm which is optimum design for detecting the HIV.

V. CONCLUSIONS

Hence Rectangular Microcantilever is an important device in the field of biosensor field with high selectivity and sensitivity. In this review and analysis, rectangular cantilever structure is analyzed to obtain maximum displacement by varying the length, width, thickness. As HIV detection is complex, the proposed microcantilever gives inferences that it produces maximum displacement of 1.6332 x10^{-8} µm with Length 1000 µm and Width 100 µm with thickness 0.5 µm for single HIV. The simulation is performed using Comsol multiphysics software and the variation of total displacement with respect to geometry of the microcantilever 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 or by designing the structure with different material having good elasticity and density properties.

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