Design of Trapezoidal Cantilever Beam for HIV Virus Detection

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Abstract

Objectives: The main objective is to design a piezoelectric cantilever MEMS sensor for effective detection of virus from a blood sample. **Methods/Statistical Analysis**: Cantilever beams are often used as biosensors in medical field because of their highly sensitive sensor platform and the ability to change its surface properties to detect a particular virus. The sensor is a trapezoidal cantilever beam with a piezoelectric material which detects the changes in the mechanical vibrations caused because of the virus absorbed on the free end of the beam. The trapezoidal cantilever is designed using COMSOL Multi physics software, where a pit is provided to trap the virus on the free end and piezoelectric material is placed at the fixed end to provide an electrical output proportional to the changes in the mass of the sample. **Findings:** The results show that the trapezoidal model can be preferred than the traditional rectangular model for detection of HIV virus since they are more sensitive to the mass of the sample provided at the tip. **Application/Improvements:** The design can be improved by varying the geometry of the cantilever beam and also by introducing cross section area across the beam to improvise the mass distribution and stiffness.

Keywords: COMSOL, Cantilever, HIV, MEMS, Piezoelectric, Trapezoid

1. Introduction

During the inception of Micro ElectroMechanical Systems (MEMS), its application in biomedical technology was recognized¹. Cantilever beams is one of the most commonly used structures because we can change its surface according to the property of the bio molecule². The trapping of the bio molecule on the surface of cantilever can be done by using various biomarkers according to the property of the bio molecule, so that it gets trapped on the cantilever beam³.It is possible to detect the protein-antigen-antibody complex formed on the surface by observing the changes in the MEMS devices⁴. AIDS epidemic is a worldwide concern. Human Immunodeficiency Virus (HIV) is formed because of the collapse of the immunity system and in turn causes many lives threatening situations. The structure of the HIV virus is different from other retro viruses. It is roughly circular in shape with diameter of 120nm which is greater than the regular size of the virus. Thus for the detection of this virus, a trapezoidal cantilever beam is taken than the conventional rectangular beam. This paper proposes the possibility of easy detection of HIV virus using the trapezoidal cantilever model.

2. Principle

In this paper, HIV virus is detected using because of the changes in the mechanical motion if the cantilever beam. The cantilever is based on dynamic sensing mode, where there is shift in its natural resonant frequency when a mass of a particular blood sample is provided to the cantilever⁵. Here the mechanical action of cantilever is converted into voltage to measure the mass of the virus. A trapezoidal cantilever beam made to oscillate by giving electromagnetic induction of 2 Volts, at its own resonance frequency. This action produces strain, which is proportional to the stress at produced at the fixed end and thus produces electrical voltage across the piezoelectric material (PZT-5A)⁶. When a sample in mass is given to the pit of the cantilever

at the free end, the resonance frequency of the cantilever reduces in turn increasing the deflection of the cantilever and the stress formed at the fixed end of the cantilever. Different from the classic rectangular mass sensors in this work a grooved trapezoidal structure is taken as the key elastic element. Since the change in geometric dimensions especially at the tip increases the sensitivity of the mass of the virus present at the tip.

3. Design of the MEMS Sensor

The design consists of a grooved trapezoidal shaped cantilever beam, where one end of the cantilever is fixed and the grooved end is left free. The schematic representation of trapezoidal beam is as shown in Figure 1.



Figure 1. Schematic representation of trapezoidal cantilever beam.

The trapezoidal beam has dimensions (33, 0), (0,500), (100,500), $(63, 0)^7$. A layer of poly silicon is the base material of cantilever beam. The second layer is made up of SiO₂ which acts as the insulator. A pit of dimensions (37, 10), (30,150), (70,150), (57, 10) is placed at the free end to trap the virus. At the fixed end a piezoelectric material, Lead Zircon ate Titan ate (PZT-5A) is placed with dimensions (5,420), (0,500), (100,500), (94,420).

The piezoelectric material is placed between upper and lower platinum layers they operate as an electrodes to measure the voltage across piezoelectric material. The layer of silicon dioxide is placed so that the cantilever beam and the platinum electrodes are isolated from each other.

3.1 Simulation using COMSOL

The simulation process of trapezoidal model is done using COMSOL Multi physics software. It is done using three types of physics. They are; Structural mechanics, Electro mechanics and Piezoelectric devices. Electromagnetic induction of 2V is given to the cantilever to oscillate the beam.

Meshing used is the courser mesh which is a physics controlled mesh. At different Eigen frequencies, voltage is obtained for different samples of mass. The voltages for the trapezoidal model for different mass samples are obtained. The "terminal" feature of COMSOL software is used so one of the platinum electrodes can be connected to an output circuit to get the output voltage. The "ground" feature is used to ground the other platinum electrode. Thus when sample mass =20ng, 30ng, and 40ng the voltage for each Eigen frequency is obtained. The Figure 2 to Figure 4 shows the simulation models for each of the mass mentioned respectively.



Figure 2. Simulation model when sample mass=20ng.

4. Results and Discussions

We can infer from the above simulation that as the sample mass increases, the voltage also increases through which detection of HIV virus can be easily detected.

Also by comparing the classic rectangular model and the currently designed trapezoidal model we observe that the trapezoidal model shows more deflection than the rectangular beam when same mass is given to both the models⁷. Eigen frequency analysis can be chosen in the study option to obtain the voltage for each Eigen frequency.



Figure 3. Simulation model when sample mass=30ng.



Figure 4. Simulation model when sample mass = 40ng.

Mass in g	Eigen freq in Hz	Voltage in µV
20	6.115e5	8.43*10-5
	1.065e5	6.3*10-5
	1.984e5	4.85*10-5
	6.747e5	8.65*10-5
30	2.625e5	2.49*10-4
	1.346e5	3.33*10-4
	2.588e4	3.35*10-4
	6.695e5	4.56*10-5
40	1.577e5	3.75*10-4
	2.700e4	2.20*10-4
	1.065e4	2.76*10-4
	9.644e5	3.05*10-4

 Table 1. Voltages at different frequencies

PZT5A is used here as the piezoelectric material because it has excellent capability to handle power⁸. The output may require a signal conditioning circuit because while measuring the output with a voltmeter whose input impedance is much lower than the output impedance of the sensor. The values of the voltages obtained for each Eigen frequency and for each sample mass of the trapezoidal cantilever is shown in Table 1.

5. Conclusion

Thus a piezoelectric trapezoidal micro cantilever beam was designed using COMSOL software for the detection of HIV virus. Here the classic rectangular model is converted into grooved trapezoidal model and it is observed that the geometric changes of the rectangular beam gives rise to greater deflection of the cantilever and greater sensitivity of the virus present in the sample.

Sample mass were given to the trapezoidal beam. The voltage obtained rises from microvolt to mill volt as the sample mass increases. So the voltage obtained at each Eigen frequency is equal to the number of HIV virus present in the sample. Comparison of the rectangular model with the trapezoidal model can be done and we can conclude that trapezoidal model is more preferred, because the trapezoidal model shows more deflection when compared to rectangular model when the sample mass is applied to both structures.

The highest quantity of virus that can be bound to the pit depends on the properties of surface of the cantilever and the nature of the virus, thus as we have considered the HIV virus which is roughly circular in nature and has diameter of 120nm. The size of this virus is more compared to average size of other viruses. Since the area at the tip is small HIV virus can be effectively detected using the trapezoidal model of cantilever beam. The piezoelectric voltage obtained is proportional with detection of the virus.

In addition to this, a cross-section can be introduced between the poly silicon and SiO_2 layer. Thereby we are not only changing the structure but also the cross section profile to equalize the stiffness and mass distribution⁹. Also, various biomarkers that are suitable for trapping the HIV virus can be researched. The possibility of whether it can be fabricated successfully on the trapezoidal beam and results obtained after fabrication can also be researched.

6. References

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