Analysis of MEMS cantilever Geometry for Designing of an Array Sensor

Smita Priyadarsini, J. K. Das, Ananya Dastidar

Abstract---Microcantilevers are the most simplified MEMS based devices in terms of fabrication as well as operation. MEMS cantilever sensors have slowly evolved in their applications and can be found almost everywhere in today’s life. The popularity of these sensors is growing day by day mostly due to its unique advantages that they possess. Microcantilever based sensors have enormous potential for the detection of various target molecules in gaseous, vacuum and liquid medium. Microcantilevers are employed in physical, chemical and biological sensing. They have also have wide range of applications in the field of medicine, specifically for the screening of diseases, detection of point mutations, blood glucose monitoring and detection of chemical and biological warfare agents. These sensors have several advantages over the conventional analytical designs and methods in terms of high sensitivity, low cost, simple procedure, low analyte requirement (in µl), non-hazardous procedures and quick response. In this paper we will study the different characteristics of two types of cantilever beam by varying three different types of materials namely silicon, silicon dioxide, Polysilicon. In general we will study the natural resonant frequencies or eigen frequencies of the beams by varying the thickness of the beams.

Keywords---MEMS, microcantilever, sensors, sensitivity

I. INTRODUCTION

In recent years we have experienced a strong inclination towards miniaturization. The reason behind this growing trend is that small components can perform tasks that large systems cannot. At the same time, technology driven due to IC-fabrication processes allows the production of miniature components in large volumes and at low prices. Micro Electro Mechanical Systems (MEMS) is the technology which mainly involves the integration of miniature multiple electronics and mechanical elements such as sensors and actuators integrated into a single substrate. Based on the measurand or the type of input that are used, many different types of sensors are used in various applications in our day today life.

To understand the methodology and processes used in this work it is important for us to have background information on the MEMS cantilever-type sensor. Many different aspects will be covered, in this chapter

A. Background

The most researched area of micromachines is into Micro Electro Mechanical Systems (MEMS). These systems are a combination of mechanical and electrical components built into incredibly small devices that are fabricated using sophisticated integrated circuit (IC) processing technologies. MEMS are intricate devices that can have several moving parts and they are coupled together with other MEMS which can sense, analyse as well as perform complex operations. In addition to that it should also be able to control and actuate motion on the microscale.

Fast development of micro electrical mechanical systems (MEMS) has led to many success stories in the field of biomedical applications. A biosensor is a chemical sensing device in which an analyte is biologically derived is coupled with a transducer which in turn senses the change and gives us a suitable output. A sensor basically consists of two parts one is a bioelement and the other is a sensing element. These bioelements can be any of the enzymes, antibodies, living cells, tissues etc and the sensing part may be an electric current, electric potential etc.

These MEMS generally range from 1-100 micrometers and have certain advantages over other biological sensors like low manufacturing cost, compact size, low weight, low power consumption and increased multifunctioning. In this paper we are going to focus on one of the simplest bioMEMS structure i.e a microcantilever sensor.

If we see the applications of these microcantilever sensors then there are other uses of these by using them as arrays and can be used as detectors. These multiple array oscillators are used for various biosensing applications [4]. The concept of self sustainedoscillations(SSO) is the principle that are used to maintain oscillations of dynamic MEMS sensor [4]. In a resonant mass sensing systems a MEMS structure is oscillated at its resonant frequency. This shift in resonant frequency is sensed which further detects the minute amount of chemicals that bind the sensor surface.

From the above we come to the conclusion that MEMS devices are a very promising area of research and to study the behavior of MEMS cantilever beams and its application. We propose to implement it in ANSYS & COMSOL.

II. MATERIALS AND METHODS

A. Simple MEMS Cantilever Beam

We began our work by considering a simple MEMS cantilever beam. This beam is named as Type 1 beam. This cantilever is a fixed- free type of beam i.e one end of the beam is fixed and the other end is kept free.
The load applied here is constant and a uniformly distributed body load which is applied in the negative z direction. Here the length of the beam is L, width by W and thickness is T and Youngs Modulus E of the material used and q is the force applied. With the help of these dimensions we can calculate the Flexural Rigidity, I.

The deflection of the uniform area cantilever under body load is calculated by

\[ D = \frac{qL^4}{8EI} \]

Where,

\[ I = \frac{WT^3}{12} \]

B. Paddle shaped Cantilever Beam

The load applied here is constant and a uniformly distributed body load which is applied in the negative z direction. Here the length of the beam is L, width by W and thickness is T and Youngs Modulus E of the material used.

With the help of these dimensions we can calculate the Flexural Rigidity, I.

\[ D = \left[ \frac{qL^4}{128EI_1} \right] \left[ 1 + \frac{15I_1}{I_2} \right] \]

Here \( I_1 \) and \( I_2 \) are flexural rigidity of area 1 and area 2 respectively and q is the applied force.

C. Materials used in Designing of MEMS cantilever

This part will cover the materials used in “silicon-based” MEMS and microcantilever. As such, silicon will be the principal material to be studied. Other materials to be dealt with are silicon compounds such as: SiO\(_2\), SiC, Si\(_3\)N\(_4\) and polysilicon.

### Table 1: List of Materials and their Properties

<table>
<thead>
<tr>
<th>Materials</th>
<th>Youngs Modulus ((10^{11} \text{ N/m}^2))</th>
<th>Poissons Ratio ((\text{g/cm}^3))</th>
<th>Density ((\text{g/cm}^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>1.90</td>
<td>0.27</td>
<td>2.30</td>
</tr>
<tr>
<td>Polysilicon</td>
<td>1.60</td>
<td>0.23</td>
<td>2.32</td>
</tr>
<tr>
<td>SiO(_2)</td>
<td>0.73</td>
<td>0.15</td>
<td>2.27</td>
</tr>
<tr>
<td>SiC</td>
<td>0.74</td>
<td>0.45</td>
<td>3.21</td>
</tr>
<tr>
<td>Si(_3)N(_4)</td>
<td>2.50</td>
<td>0.23</td>
<td>3.10</td>
</tr>
</tbody>
</table>

III. MEMS CANTILEVER BASED SENSING

MEMS cantilever sensor is based on the mechanical deformation of the structure, or in other words the deflection of membrane or beam structure. When the cantilever is loaded with some target, it gets deformed. The MEMS cantilever will then bend. As this deformation occur, the structure changes shape of the beam, and points on the structure gets displaced. The concept behind deflection occurs when a disturbance or load is applied to the cantilever free end or along the MEMS cantilever surface. Normally the disturbance or loading is a force or mass that is applied to the surface of MEMS cantilever which result the bending of the MEMS cantilever.

A. MEMS Cantilever based Bio Sensing

In case of the microcantilever based biosensors which works on the principle of conversion of bio recognition into some kind of nanomechanical motion. The reason for nano mechanical motion is due to the free energy change on the
surface of the cantilever due to the reaction between the target analyte binding with probe coating molecule. In order to detect a specific target molecule, the microcantilever transducer is fabricated with some microfluid coating on the surface based on the nature of the target molecule. This film coating is a chemically sensitive layer which provides specificity for analyte recognition. The principle relies on transduction of chemical or physical processes into some mechanical response. After exposure to analyte, target molecules diffuse into the cantilever coating, which begins to bend, adding on the mass increase, a change of interfacial stress occurs between coating and cantilever occurs resulting in a bending of cantilever.

Here we compare the different values of deflection and stress that we have derived from the above simulations and plotted them in a comparative graph in Fig 2.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Maximum Stress (N/m)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>5.2 x 10^6</td>
<td>6.36 x 10^-10</td>
</tr>
<tr>
<td>Poly silicon</td>
<td>5.27 x 10^6</td>
<td>6.43 x 10^-10</td>
</tr>
<tr>
<td>SiO2</td>
<td>5.31 x 10^6</td>
<td>6.47 x 10^-10</td>
</tr>
<tr>
<td>SiC</td>
<td>5.35 x 10^6</td>
<td>6.69 x 10^-10</td>
</tr>
<tr>
<td>SiN</td>
<td>5.26 x 10^6</td>
<td>6.45 x 10^-10</td>
</tr>
</tbody>
</table>

In the above table we have found out that the maximum stress and the maximum deflection is in case of SiC and is in range of 10^-6 to 10^-4.

From the table and the comparison graph shown above we can conclude that SiC can be a better substitute for designing a Bio-MEMS which requires higher sensitivity.

C. Designing Of A Proposed Bio-Sensor Array

From the previous section we have seen the advantages of SiC over other materials. So now we design an array of cantilever made of off SiC and then coat each of the layer with different polymer coating. By coating this array with different polymer
layer we are making each beam target specific. Which can be simplified as that each cantilever is sensitive to a particular material. When the polymer layer reacts or binds with a particular material then increase in the mass leads to the bending of the cantilever beam thus by acting as a biosensor.

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**Fig 8** Designing of a BioMEMS Cantilever Array Sensor.

**Fig 9** Deflection when beam 1 is reacting to an Analyte

**IV. CONCLUSION**

Calculations were made to determine the deflection and the stiffness or spring constant of the cantilever beam of various materials. A comparison among the resonant frequencies and deflection were made and we can infer that both the resonant frequencies and deflection gets decreased if the thickness of the beam is kept increasing. Similarly the deflection of the beam keeps on decreased decreasing by adding the thickness and the stiffness gets on increasing by increasing the beam thickness. Then we vary the length of the beam by adding two different materials along with the materials previously used we infer that SiC can be used as a better materials for designing Bio-MEMS. And lastly a proposed cantilever array was designed.

**REFERENCES**


