Enhancement of Micro cantilever’s Rectangular and Triangular Beam for Improving the Sensitivity of Biosensor – a Comparative Study

S Urekabharathi and K G Padmasine
Department of Electronics and Instrumentation, Bharathiar University, Coimbatore.

Abstract. Micro-Electro-Mechanical Systems (MEMS) is the mixing of factors like mechanical, sensors, actuators, and electronics on a common substrate through the consumption of micro-fabrication era or micro-technology. A type of beam is called “cantilever” which provides assistance at only one end. This work affords to have a look on MEMS based entirely micro cantilever beam which are employed in medical software systems and are a component to slicing region reasonably evolved sensors. The beams of the Cantilever are the most omnipresent systems within the area of micro-electromechanical structures (MEMS). MEMS cantilevers are normally made from silicon (Si), silicon nitride (Si₃N₄), or poly-silicon. A procedure on growth in deflection of micro cantilever beam is essential for enhancing the sensitivity of biosensor. The sensitivity level of a microcantilever biosensor relies upon on its deflection that occurs because of the antigen-antibody interplay. The deflection can be elevated by way of growing the length or lowering the thickness of micro cantilever beam but it'll minimize the reverberating frequency of the beam. This minimizes the resonant frequency and that makes the cantilever vulnerable to thermal noise and low frequency vibrations which immediately affect the size of deflection. In this method, the rectangular and triangular shapes are taken into consideration and the comparative evaluation is established. The outcomes display that the deflection of triangular beam is two times extra than rectangle fashioned beam.

Keywords: MEMS, micro cantilever, materials, shapes, sensitivity

1. Introduction
The method MEMS is called as the compilation of micro-sensors and actuators which will be able to determine its surroundings and it has the capacity to respond to alterations in the surroundings with the help of a microcircuit control. An endeavor to miniaturize both the sensors and actuators for the intention of minimizing dimension, load, energy expenditure, and the manufacture cost. Assimilating micro-machines and microelectronics on the similar chip is promising. In certain cases, the proper method performance must be obtained which is more than macro terms. MEMS prepared micro-sensors are employed for assessing the physical features. Transducer is a fundamental unit of a sensor that helps to sense the substantial transform and provides equivalent rejoinder which is scalable and transforms the scalable retort into electrical signal with the aid of detailed standard of transduction. Both the micro-cantilevers and beams are practical elements of transducer, utilizing which numerous physical alterations can be graded. The fundamental method is the beam deflection and framework of cantilever. The sensitivity of deflections is by capacitive or even piezoresistive dimension [8]. The disparity among the beam and a cantilever is that a beam is preset at both the ends while the cantilever is preset at only one end. The projected approach displays that the possessions of discrepancy in dissimilar materials and compares the output simulation results for SiO₂ Si₃N₄, Poly Si, Al and SU₈ using Ansys13.0.

The method of analytes interface is a procedure that is taken by the biosensors which has to be identified with organically resultant biomolecules, like enzymes of confident forms, antibodies, and another type of protein. These types of biomolecules when associated to the block of sensing can
modify the production signals of the sensors when they correspond with the analyte. This type component identification are minute measure cantilever beam framework, longer as contrasts to breadth, and include a width much less significant than its time-span or size. The biosensor is erected by a micro cantilever and an exterior piezoelectric or piezoresistive for generating pulsation.

The sensor based on piezoelectric micro cantilever helps to discriminate the variation occurred in the reverberation frequency of a micro cantilever and which is also to discover the preserved biomolecule mass whereas the base of the micro cantilever piezoresistors are employed to scale the strain stimulated resistance variation generated by a explicit biomolecule [2]. After absorbing the biomolecules, the material identification purposely adsorbs the distant feature, carrying about a modest volumetric variation in the material sensing. This volumetric variation is scaled as an uncomplicated resistance alteration in the piezoresistive micro cantilever, and the identification of biomolecules at the micro cantilever’s free end, a diminutive region of gold is enclosed to grasp connecting infections. In the same time, when the device is offered to a situation with objective diseases as shown in fig.1, the antibodies enclosed on the micro cantilever’s free end will confine them, comprehending a shift in reverberation frequency. This progress is professed by the piezoresistive constituent. From the reverberation shift, the collection of the infection can be acquired.

![Figure 1: MEMS acts as a Micro sensor](image)

Due to the excessive elastic modulus silicon, cantilevers show to a fantastic degree of low deflections for a given surface pressure variation. Subsequently, to increase the deflection, polymer cantilevers may be applied. The elastic modulus of polymer cantilever can be utilized, it's far a whole lot lower than silicon, and the deflections triggered are accelerated manifold. Fabrications of this type of devices are mush behind the quantity of traditional machining, the advancements used to supply these minute additives are known as micro fabrication or micromachining. 3-d microstructures can be generated with the aid of relinquishing parts of base material by a corporeal or etching system, while the thin film deposition methods are employed to manufacture layers of silicon cloth on the bottom material [4].

The device sensitivity is illustrated as (frequency/mass) with the unit s⁻¹kg⁻¹. Here it is imperative to construct the sensitivity of micro cantilever beam, because the enormity of force implicated is very insignificant. Tremendously low deflections impose utilization of progress instruments, for instance, optical and laser deflection recognition, employed for accurately scaling the deflections. The sensitive design of cantilever should professionally switch the stimulus into a huge cantilever deflection, dispossessed of much disturbing the reverberating frequency of the micro cantilever beam. To augment the sensitivity of cantilevers different design and methodologies have been reported [6].

2. Operational Modes

Micro Electro Mechanical Systems (MEMS) have come into existence only in the last decade. The Microcantilevers are the easiest MEMS-based sensors. A cantilever is one which is predetermined at one end and the other end of the micro cantilever is free to move when it feels some stress [10]. A microcantilever is a method that can be employed as a physical, biological or chemical sensor by identifying the variations in cantilever winding or vibrational frequency. One part of the cantilever is
said to be auxiliary, for instance, a pillar or plate, is tend to be anchored at one part to a inflexible support and other end is free. The sensors of Micro cantilever can be performed in air, liquid or in vacuum [9]. Two types of approaches are generally employed for the functioning of micro cantilever for discovering various applications are the Adsorption induced deflection and the reverberating frequency shift. Cantilevers are operated in the following modes.

2.1 Mode of Deflection - Static
The deflection mode of the microcantilever is said to be static which is associated to the divergence in surface stress of the microcantilever (two faces). In this type of mode, the cause of the deflection of the microcantilever is due to the calculation of outside force or stress or load produced on or inside the cantilever is scaled as shown in figure 2 below.

![Figure 2: Mode of Deflection – Static](image)

2.2 Mode of Deflection - Dynamic
This mode of deflection do not entail the functions of only one surface of the cantilever, as the cantilever reverberating frequency variation is based on the entire mass adsorbed on mutual sides.

![Figure 3: Mode of Deflection - Dynamic](image)

The sensitivity level of the reaction of the cantilever is based on its mechanical properties, which are evaluated chiefly by the associated spring constant and resonant frequency. These features depend on the material of the cantilever and its properties and it is given in figure 3.

Winding of the cantilever is an abrupt side effect of the particle adsorption on the facade of the cantilever. In this, it is moderately tough to attain the reliable data regarding the gauge of atoms since surface exposure is hidden, though variation of the mass can be attained by the reverberation frequency shift method. The reverberating frequency of fluctuating cantilever in Hz is given by the equation,

\[ W = \frac{k}{m}^{\frac{1}{2}} \]  

(1)

Where, K is denoted as the spring constant and m is effectual mass of cantilever. By totaling mass, frequency shift towards the lower value and the variation in the mass can be calculated. This method is appealing to discover a small mass [1]. Conversely, this dynamic mode of function poses problem such as high damping of cantilever oscillations because of high thickness of adjacent medium, Piezoelectric or Piezoresistive micro cantilever discover the variation in the reverberation frequency
of a micro cantilever in order to resolve the mass of engrossed molecule.

3. Methodology and its Design

The array of micro cantilever sensors are advised and modeled with ANSYS tool. ANSYS Multi physics software was activated to accomplish the bound aspect assay on assorted micro cantilever shapes to adjudge their sensitivity. The geometry of the micro cantilever is the best capital constant of the device. Distinctive micro cantilever geometries will accept altered frequencies and also the similar abundance shifts, alike afflicted by an agnate infection. Keeping in apperception, the end ambition to amplify abundance shift, the geometry of the micro cantilever is optimized application in ANSYS.

The approach is comprised of cantilever consisting of measurement lengthwise, thickness, and breadth, whose one end is anchored to a rigid support and the other end, is subjected to a load (added mass per unit area) or left free which results in the changes in the deflection of microcantilever in upward and downward directions [11]. The k is called as spring constant and f is said to be the resonant frequency for the rectangular shaped compressed at one end are provided by

\[ f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \]  

(2)

The spring constant is assumed to be

\[ k = E t^3 w/4t^2 \]  

(3)

The variable k is the spring constant and it is the function of a variety of parameters like,

- The elasticity property of a material is given as Young’s modulus \( \rightarrow E \)
- The width of the beam is denoted as \( \rightarrow w \)
- The beam length is denoted as \( \rightarrow l \)
- The beam thickness is denoted as \( \rightarrow t \)

4. Cantilever Beam – Parameters

Cantilever beam has one end fixed and second is freely moveable to deflect as per provided load. The cantilevers have more length as compare to width and have optimal thickness. Without load the cantilever is at the resting state and therefore initially it is horizontal and straight. When force is applied the horizontal axis of the beam is deformed into a curve. Deflection of cantilever depends on length of cantilever, cross-sectional shape of beam and type of material used. Cantilever deflection also depends on the point where load is applied and supporting mechanism of the beam. A Micro-cantilever is a machine that can be employed as various sensors which includes chemical, physical or biological sensor by analyzing the variations in cantilever meandering or vibrational frequency [7].

According to the above prescribed equations first equation is Stone’s equation, that associates deflection of cantilever end and ‘\( \delta \)’ is provided to applied stress ‘\( \sigma \)’ and it implies that the cantilever beam at the deflection end is directly proportional to the stress that is applied. Where the parameters ‘\( \theta \)’ is called as the Poisson’s ratio, the variable ‘E’ is called as the Young’s modulus, the parameter ‘\( L \)’ is called as the length of the beam and finally the parameter ‘\( t \)’ is the breadth of the cantilever. The second equation interrelates the ‘k’ i.e. spring constant to the magnitude of the cantilever and material constants:

\[ \delta = \frac{3\sigma(1-\theta)}{E} (L/t)^2 \]  

(4)

\[ k = E t^3 w/4t^2 \]  

(5)

where, ‘F’ is denoted as the force and ‘\( w \)’ is width of the cantilever. The cantilever beam’s entirely depends up on the beam magnitude i.e., measurement lengthwise, thickness, breadth and also relies on an assortment of material properties that is employed for cantilever construction.
Equations for deflection of cantilever, when load is applied at the end:

\[
d(x) = \frac{-Px^2 (3L-x)}{6EJ}
\]  

Equations for maximum deflection of cantilever, when load is applied at the end:

\[
d_{\text{max}} = d(L) = \left(-\frac{PL^3}{3EJ}\right)
\]  

Equation for deflection of cantilever, when point load is applied at the intermediate point:

\[
d(x) = \left(-\frac{Px^2}{6EJ}\right), 0 \leq x \leq a
\]
\[
= \left(-\frac{Pa^2}{6EJ} (3x-a)\right), a \leq x \leq L
\]  

Equation for maximum deflection of cantilever, when point load is applied at the intermediate point:

\[
d_{\text{max}} = d(L) = \left(-\frac{Pa^2}{6EJ} (3L-a)\right)
\]  

5. Shapes of the Cantilever

An analysis in ANSYS has been performed by utilizing materials like SiO₂, Si₃N₄, Poly Si, Al and SU₈. In this work, rectangular shaped beam and triangular shaped beam are proposed. The design of these two shaped beams possess the requirements like length=200 µm, width=40 µm, thickness=1 with low mass density. The corresponding deflection and resonant frequency value are calculated. The material which has low young’s modulus produce high deflection and low resonant frequency [5]. The structure which shows maximum resonant frequency and deflection is selected. The resonant frequency to be maximum, which will reduce the vibration of microcantilever beam, thus we make a measurement accurately. The reason for changing the shape of microcantilever beam is to augment the microcantilever beam’s deflection [3]. The deflection of the beam can be maximized by dropping the winding inflexibility of the beam of the microcantilever. The winding inflexibility minimization can be performed by dropping the cantilever breadth or by dropping cross section region at predetermined end. The shapes with respect to their deflection are described in figure 4.

![Figure 4: Rectangular Beam](image)

Boundary condition parameters are the significant criteria in MEMs. The conditions are support, dislocation and force boundary conditions for both structures and solids. In this method, the force of 1µN is given at the cantilever edge which is fixed and it is figured in 5.
Figure 5: Force applied at point with fixed edge

The model of ANSYS 13.0 is simulated and it is given in Fig. 6 (a) and (b). In this method, the end which is blue color represents its fixed end and the other end is said to move freely. Hence the result of force initiated at the free end has the utmost deflection which is represented by Red color and the least amount cantilever’s deflection is represented in blue color.

Figure 6 (a) and (b): Deflection Curve of Microcantilever by Applied Force

In the same way, the triangular beams are proposed and it is given in figure 7.

Figure 7: Triangular Beam – Deflection

Further, reduction in cantilever thickness will affect the structural integrity for fabrication. Hence, the cross sectional area is reduced by providing notches in the fixed end. This feature can be attained by reliable substance when employing the approach of finite element that should utilize an adequate constituent mesh and that must according the dimension and shape of the constituents. Free meshing is said to be tougher to organize as disparate to recorded meshes that is said to be very perfect.
6. Results and Discussion

The designing the shapes and orientations are based on the concept of Miller indices. The Miller Indices features are effectively used to construct the materials in cubic crystal families. The comparative study of the material change of the cantilevers is implemented and the variations in stress, strain, and total warp of cantilevers are generated. Table 1 shows the results of cantilevers with respect to young’s modulus, Poisson ratio and Density.

| Materials | Young’s modulus (G pa) | Poisson ratio | Density (kg/m$^2$) |
|-----------|------------------------|---------------|--------------------|
| SiO$_2$   | 70                     | .17           | 2200               |
| Si$_3$N$_4$ | 250                  | .28           | 3100               |
| Poly Si   | 160                    | .22           | 3100               |
| Al        | 69                     | .33           | 2710               |
| SU$_8$    | 3                      | .22           | 1200               |

Table 1: Changes with respect to the Material properties

The influence of parameters that is measurement lengthwise, breadth and material of the beam are studied. It is found that increasing the length or decreasing the deflection of cantilever beam gets increased, but it results in decrease in resonant frequency. The various shapes of the cantilever are attained randomly and corresponding deflection and reverberating frequency of different structure are calculated.

Requirements:
- Length = 200
- Width=40
- Thickness=1
- Force N=1μN (rectangle)

Based on the above requirements, the deflections are calculated with respect to the various material properties and the results are illustrated in table 2 and 3 and figure 8 and 9.

| Sl.No | Materials | Deflection(μm) |
|-------|-----------|----------------|
| 1.    | SiO$_2$   | 7.1142         |
| 2.    | Si$_3$N$_4$ | 1.728        |
| 3.    | Poly Si   | 2.925          |
| 4.    | Al        | 5.8260         |
| 5.    | SU$_8$    | 156            |

Table 2: Deflection for the Rectangular Beam

Figure 8: Deflection for the Rectangular Beam
Table 3: Deflection for the Triangular Beam

| Sl. No. | Materials | Deflection (µm) |
|---------|-----------|-----------------|
| 1       | SiO$_2$   | 14.2284         |
| 2       | Si$_3$N$_4$ | 2.898           |
| 3       | Poly Si   | 4.897           |
| 4       | Al        | 10.675          |
| 5       | SU$_8$    | 324             |

The comparative study is performed between the rectangular and triangular beam. The output tells that the deflection of triangular shape is two times greater than rectangular shape with the material properties SiO$_2$ and SU$_8$ and it is shown in table 4 and figure 10.

Table 4: Comparative Analysis

| Materials | Rectangular Beam | Triangular Beam |
|-----------|------------------|-----------------|
| SiO$_2$   | 7.1142           | 14.2284         |
| SU$_8$    | 156              | 324             |

The further increase in deflection is obtained by introducing gash in cross sectional region at predetermined end which will trim down the winding inflexibility of the microcantilever beam. The rectangular and triangular notch is introduced in cross sectional region at predetermined end. The young’s modulus is the most influencing factor which affects the deflection and resonant frequency is identified. It is seen that the width, Poisson ratio and density does not have that much effect on deflection and resonant frequency when compared to measurement lengthwise, young’s modulus and breadth of the beam of the microcantilever. The various materials such as silicon, polysilicon and silicon oxide are examined for the projected model and it is found that SiO$_2$ and SU$_8$ gives better...
output when evaluated with other type of materials.

7. Conclusion
The above projected method increases the rate of deflection at the micro cantilever’s free end while evaluating with the predetermined beams because of the huge surface region. The bioreceptors predetermined at the micro cantilever plane are more at the free end and attach about all analyte molecules at the free end of the beam. The biochemical reactivity is more due to large amount of associations at the micro cantilever’s free end that depicts the elevated level of deflection rate at the free end when evaluated to conservative rectangular beam of micro cantilever. This tells that disc shape cantilever is made up of SiO₂ and SU₈ affords the utmost deflection entailing highest sensitivity. This type of MEMS technology grasps the means to the future invention of extremely sensitive sensors and forms the scientific view point, the disputes stretch out in cantilever sensors optimization to advance their sensitivity.

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