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SHAPE OPTIMIZATION OF MICROCANTILEVER BEAM USED AS BIOSENSORS USING RESONANCE FREQUENCY SHIFT METHOD

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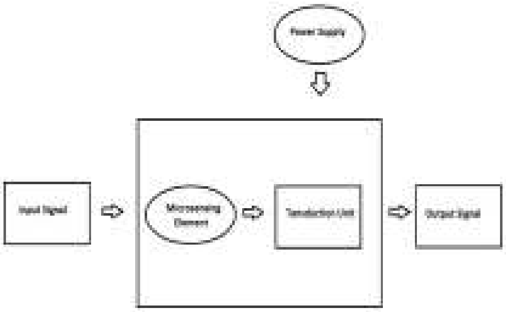
ABSTRACT

This paper presents a study on MEMS based microcantilever beam which are used in numerous medical application and are a key to cutting edge highly developed sensors.A microcantilever beam is utilized as a mass identifier where mass change can be resolved precisely in static mode by Absorption-Induceddeflection or in dynamic mode by resonance frequency shift method. Deflection and the resonant frequency of the beam are two crucial factors which determine sensitivity. The structural variation is conducted to obtain a higher frequency shift at higher sensing mode by using afinite element package (FEA),created to distinguish conceivable issues at early stage in configuration cycle before continuing to manufacture. ANSYS Multiphysicssimulation is done to find an optimized shape for the micro cantilever, taking sensitivity and frequency shift into considerations.

Keywords: MEMS, Microcantilever, FEM, ANSYS, Biosensors

MEMS abbreviates for micro-electrical-mechanical system. A MEMS is developed to accomplish a specific designing capacity or function by electromechanical or electrochemical means. Sensors fabricated by a MEMS process are mechanically like conventional sensors yet just manufactured on a micrometer scale. The core component in MEMS for the most part comprises of two foremost segments: a detecting or actuating component and a signal transduction unit. All MEMS devices depend on structure like cantilever beam, gear, pump and motors[4]. Micro scale sensors are worked to detect the presence and intensity of some physical, chemical or biological quantities such as temperature, pressure, force, sound, light, nuclear, radiation, magnetic flux and chemical radiation and chemical composition[6]. They have the benefit of being sensitive and precise with insignificant measure of required substance and quicker than the conventional instruments. Smaller framework tends to move more rapidly than large systems because of low inertia of the mass. The term Bio-MEMS has been utilized extensively lately, it includes biosensors, bio instruments and surgery devices[7]. Biomedical sensors and biosensors will have significant share in the micro scale sensor after its achievement in automotive industry. They require commonly a minute measure of sample and can perform examinations much quicker with virtually no dead volume.

Fig. 1: MEMS as a Micro Sensor



Biosensors work on the principle of the interaction of the analytes that need to be detected with biologically derived biomolecules, such as enzymes of certain forms, antibodies, and other forms of protein. These biomolecules when connected to the sensing components, can alter the output signals of the sensors when they communicate with the analyte. These detecting components are minute scale cantilever beam structure, longer as compared to width, and has a thickness much smaller than its length or width[3]. The biosensor is constructed by a microcantilever and an external piezoelectric or piezoresistive for creating vibration. Piezoelectric

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microcantilever-based sensors distinguish the change in the resonance frequency of a microcantilever keeping in mind as to find the mass of the retained biomolecule while piezoresistors at the base of the microcantilever are used to gauge the strain induced resistance change produced by a specific biomolecule. When the biomolecules are absorbed, the detecting material specifically adsorbs the foreign material, bringing about a little volumetric change in the sensing material[1]. This volumetric change is measured as a simple resistance change in the piezoresistivemicrocantilever, and the biomolecules are detected at the free end of the microcantilever, a small area of gold is covered to catch relating infections. At the point when the gadget is presented to aenvironment with target diseases as shown in fig.1, the antibodies covered on the free end of the microcantilever will capture them, realizing a resonance frequency shift. This move is perceived by the piezoresistive component. From the resonance shift, the mass of the infection can be obtained.

Because of high elastic modulus silicon cantilevers display to a great degree low deflections for a given surface stress change. Subsequently, to increase the deflection, polymer cantilevers can be utilized.The elastic modulus of polymer cantilever can be utilized, it is much lower than silicon, and the deflections induced are increased manifold. Fabrication of these devices are far behind the extent of conventional machining, the advances used to produce these minute components are called micro fabrication or micromachining. 3Dmicrostructures can be produced by evacuating parts of base material by a physical or etching process, where as thin film deposition systems are utilized to manufacture layers of silicon material on the base material.

The sensitivity of this device is characterized as (frequency/mass) with the unit $s^{-1}kg^{-1}$[1]. It is important to build the sensitivity of micro cantilever beam, because the magnitude of force involved is very negligible. Extremely low deflections necessitate utilization of advance instruments, for example, optical and laser deflection detection, utilized for precisely measuring the deflections. The sensitive cantilever design should efficiently convert the stimulus into a large cantilever deflection, deprived of much affecting the resonant frequency of the micro cantilever beam. To enhance the sensitivity of cantilevers various design and schemes have been reported.

EFFECTS OF VARIOUS PARAMETERS ONSENSITIVITYOFMICROCANTILEVER BEAM

To increase the sensitivity of a micro cantilever beam, the two key properties responsible are deflection and resonant frequency[5]. These two factors can be altered by altering three major parameters i.e., length, thickness and young's modulus. But by changing length and thickness, we have to compensate with either deflection or resonant frequency. With the increase in length, the deflection of the micro cantilever beam increases but resonant frequency decreases and with increase in thickness resonant frequency increases but deflection decreases.

A loss in deflection will reduce the sensitiveness of the beam. The beam should have a high resonant frequency to increase sound to noise ratio (S/N ratio), because a high S/N ratio will ensure a decrease in noise disturbances and precise measurements can be made [2]. This is due to the fact that as frequency increases amplitude decreases.
Bending stiffness can be increased at fixed end by reducing the thickness. But as the thickness is reduced deflection increases and frequency gets reduced. Bending stiffness is proportional to square root of frequency [3]. By reducing c/s area deflection can be increased at the cost of frequency.

METHOD OF OPERATION

Micro cantilever sensors can be operated in air, vacuum or in a liquid. Two commonly used methodologies for the operation of micro cantilever for detecting applications are the Adsorption induced deflection and the Resonant frequency shift. We have adopted dynamic mode approach to find the sensitivity of the device, which increases with shift in resonance frequency.

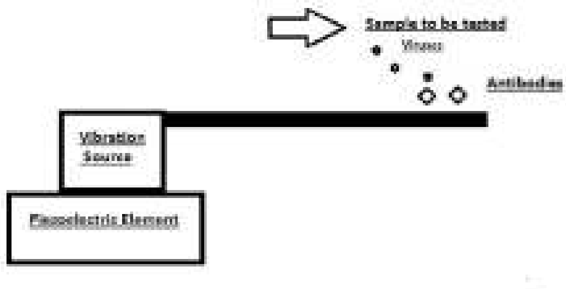


Fig.2: Adsorption of Analyte on beam Surface

Resonant Frequency Shift-Based Approach (Dynamic Mode)

Bending of cantilever is an immediate after effect of the adsorption of the particles on the surface of the cantilever. But, here it is fairly hard to acquire the dependable data about the measure of atoms since surface coverage is not known, however mass change can be obtained by the resonance frequency shift technique. The resonant frequency of oscillating cantilever in Hz is given by the formula [1]

$$W = (k/m)^{1/2} \qquad (1)$$

Where, K is spring constant and m is effective mass of cantilever. By adding mass, frequency shift towards the lower value and mass change can be computed. This strategy is alluring to detect a small mass. However, this dynamic mode operation poses issue such as high damping of cantilever oscillations due to high viscosity of surrounding media. Piezoelectric or Piezoresistivemicrocantilever identify the change in the resonance frequency of a microcantilever in order to determine the mass of absorbed molecule.

OPTIMIZING USING ANSYS

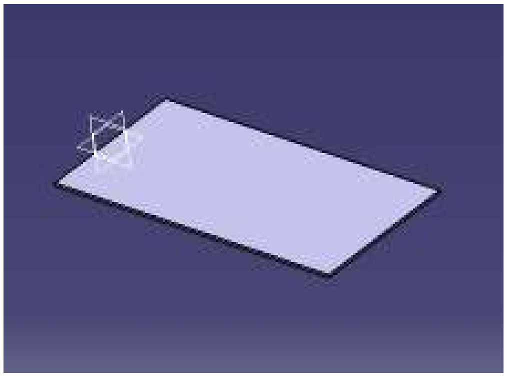
ANSYS Multiphysics software was utilized to perform the finite element analysis on various cantilever shapes to decide their sensitivity in dynamic mode. The geometry of the microcantilever is the most essential parameter of the device. Distinctive microcantilever geometries will have different resonant frequencies as well as unique frequency shifts, even affected by a similar infection. Keeping in mind the end goal to amplify frequency shift, the geometry of the microcantilever is optimized using ANSYS. Modal analysis is used to analyze the frequency shift of various geometries of microcantilevers keeping length, width, and thickness were kept the same, just differing shapes.

Table 1: Chosen material properties

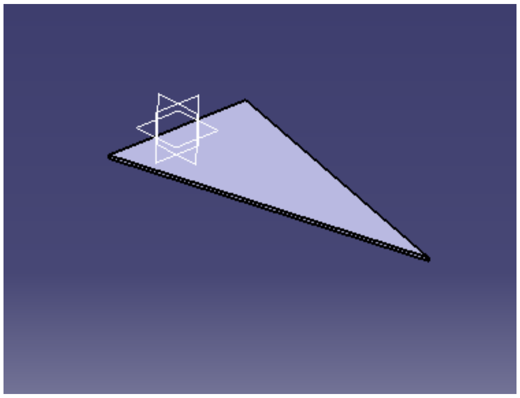
Material Properties	**Young's Modulus**	**Density**	**Poisson Ratio**
Value	100 Gpa	2850 kg/m3	0.24

Element SOLID187, a ten node tetrahedral structure element in ANSYS, was used to do the modal analysis. SOLID187 element was chosen due to support of meshing irregular geometries. The molecule's mass is recreated by utilizing a little mass with same density as the cantilever, with length 1µm, width 1µm and thickness 0.1µm, making the mass around 0.285pg. The particle is located 5µm from the free end of the cantilever. Beginning with a fundamental cantilever shape shown in Fig. 3A, which is rectangular in shape, length L=50µm, width W=25µm, the frequency shift is 29 Hz [1]. In fig 3B, a Triangular cantilever, is shown. The frequency shift of B is 506Hz [1], an order of magnitude larger than shape A.

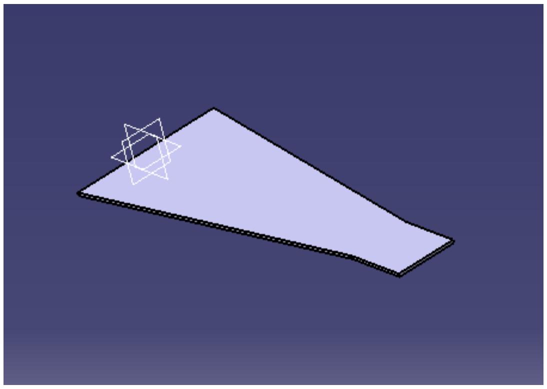
Fig. 3: Optimized Shapes



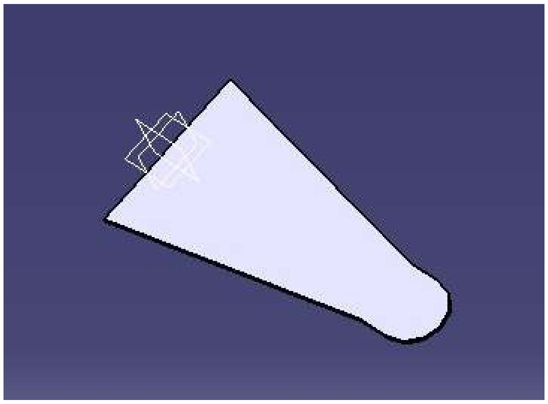
Shape A: Rectangular Cantilever



Shape B: Triangular Cantilever



Shape C: Trapezoidal End Cantilever



Shape D: Proposed Shape

Another advantage of shape B is that the stress intensity is almost uniform along the length of the cantilever. However, there is one burden of utilizing a triangular cantilever i.e. there is lack of region at the free end of cantilever to catch the bio particles of intrigue. To overcome this problem, trapezoid-like cantilevers are utilized as shown in fig. 3C. Using a similar geometry as triangular cantilever, the tip is a square with l_1=10um, w_1=10um as shown in fig. 3C.

RESULTS

Higher Resonance Mode Analysis

Since cantilevers have higher order resonance modes, it is desirable to study on the frequency shift at higher order resonance. If the frequency shifts are larger, then it is ideal to work the cantilever at higher order resonance modes. ANSYS simulation study was carried out on shape C, to research the trapezoid-like cantilever. With measurement L=50µm, W=25µm, thickness=0.5µm, l_1=10µm, w_1=10µm. We simulated the resonant frequencies of the cantilever with a particle and without. The results are given in table 2.

Table 2: Shift frequency in different modes (Shape C)

Order (Hz)	1	2	3	4	5
Resonance Frequency (Without particle)	265310	1316700	1980700	3489700	4655500
Resonance Frequency (With particle)	265570	1319800	1985500	3513300	4673400
Shift Frequency	260	3100	4800	3600	17900

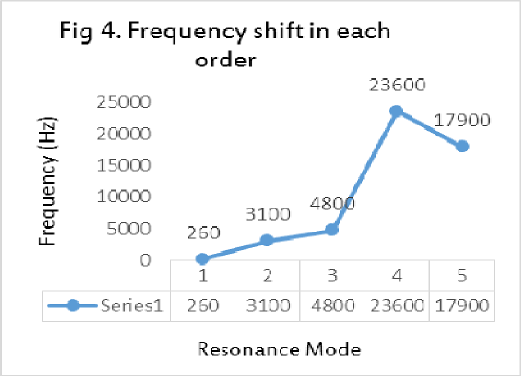


Fig 4. Frequency shift in each order

Further optimizing shape C, with some elementary modifications, without much altering the dimensions, Shape D is arbitrarily suggested as shown in fig 3D. ANSYS simulation on shape D was carried out to investigate the proposed shape. With dimension L=50µm, W=25µm, thickness=0.5µm; *l*=10µm, *r*=5µm. The resonant frequencies of the cantilever with and without a particle were stimulated. The results are given in table 3.An abrupt increase in resonance frequency shift is noticed in mode 4.

Table 3: Shift frequency in different modes (Proposed Shape D)

Order (Hz)	1	2	3	4	5
Resonance Frequency (Without particle)	276120	1371000	2023400	3619900	4873000
Resonance Frequency (With particle)	276490	1370600	2022900	3682400	4874700
Shift Frequency	370	400	500	62500	1700

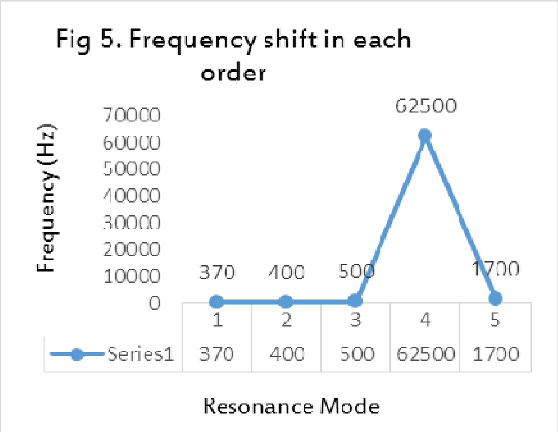


Fig 5. Frequency shift in each order

The change in resonant frequency and or surface stress due to change in mass is called the sensitivity of the sensor. The mass of the applied particle is 0.285pg, while frequency shift is 23600 Hz for Shape C and 62500 for Shape D. Thus, the sensitivity is found to be

S = Resonant frequency / Change in mass

Shape C,

S= 23600 Hz/ 0.285pg = 8.280e19$s^{-1}kg^{-1}$

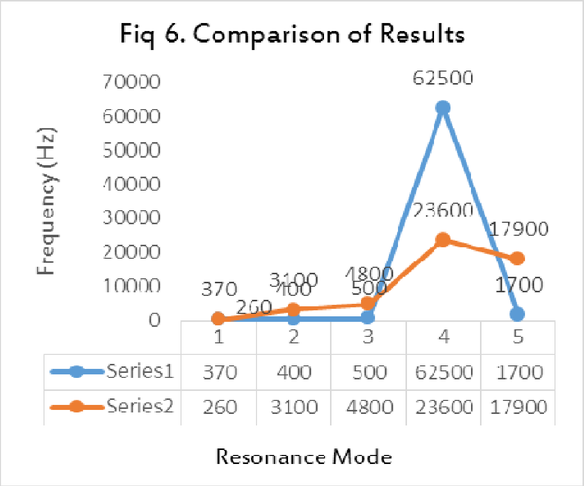
Shape D,

S= 62500 Hz/ 0.285pg = 21.930e19$s^{-1}kg^{-1}$

A significant increase can be noticed in the sensitivity of the micro cantilever beam and a comparison can be made between Shape C and D.

CONCLUSION

Hence, such an optimization is done to keep the deflection approximately constant by obtaining higher frequency shifts at higher resonance mode. The different shapes are obtained arbitrarily and resonant frequency shift of shapes C and D are calculated. The study proposed and analyzed a new cantilever design which shows high resonance frequency shift at higher mode than C, B and A. Fig. 6 depicts a comparison between our two preferred shapes and it clearly shows the variation in shift at 4th resonance mode. A 62% increment is observed in the case of sensitivity of shape D as compared to shape C. The sensitivity of shape D is 21.930e19 $s^{-1}kg^{-1}$and frequency shift for 4th mode is 62500 Hz.


Fiq 6. Comparison of Results

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