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Optimization of Microelectromechanical System based Microcantilever Material and Structure for Biosensor Application

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ABSTRACT

Microcantilever has been proven as an outstanding platform for extremely sensitive chemical and biological sensors. Microelectromechanical system (MEMS) cantilever-based sensor is becoming popular in recent years due to its high sensitivity, high selectivity, easy to fabricate and can be easily integrated with on-chip electronic circuitry. In this work, optimization of material and structure for MEMS-based microcantilever used for biosensor application was done using dynamic mode sensing concept. The analysis was carried out for different types of materials with different structures. The simulation was done using COMSOL multiphysics finite element analysis software and was analyzed with solid mechanics principle. The microcantilever materials used for analysis are silicon, polyvinylidene fluoride, silicon nitride, and SU8.

Key words: *Biosensor, COMSOL, Dynamic study, Microelectromechanical system and microcantilever.*

1. INTRODUCTION

Microelectromechanical systems (MEMS) is a technique of combining electrical and mechanical components together on a chip, to produce a system of miniature dimension. MEMS-based sensors have offered remarkable possibilities in detection automotive electronics, bio-medical equipment, clinical diagnosis, drug screening, and pathogen detection. Micromachined cantilevers are gaining more and more interest as biochemical sensors, where the way in which the binding of chemical species changes the mechanical properties of the cantilever is utilized. These biological molecules are first immobilized onto the microcantilever which is later determined through static or dynamic techniques. In static detection, molecular binding onto the surface of a cantilever beam induces stress gradient across the thickness of the cantilever. This creates a bending moment on the ultrathin cantilever, where the optical methods can then be used to determine the deflection of the light beam [1,2]. In the dynamic analysis, targeted species that bind onto the cantilever surface will produce a shift in resonance frequency of resonating structures [3,4].

2. EXPERIMENTAL

The dynamic study on MEMS microcantilever for different types of materials such as silicon, polyvinylidene fluoride (PVDF), silicon nitride and SU8 and for different structures was carried. The different material properties are given in Table 1. The structure of the microcantilever is the most important parameter of the device. Different microcantilever structures (Figure 1 a-g) will have different resonant frequencies as well as unique frequency shifts, even under the influence of the same mass [5]. The particle's mass is simulated using a small mass with length 1 µm, width 1 µm, and thickness 0.1 µm, making the mass about 0.285 pg.

Microcantilevers when used as biosensors, the bending of the cantilever is a direct result of the adsorption of the molecules onto the surface of the cantilever. However, it is difficult to obtain the

Table 1: Material properties.

Material	Density, kg/m^3	Young's modulus, Pa	Poisson's ratio
Silicon	2329	$170e^9$	0.28
Silicon Nitride	1780	$250e^9$	0.23
PVDF	3100	2900	0.34
SU8	1190	$0.4e^9$	0.22

PVDF=Polyvinylidene fluoride

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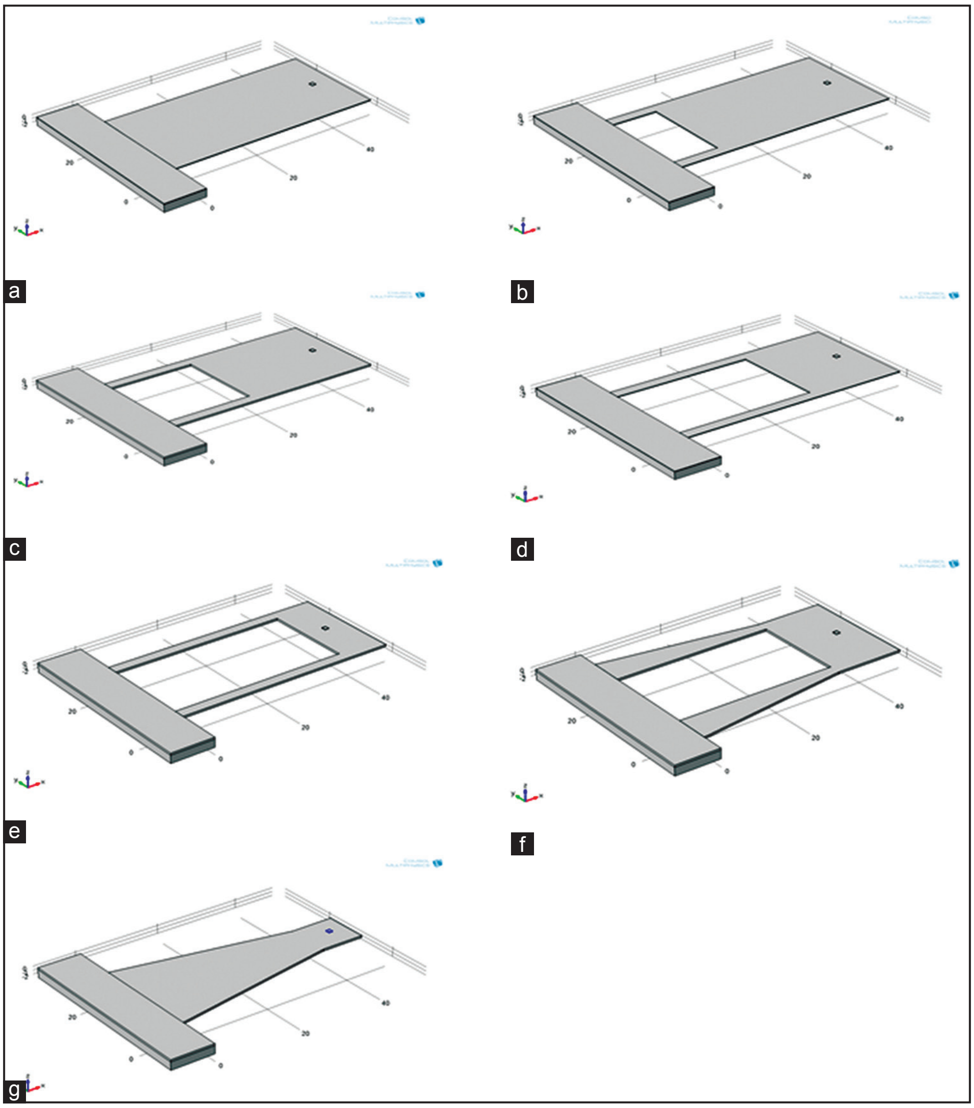

Figure 1: (a-g) Different structures of microcantilever.

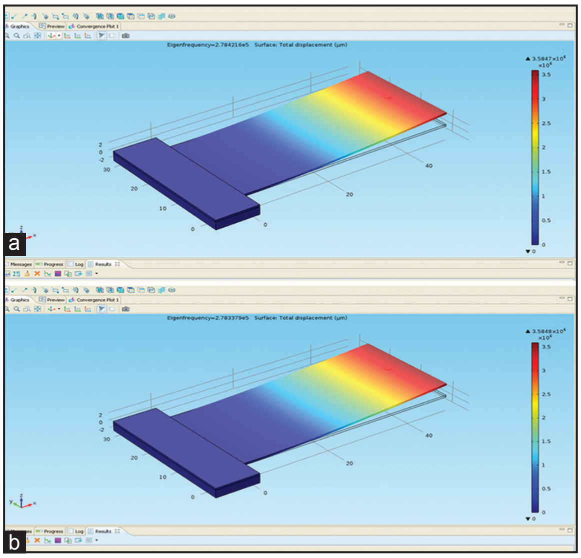

Figure 2: Simulated results at first mode of eigenfrequency for rectangular microcantilever for silicon material, (a) without mass, (b) with mass.

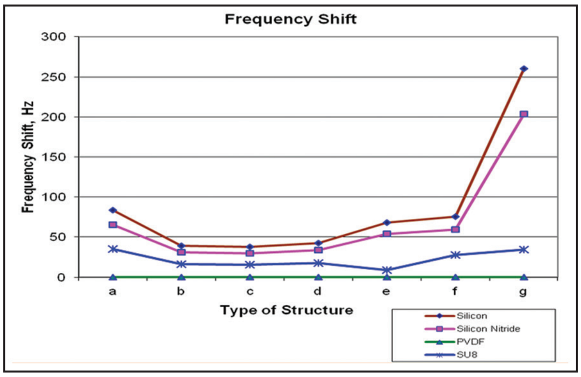

Figure 3: Frequency shift for different types of materials.

reliable information about the amount of molecules because surface coverage is not known, however, mass change can be determined accurately by the resonant frequency shift method [6].

Resonance frequency of microcantilever is:

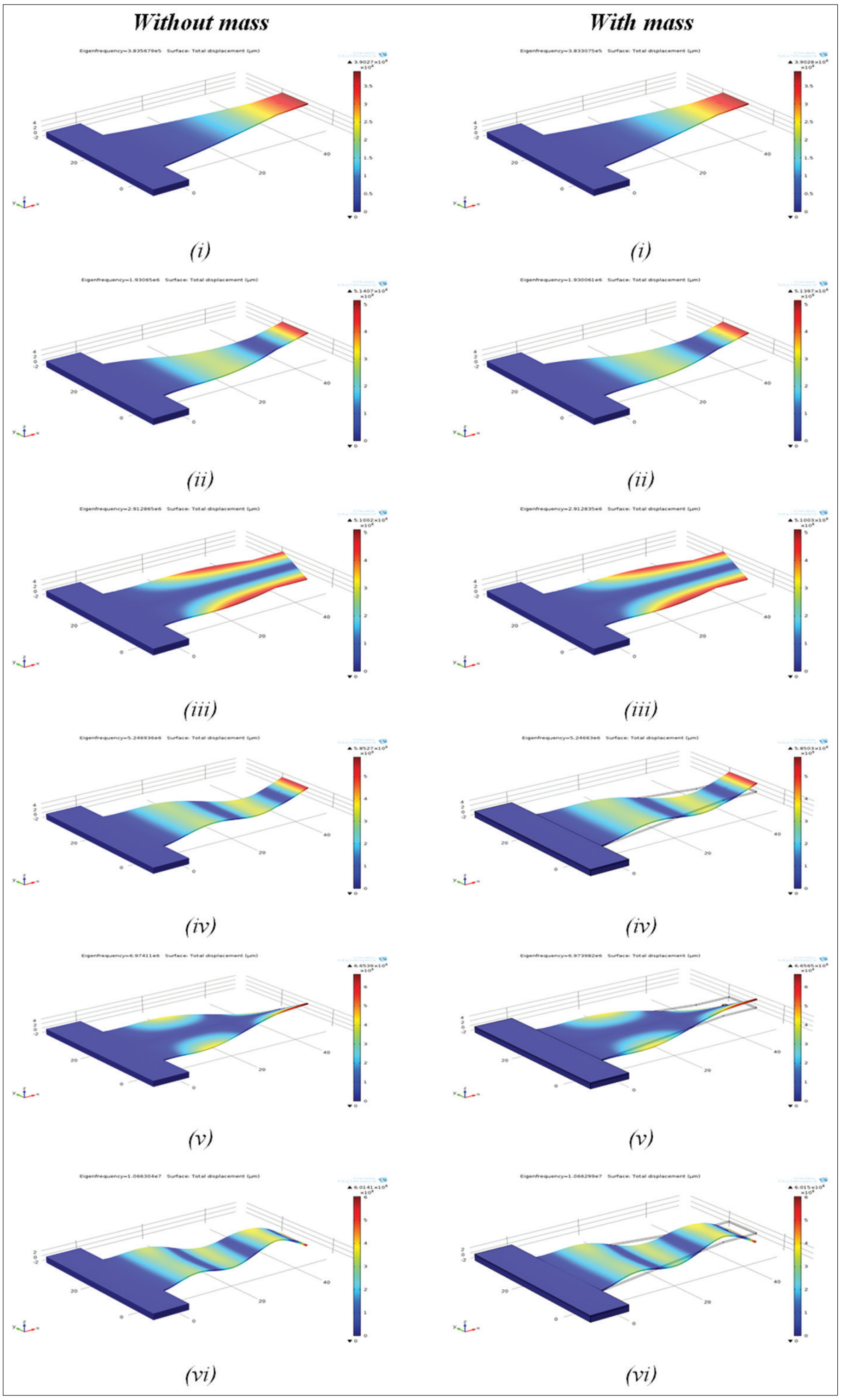

Figure 4: (i-vi) Simulated results at six modes of eigenfrequencies for trapezoid microcantilever without and with mass.

$\omega_R = (k/m)^{½}$

$f_0 = 1/\Pi\ (k/m)^{½}$

$f_1 = 1/\Pi\ (k/m + \Delta m)^{½}$

$\Delta f = f_0 - f_1 = 1/\Pi\ ((k/m)^{½} - (k/m + \Delta m)^{½})$

Where,
f_0 = Resonance frequency without mass, f_1 = Resonance frequency with mass, k = Spring constant, m = Mass, Δm = Change in mass, Δf = Resonance frequency shift.

First, the influence of effective mass of the cantilever near the free end on the performance is studied. Figure 2a and b represents simulated results at first mode of eigenfrequency for rectangular microcantilever without and with mass for silicon material.

Figure 3 gives pictorial representation of frequency shift in the first mode of eigenfrequency for different materials like silicon, PVDF, silicon nitride and SU8 for different cantilever structures.

From the analysis carried out, it is very clear that frequency shift is more for silicon material for basic Structure A and trapezoid Structure G. Hence, further analysis is carried for silicon material with basic Structure A and trapezoid Structure G to study the frequency shift in all six modes of eigenfrequency. Since cantilevers have higher order resonance modes, it is worth doing a study on the frequency shift at higher order resonance [5].

The simulation was performed to investigate silicon material basic cantilever (Structure A) and silicon trapezoid-like cantilever (Structure G). The resonance frequencies were simulated for the cantilever without mass and with a mass (Figure 4).

3. RESULTS AND DISCUSSION

Figures 5 and 6 shows frequency shift in each eigenmode for basic Structure A and trapezoid Structure G, respectively, for silicon material. The disadvantage of using higher order modes is that higher modes have smaller vibration amplitudes [5], making sensing much harder.

From the Figures 5 and 6, it is very clear that frequency shift is more for trapezoid structure. In Figure 6, we can see that Mode 2 has twice the frequency shift as Mode 1, and Mode 4 has almost same frequency shift as Mode 1 resulting in our choice of Mode 2 in trapezoid structure.

From the analysis, it was found that sensitivity of the microcantilever for the mass of the applied particle 0.285 pg, for the frequency shift of 589 Hz (using cantilever shape "g" and operating at the second mode of eigenfrequency) sensitivity is found to be as follows:

$$S = 589\ \text{Hz}/0.285\ \text{pg} = 2.06 \times 10^{18}\ \text{s}^{-1}\text{kg}^{-1}$$

4. CONCLUSION

Dynamic study of MEMS-based microcantilever was studied for different structure and material. COMSOL multiphysics finite element software was used for analysis. The study was carried out for basic microcantilever structure (Figure 1a). From the results obtained (Figure 2), it was found that silicon material shows more frequency shift. Also from the analysis, it was found that the frequency shift is more for silicon material (Figure 3) for basic structure and trapezoid structure.

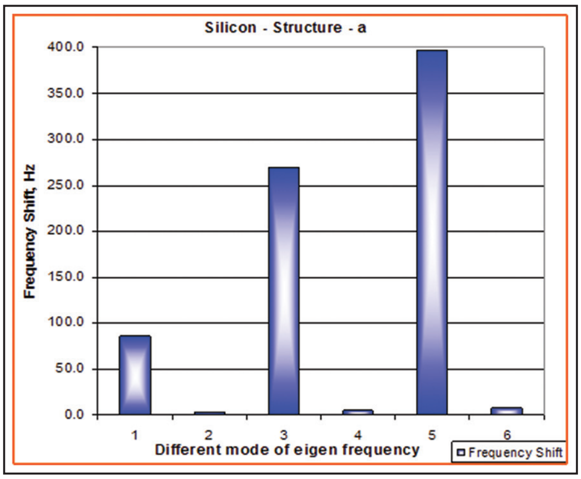

Figure 5: Frequency shift in each eigenfrequency mode (Structure A).

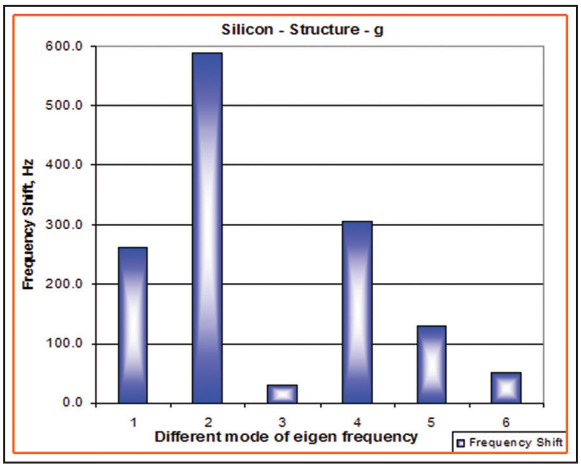

Figure 6: Frequency shift in each eigenfrequency mode (Structure G).

Thus from the analysis carried out, the final material optimized is silicon material and structure of the microcantilever is trapezoid structure in second eigenfrequency mode.

5. ACKNOWLEDGMENT

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***Bibliographical Sketch**

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