Modal Analysis of Microcantilever using Vibration Speaker

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Abstract

The dynamic response of microcantilever which is simple Micro Electro Mechanical Systems (MEMS) structure, to sine wave excitation is studied using the vibration speaker set up in the atmospheric damping. Microcantilever is fabricated using micro wire cut EDM process for high precision. Mostly Silicon material is used for microsystems based structure. Here stainless steel was used and machined for fabricating the microcantilevers. In this study, the mode shapes and corresponding natural frequencies have been formulated in experimental analysis. These Eigen frequencies and mode shape values have been compared with the results of numerical simulation values using COMSOL Multiphysics software. In addition to that the microcantilever with various profiles can be analyzed to improve the sensitivity of the microcantilever for various applications.

Keywords: *MEMS; Microcantilever; Modal analysis; COMSOL multiphysics; Vibration Speaker*.

1. Introduction

Microcantilever beam is presently focused for developing the sensors in the field of biomedical, chemical, security systems, explosive detections, micromechanical sensors. Modal analysis is mainly important for finding the dynamic characteristics of structures. The sound pressure is applied to the microcantilever to obtain the dynamic characteristics of micro structures [1]. Generation of mechanical vibration can be produced by using vibration speaker where the structures are mounted on the vibration speaker. To this vibration speaker, we can apply sine wave signal at different frequencies in the range to measure the dynamic characteristics of the structures [2]. Dynamic mode is a challenging task to vibrate a microcantilever array in atmospheric damping and liquid environment [3]. The microcantilever beam commonly has four modes of dynamic condition which are transverse mode, lateral mode, torsional and longitudinal mode [4-5].

Microcantilever under the dynamic mode uses to find the mass change affected the resonant frequency to measure the amount of molecular species adsorbed on the surface of the microcantilever. Pico gram level also can be possible using the microcantilever. The fundamental resonant frequency is also critical when the microcantilevers are operated in the dynamic mode. [5-10]

In this paper, Microcantilever with rectangular cross sectioned geometry has been simulated by using COMSOL Multiphysics to deduce the natural frequencies and mode shapes in the atmospheric condition. Also, the resonance frequencies and mode shapes are measured experimentally using vibration speaker excitation with the assistance of digital microscope.

2. The principle and models

The natural frequencies of microcantilever can be determined by using the modal theory. Based on the Stoney's equation for thin films, natural frequency of the microcantilever is as follows.

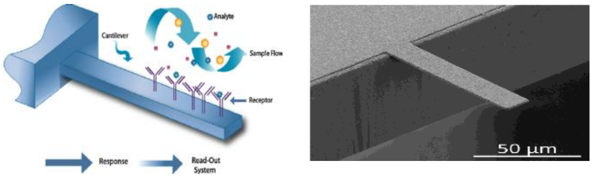

Figure 1. Biosensor and fabricated structure [10]

The relationship between the surface stress and deflection based on the Stoney's equation [4],

$$\Delta\sigma = \left(\frac{Et^2}{3(1-v)l^2}\right)\Delta z \qquad (1)$$

Where t, l are the thickness and length of the microcantilever, and E and v are the elastic modulus and Poisson's ratio of the material.

The basic natural frequencies for microcantilever beam with the rectangular section of mass density (ρ) equation is given by [4]

$$f_n = \frac{1}{2\pi}\sqrt{\frac{E}{\rho}} \cdot \frac{t}{l^2} \qquad (2)$$

2. Design and fabrication

Basically Silicon based materials are used to fabricate the microcantilever structures. Extensively, Single crystal silicon, Polycrystalline silicon, silicon dioxide, silicon carbide and silicon nitride materials are very common in Integrated Circuits (IC) fabrication also in micro beams. In biomedical applications, conductive polymeric material has been used for its strength and sensitivity which is higher than as high as silicon based material properties. Here Stainless steel is used for Microcantilever fabrication. Elastic modulus is the important property for microcantilever beams which is fully based on the spring constant of the micro structured beam. Microcantilever beam is fabricated by using micro wire cut electrical discharge machining.

Based on this equation (2), the fundamental natural frequency values are, with the dimensions length (l) = 35000 µm, width (w) = 1000 µm and thickness (t) = 30 µm, Elastic modulus (E) = 200 GPa and Poisson's ratio (ν) = 0.33.

f_1 = 39.157 Hz
f_2 = 245.4 Hz
f_3 = 687.4 Hz
f_4 = 1346.5 Hz

These are fundamental natural frequencies have been calculated by using equation (2). The first four mode shapes only is taken into the account for the experimental section.

3. Experimental set up

Dynamic response of the microcantilever beam is analyzed to find out its Eigen frequencies, mode shapes and displacement through vibration speaker based sine wave excitation. Power is supplied to the vibration speaker.

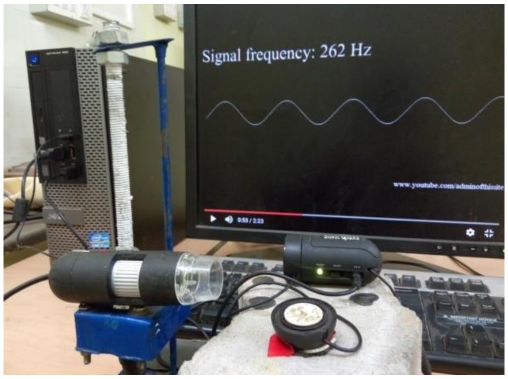

Figure 2. Experimental setup

For obtaining the concept of sine wave excitation, the sine wave audio spectrum is given to the vibration speaker where the amplitude is not enough to produce the mode shape of the microcantilever upto 1 Hz to 20000Hz to the micro systems structure.

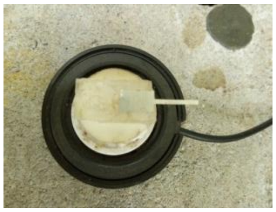

Figure 3. Microcantilever fixed on vibration speaker

The shape of the modes has been captured by using the digital microscope which can use to magnify the structure upto 500X. All mode shapes have been taken as an image while forming the mode shapes under specified frequency range.

4. Numerical simulation using COMSOL Multiphysics

Three dimensional microcantilever was modeled using COMSOL Multiphysics. Stainless steel has been selected as a material for the model. The material parameters are as follows; density ρ = 7850 kg/m^3, Elastic modulus E= 200 x 10^{9}GPa and ν = 0.33. The frequency response of microcantilever is simulated using Eigenfrequency analysis in COMSOL Multiphysics.

Solid mechanics module has been used for the mechanical simulation. The microcantilever structure is fixed at one end, free at other end. Lateral mode of vibration and respective mode shapes have been analyzed with the COMSOL results.

5. Results and Discussion

The natural frequencies (f_n) with respective mode shapes of the lateral vibration of microcantilever are obtained through Eigen frequency analysis using direct solver. Figure shows mode shapes and natural frequencies of simulated and experimental values for the microcantilever.

Table 1. Theoretical, experimental and simulated frequencies with relevant mode shapes of microcantilever beam

Natural Frequency (f_n)	Analytical (Hz)	Experimental (Hz)	COMSOL (Hz)
First mode shape	39.157	41	39.306
Second mode shape	245.4	247	246.462
Third mode shape	687.133	695	690.729

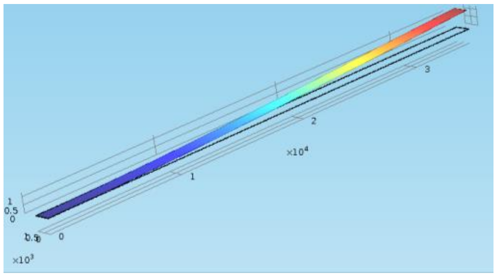

Figure 4. First mode shape by simulation at 39.306Hz

Figure 5. First mode shape by experimental at 41Hz

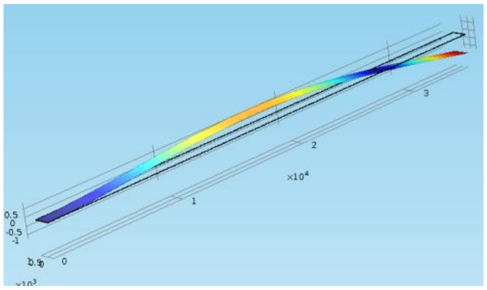

Figure 6. Second mode shape by simulation at 246.46Hz

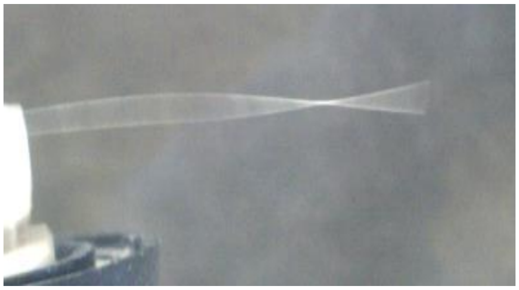

Figure 7. Second mode shape by experimental at 247 Hz

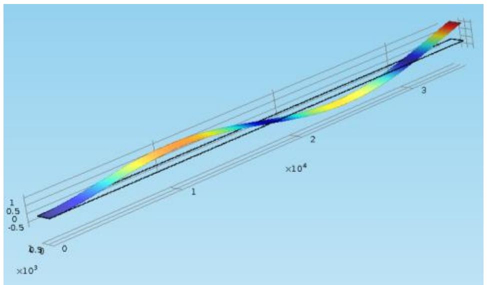

Figure 8. Third mode shape by simulation at 690.72Hz

Figure 9. Third mode shape by experimental at 695 Hz

In the figure 4 – figure 9 all the mode shapes and natural frequency values have been are shown. Mode shapes have been formed well compared with the theoretical and COMSOL simulation results.

Table 1 shows that the values of analytical, experimental and simulation of natural frequencies at all three modes and good agreement is obtained. First mode shape was formed at the frequency of 40Hz in the experimental section.

Also COMSOL and analytical mode shapes were good with the all other three mode shapes of experimental method of finding mode shapes. Theoretical and simulated values of modal analysis resonance frequencies are very similar to their respective values 39.157Hz, 245.4Hz, 687.133Hz and 39.306Hz, 246.462Hz, 690.729Hz. In the experimental, the frequency values have been taken with corresponding mode shapes formed.

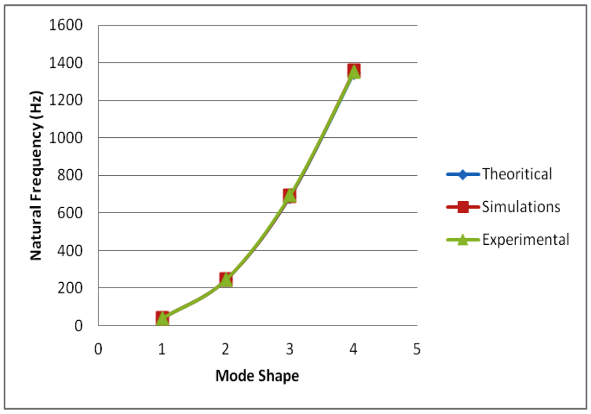

Figure 10. Theoretical, experimental and simulated frequencies and mode shapes

6. Conclusions

In this paper, dynamic response of the microcantilever made up of stainless steel has been reported by the sine wave excitation using vibration speaker. The vibration speaker frequency range is 20Hz to 20000Hz which is applied as audio spectrum. The mode shape and natural frequency values have been measured in the experimental set up by using the digital microscope. Also these values have been validated with the Numerical simulation values simulated by COMSOL Multiphysics software and theoretical values. Finally, Dynamic characteristics of the microcantilever have been concluded that modal characteristics of a microcantilever, natural frequencies and mode shapes can be obtained by using vibration speaker excitation. Also Vibration characteristics are shown good agreement with the theoretical and COMSOL simulated values. In future, the cantilever having various profiles can be used for enhancement of sensitivity of microcantilever.

7. References

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