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Geometrical consideration and modelling of MEMS based accelerometer

Diksha Sharma[1], Sumreti Gupta[2], Rasmeet Kour[3], Sameru Sharma[4]
[1,2,3,4]Department of Electronics and Communication Engineering, GCET, Jammu
[1]ds929819@gmail.com , [2]retigupta8@gmail.com, [3]rasmeet.kour@live.com, [4]sameru33@gmail.com

Abstract**—** MEMS (Microelectromechanical) is an advanced technology that finds its application in several fields i.e. mechanical, electrical, biomedical and many more. This paper focuses on the application of MEMS devices exclusively in the mechanical field. The field of application categorizes itself depending upon the type of sensor being employed in the application and the way it is allowed to function. Pressure sensors have maximum demand in mechanics. After pressure sensors, the second largest demand is of accelerometer sensor. In this paper we will discuss on geometrical consideration requisite for MEMS-based accelerometer. Further, we will support our theory by simulating analytical equations using MATLAB.

Keywords**—** MEMS, microcantilever, sensors, accelerometer, MATLAB.

I. Introduction

MEMS technology is finding its importance in various fields of application. The field includes health science, engineering structures, electrical, physics, electronics and many more. The attractive features of MEMS devices that have fascinated several researchers towards it includes its high sensitivity, high flexibility, high reliability, its capacity to integrate on a single chip due to its miniature size, parallelism and many more [1]. Talking about MEMS components, it mainly comprises of four major components: microactuator, microsensors, microstructures, and microelectronics. Figure 1 shows the various components that together integrate to form a MEMS device.

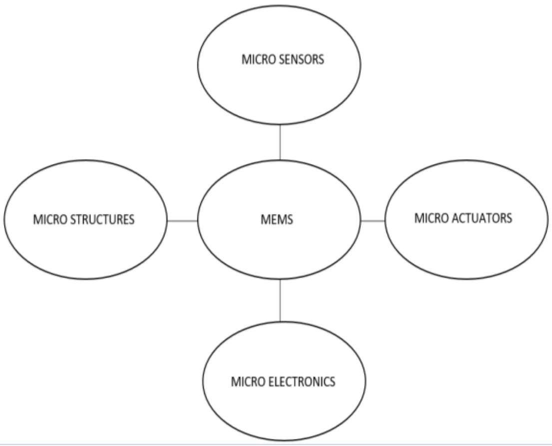

Fig.1. Figure depicting essential components of MEMS devices

Microstructure comprises of a solid structural body that is used as a mean for sensing and detecting purposes. Microsensors are designed for the purpose of detecting any change (thermal, electrical, electromechanical) that incurs due to any disturbances around the system's environment. Any physical changes incurred are then sent to the microelectronics block where it processes these physical variables. Any modification done by the microelectronics are then sent to the microactuator block which acts accordingly in response to the changes of the system's environment.

II. MICROCANTILEVER

Microcantilever is basically a subcomponent of microstructure block that is one of the major components of MEMS devices. Microcantilever is a beam-like structure of submillimeter size whose one end is kept fixed and other end is allowed to vibrate freely. Due to its miniature size, it finds its application mainly in the biomedical field. Applications of microcantilever are discussed in later sections. If we talk about its composition, the microcantilever is devised from silicon material. Table 1 shows the characteristic properties of silicon. Silicon is considered as the most appropriate material for designing microcantilever and thus utilizing it for fabricating microsensors. The features that allowed it to substitute other metals and materials include its high thermal conductivity, its ability to withstand high temperature, high sensitivity to strain, stress and many other environmental aspects. One of the most important reasons of choosing silicon over other materials is that it offers high young modulus. In order to design a device for detection and sensing purposes, it is desired that the material should not undergo deformation under load. Thus silicon proves to be quite stiff material for being used for such application. Figure 2 shows the three-dimensional view of microcantilever.

Table1 Silicon material properties

Density	2329kg/m^3
Young's modulus (ρ)	170e9 Pascal
Poisson's ratio	0.28

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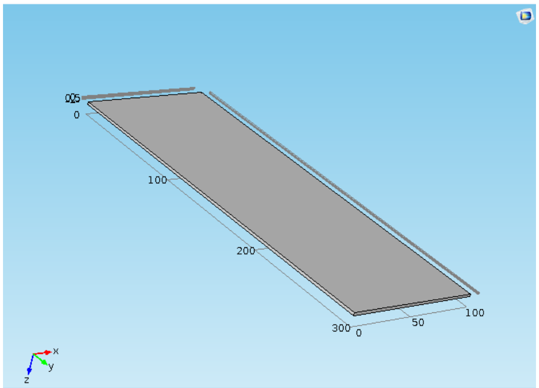

Fig.2. 3-D view of microcantilever having dimension (300*100*2)µm

III. ACCELEROMETER

As discussed earlier that depending upon the nature of application, we accordingly modify our microsensors. Here in this paper, we are designing microcantilever for being used as accelerometer. Accelerometer is designed by suspending a silicon mass with a spring. The resulting structure will obey newton's classical law [3]. Accelerometer works on the principle that whenver cantilever is exposed to some loading, the spring will experience some stress and strain. The measurement of stress and strain can be used for measuring acceleration. The driving force will come from the acceleration that will act on the silicon mass causing silicon mass to get displaced by certain distance x. Measurement of stress and strain involves piezoelectric and piezoresistive effects into consideration [4]. Figure 3 shows the sensing principle of accelerometer.

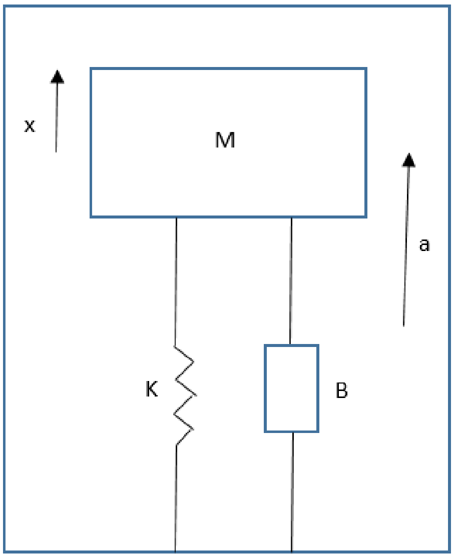

Fig.3. Figure depicting sensing principle of accelerometer

Figure 4 shows the structural model of accelerometer. The accelerometer is provided with a proof mass made up of silicon. The piezoresistor are installed for measuring any change in the resistivity. Under uniform loading, the variations in resistivity are more significant as compared to dimensional changes. This unique feature of semiconductor material allowed researchers to have these materials for stress sensitivity applications.

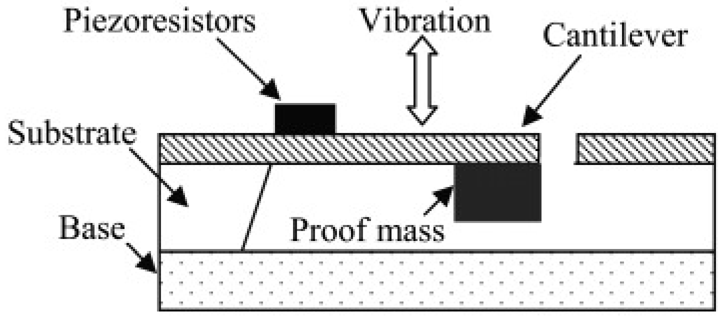

Fig. 4. Structural model of accelerometer

IV. MODELLING OF ACCELEROMETER

The fundamental working operation of accelerometer along any one particular axis under the influence of some externally applied force can be expressed using analytic equation of mass-spring-damper system which is given as:

$$M\frac{d^2x}{dt^2} + B\frac{dx}{dt} + Kx = F \quad (1)$$

A. Silicon Mass

The mass suspended at the free end of the cantilever depends on the geometry of the cantilever. The expression follows as:

$$M=\frac{\rho t(s_1^3-s_2^3)}{3(s_1-s_2)} \quad (2)$$

t= thickness of silicon mass

B. Damping coefficient

Damping coefficient is the consequence of the interactions that occur between silicon mass and the air that exists between the silicon mass and the bottom encapsulation (space between the casing and proof mass). The expression for this is given as:

$$B=\frac{0.42 v a_2^4}{d^3} \quad (3)$$

v is the viscosity of air.

C. Spring constant

The spring constant, sometimes also called stiffness constant is helpful in determining the natural frequency of the cantilever. In case of microcantilever which is designed for sensing and detection purposes, it is always desired to have a cantilever that undergoes maximum vibrations. The magnitude of vibrations depends on the geometry of the cantilever beam, silicon material's properties i.e young modulus, poisson's ratio, density.

$$K=\frac{3EI}{l^3} \quad (4)$$

D. Natural frequency

The natural frequency is the measure of free vibrations of cantilever beam as discussed earlier. Its magnitude mainly depends on the silicon mass M and spring constant K.

$$\omega=\sqrt{\frac{K}{M}} \quad (5)$$

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E. Resonant frequency

Resonant frequency is basically the vibrating frequency of the cantilever beam that comes into picture whenever some driving force tends to allow the cantilever beam to oscillate. When the oscillating frequency matches the natural frequency, the resultant vibrations would be of higher vibrations, the magnitude of which can be calculated using the following expression:

$$f=\frac{0.162*w*t^3\sqrt{E}}{\sqrt{y}*l^2} \quad (6)$$

where y= young's modulus.

F. Deflection of beam

In order to find out that by what amount the cantilever has been displaced, the analytical expression in terms of cantilever beam parameters. The expression is as under:

$$\delta=\frac{Fl^3}{3EI} \quad (7)$$

where I= moment of inertia

The expression for moment of inertia depends on the crossectional area. Since we have designed a cantilever beam which is rectangularin shape, the expression is given as:

$$I=\frac{bh^3}{12} \quad (8)$$

V. RESULT AND ANALYSIS

Whenever a cantilever beam is subjected to uniform loading, it experiences different stresses along the beam length. The deflection is maximum at the free end and almost negligible deflection at fixed end. Designing of an accelerometer should be such that it will give maximum deflections. Here we have simulated the analytical expression on MATLAB. Figure 5 shows the behavior of cantilever when subjected to the force of 1μN. From the simulation results it is presented that for using cantilever as an accelerometer with beam length around 250-300μm, width around 40-100μm and thickness of 2μm is selected.

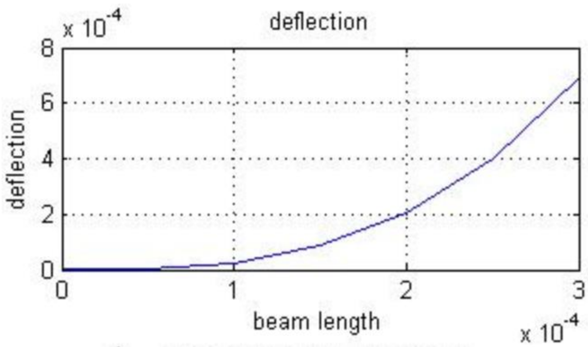

Fig.5. Deflection verses beamlength plot

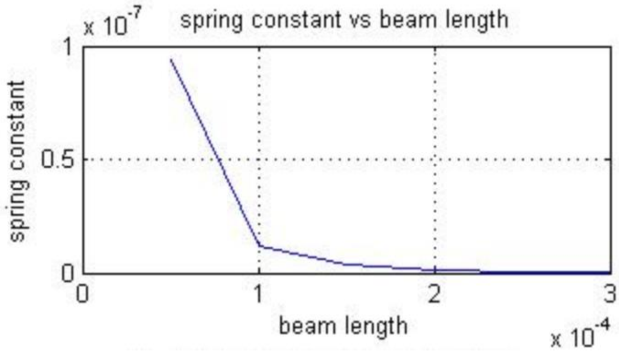

Fig.6. Spring constant verses beam length plot

Figure 6 represents the plot between spring constant and beam length. It is observed that with increase in beam length the spring constant tends to decrease. This implies that shorter the beam length, more will be the stiffness. Consequently, the cantilever beam will provide negligible vibration under loading.

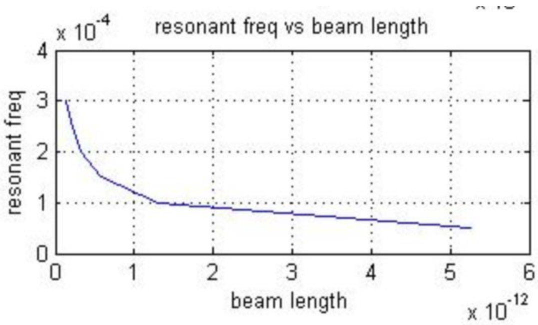

Fig.7. Resonant frequency verses beam length plot

As discussed earlier that the cantilever with higher resonant frequency is desired. Cantilever with higher resonant frequency reflects that the cantilever will undergo maximum vibration when subjected to some external force. Figure 7 represents the response of cantilever in terms of resonant frequency at different beam lengths.

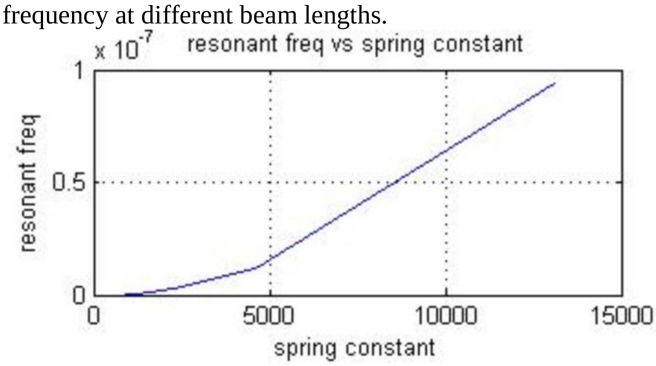

Fig.8. Resonant frequency verses spring constant

As discussed earlier the analytical expression for resonant frequency in terms of spring constant, it is seen that both the variables are directly related to each other. Figure 8 shows the resonant frequency verses spring constant plot where we proved experimentally, that with increase in the magnitude of

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spring constant, the resonant frequency of the cantilever varies linearly.

VI. APPLICATIONS

A. MEMS sensor for continuous monitoring of glucose

The MEMS sensor is designed using cantilever beam which is coated with a layer of copolymer[5]. When the cantilever beam is allowed to vibrate in a sensing environment, the glucose-copolymer interaction causes the cantilever beam to vibrate in the medium. The vibrations which are the function of resonant frequency are then measured used to determine the concentration of glucose.

B. MEMS Pathogen sensor

Introduction of MEMS pathogen sensor proved helpful both for the food and beverage industry and for assessing drinking water quality. MEMS sensors proved itself an efficient tool for sensing bacterial disease-causing microorganisms[6]. For instance, in order to sense the presence of Bacillus anthracis that causes Anthrax disease, Francisella tularensis which is responsible for causing tularensis disease, the specific sensors for sensing respective spores have been developed.

C. MEMS for measuring rheological properties of blood

MEMS devices calibrated with an array of microcantilevers are being used for measuring rheological properties of blood[7]. Most of the problems such as hypertension, heart attacks, thickness in blood are due to increased or decreased levels of viscosity and density of blood. In order to measure the viscosity and density of blood, the cantilever is allowed to vibrate in viscous medium. The cantilever is allowed to vibrate in dynamic mode where its performance is calculated in terms of resonant frequency and quality factor. The determination of resonant frequency allows to measure the viscosity and density using analytical expressions.

VII. CONCLUSION

We have discussed various parameters that are essential for designing an accelerometer. The designing of accelerometer begins with the right choice of dimensions for cantilever beam. With the help of MATLAB we concluded that with subsequent change in the beam length, beam width and beam thickness, the parameters that are used for determining the performance of the accelerometer varies accordingly.

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