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FREQUENCY MODE ANALYSIS OF SILICON BASED MEMS STRUCTURES

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Abstract - *MEMS has been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by combining silicon-based microelectronics with micromachining technology. Micro-Electro-Mechanical Systems (MEMS) are miniaturized mechanical devices that are driven by electricity. They can serve many and simultaneous purposes, generally falling into the categories of sensors and actuators. Examples of MEMS include the sensor that triggers the air bag in your car (an accelerometer) and the massive market of motion sensors in iPhones, Nintendo Wiis etc. (also accelerometers). Micro Electro Mechanical Systems are more sensitive to environment and the environmental changes. Performance of MEMS structures can be studies easily by using the Physics formulas like Stress, Strain etc. under low frequency conditions but it's performance under high applied frequency conditions are no related physics and it has to be studied to it's performance under applied high frequency values. The study of MEMS structures can be mainly useful for the fabrication of high-resolution sensors.*

Key Words: Stress, Strain, frequency, High-resolution sensor, actuator, Mechanical device.

1. INTRODUCTION

MEMS structures placed in environment undergo physical changes in their structure. This change in can be useful to create electrical changes in applied current. So, the mechanical energy can be converted to the electrical energy as a transducer. The generated electrical energy is useful for creating potential difference. Micromachined transducers have largest impact in overall MEMS market. The main method of sensing mechanical measurands have been around for many years and therefore applicable to many sensors. Some physical effects favor the fabrication of the high-resolution sensors. Micro Electro Mechanical Systems are the atomic level layers made of silicon and resembles the activity of Macro electronic devices made for the same functionality. Energy consumption is reduced because of the reduction in size and the number of atoms that are consuming energy to perform the same action by the Macro Electronic Systems.

1.1 Mechanical Resonance

Mechanical resonance is the tendency of a mechanical system to respond at greater amplitude when the frequency of its oscillations matches the system's natural frequency of vibration (its resonance frequency or resonant frequency) than it does at other frequencies. It may cause violent swaying motions. Mechanical resonators work by transferring energy repeatedly from kinetic to potential form and back again. In the double clamped beam, all the energy is stored as mechanical energy when the beam is instantaneously motionless at the top of its swing. As the beam descends and picks up speed, its potential energy is gradually converted to kinetic energy, which is proportional to the beam's mass and to the square of its speed. When the beam is at the center of its travel, it has maximum kinetic energy and minimum potential energy.

2. DOUBLE CLAMPED BEAM

A beam with it's both ends fixed and the distance between the both ends is denoted as the Length l and the beam also has the variable width w and thickness t. The length of the beam experience physical changes with applied forces. If the electrical energy is applied along the length, the length of a beam vibrate with different modes of vibration and these modes of vibration should be noted to plot the graph and the characteristics was obtained.

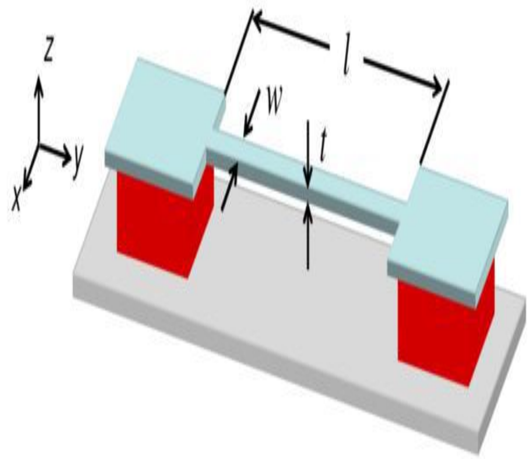

Fig-1: Double clamped beam

2.1 MEMS Double Clamped Beam

MEMS structures placed in a cavity which is in contact with the environment. They are developed through atomic deposition and connecting the atoms through bonding. These structures can't be seen through the eye. The microscopic view of MEMS beam is shown below. The beam is attached at the both ends in this context to study it's characteristics as a double clamped beam. The free beam length between the both the fixed ends allowed to swing along it's length in the different bending modes. Since they are very small in size, they can't be seen through eye directly. They can be seen only under the microscope or electron microscope to take measurements. microscopic view of double clamped beam is:

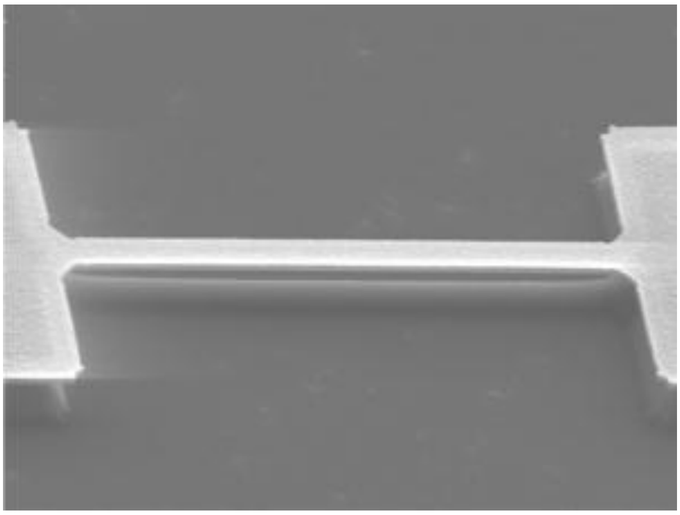

Fig -2: Microscopic view of MEMS Double Clamped Beam

The applied frequency to the beam with the presence of electricity in a beam can cause oscillations or swinging of a beam. The bending of a beam can cause in different modes of bending. The first order bending involves the bend of a beam along the length with one antinode at both the ends of a beam are fixed. Similarly, different bends can appear along the length, width and surface of a beam with the increase of a frequency.

3. BENDING MODES

The beam placed in a cavity has different bending modes based on the different range of frequencies applied. First three modes of bending will be studied to make a conclusion in comparison with the Physics equations and to draw the relation between the order of bending and the applied frequencies. Change in applied frequency to a beam causes the change in displacement of a beam in it's middle portion. This change in displacement helps to draw a relation between frequency and bending amplitude. When the applied frequency and mechanical resonance of beam matches, beam vibrate with resonance frequency.

3.1 First Bending Mode

The first order bending studied with different positions of a beam inside the air cavity. The maximum displacement can occur at the resonant frequency of a beam. Change in position of a beam can cause shift in the resonant frequency. The beam is said to resonate when the applied frequency matches with the natural frequency of a beam. The maximum bending point can be observed along the length of a beam at particular point in first order bending mode. In first order bending mode, the beam starts bending at the middle. The displacement is more across the Centre. Moving towards the edges of a beam, displacement of a beam reduces. The displacement of a beam is towards the ground terminal. All the sides of a air cavity remains unchanged or zero charged. The medium is provided with the air inside it.

The resonant frequency values of a beam is noted for studying the beam characteristics. The dimension of a beam changes, the resonant frequencies of a beam noted for corresponding dimensional changes. With the increase of frequency, the changes in bending of a beam is noted and results are obtained. First order bending is shown as:

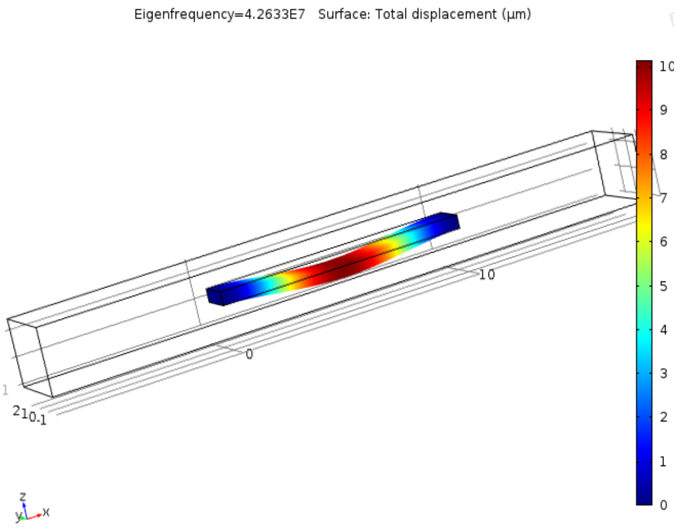

Fig -3: First Bending Mode

3.2 Second Bending Mode

In second order bending mode, the beam starts bending at two positions. The displacement is along the length. Moving towards the edges of a beam, displacement of a beam has uniform variations. The displacement of a beam is towards both bottom and down. All the sides of a air cavity remains not charged or zero charged. The beam resembles the sine wave in a second order bending mode. The red zones shows the area with more displacement. The dark blue zones shows the areas of minimal displacement or zero displacement. The second order bending mode, values were noted and tabulated to plot the graph. The graph shows the relation between the beam thickness and resonant frequency of beam.

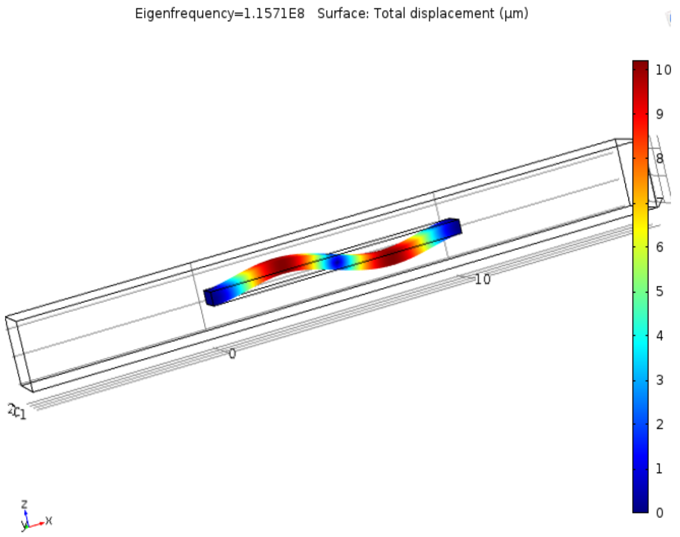

Fig -4: Second Bending Mode

3.3 Third bending Mode

In Third order bending, beam bends at three positions resemble the Sine wave with three Anti Nodes. Beam bends at three positions. Two displacements towards the up and one displacement towards the ground. Dark red color represents maximum bending of a beam and dark blue color represents the No-displacement. Third order bending beam can be seen as:

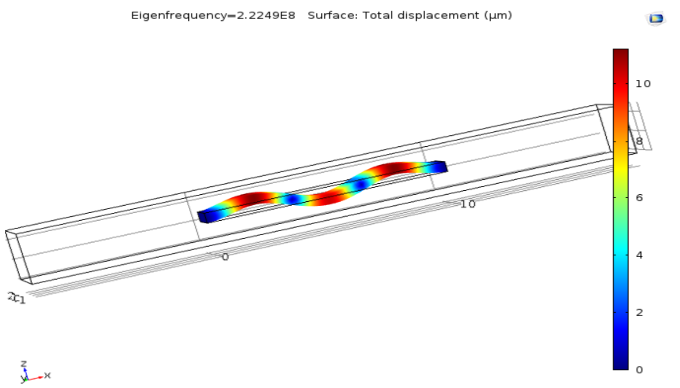

Fig -5: Third Bending Mode

Maximum displacement occurs at 222.49 Mega Hertz and the maximum displacement is more than 10um. Beam inside the cavity is moved for different positions and frequency values were noted. These frequency values helps to plot a graph and draw the relation between the applied frequncy and the amplitude of vibration. From the plotted graph between these two values helps to draw the proportionality between the Eigen frequency and total diaplacemet of a beam placed in a cavity or Air Medium.

3.4 Frequency-Beam Thickness Relation

The graph drawn between beam thickness and resonant frequency of a beam as the resonant frequency changes according to the thickness of a beam. The resonant frequency varies from 20 MHz to 80 MHz as the beam thickness varies from the 0.5 um to 1 um. The graph drawn resonant frequency versus beam thickness is:

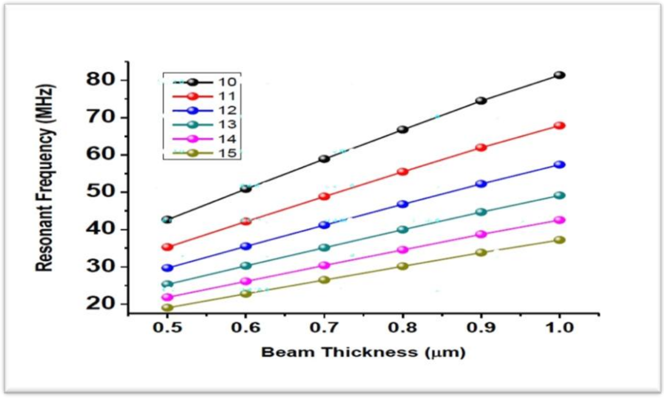

Chart -1: Resonant frequency vs. Beam thickness graph

Different colors in a graph gives the length of a different beams varying from 10um to 15um. Relation between the thickness and resonant frequency for different lengths of a beam are shown in a graph. With the increase of beam thickness, resonant frequency of a beam also increases. With the increase of resonant frequency, length of a beam reduces. So, the obtained relation between the resonant frequency and beam thickness from the analysis is:

$$\text{frequency} \propto \text{beam thickness}$$

With the increase in beam thickness, frequency at which beam resonates also increases. Above graph also says that the change in length also have a effect on the resonant frequency. Increase in length of a beam reduces resonant frequency of a beam.

3.5 Beam under Applied Mass

Mass is attached to length of a beam to resemble the practical experiment in which the mass is placed along the length of a beam. When beam hit the mass placed along it's length during the swinging. Hitting of a beam with weight causes the shift in resonant frequency of a beam. Different magnitude of masses were added to the length of a beam in each run time.

Beam is studied under three mass conditions. They are: i. Beam with no applied mass, ii. Beam with applied mass of 10pN, iii. Beam with applied mass of 20pN. Change in frequency is noted between the 7 MHz to 8 MHz. Change in amplitude is noted up to 0.02 Atomic Units with the step size of 0.005 a.u. Change in frequency is noted between the 7 to 8 MHz with step size of 0.2 MHz where the notable shift in frequency can be observed. The graph was drawn between the change in amplitude with applied mass and change in frequency of a beam with applied mass.

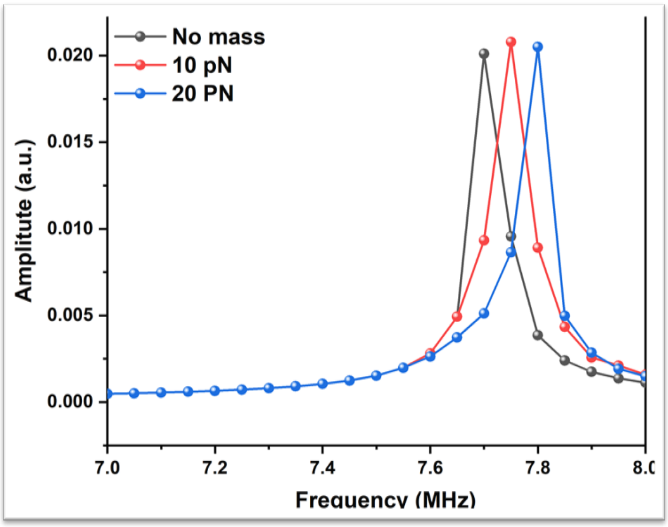

Chart -2: Amplitude vs. Frequency Graph

When the mass is not applied the resonant frequency of a beam is 7.7 MHz. Applied mass of 10pN causes frequency shift to 7.75 MHz and applied mass of 20pN causes frequency shift to 7.8 MHz. With the increase of frequency, frequency shift also increases.

Shift in frequency α Applied mass

CONCLUSION

This paper studied the behavior of a beam with different frequencies applied. The beam undergo change in length when the external frequency is applied. When the mass is applied to the beam, the beam suffer stress. Under these applied frequency conditions, frequency is applied to the beam. Increase in mass changes the shift in frequency of a beam. This shift in frequency can help to high resolution mass detection sensing.

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