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Modeling and Characterization of Tunable Piezoelectric Actuator

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Abstract— The hub of this paper to study the effect resonance frequency of piezoelectric MEMS. The modeling and characterization of piezoelectric resonator using COMSOL Multiphysics. An investigative relation was developed based on the shift in resonance frequency caused by the addition of a different material on the PZT. The theoretical analysis is done with a user-friendly SPICE Circuit Editor interface constructed for easy introduction of design dimensions , material parameter values and force signal stimuli. A piezoelectic device can actutate a cantniliver beam simply by applying an AC voltage over the device.The cantilever beam itself has resonant modes that causes peaks in vibrations when the frequency of applied voltage passes the resonance frequency of each mode .If another piezoelectric device is attached to the cantilever, it is possible to tune the resonance by connecting that device to a passive external circuit.In this model, different materials are used for designing o tunable actuator. We have observed the graph between displacement and frequency of various materials. And the best material found from analysis is Lead Zirconate Titanate. This model investigates how the external circuit influence the resonance peaks of cantilever beam and also improve the quality.

Keyword— MEMS, Piezoelectric effect, Lead Zirconate Titanate(PZT-5A),Resonance,COMSOL,Tunable,deformation

I. INTRODUCTION

MEMS is Micro-Electro-Mechanical System Technology is a capable technology for low-loss, high linearity applications[1]-[4]. Piezoelectrically transduced micro resonator have become attractive research topic in ultra-mass detector, bio-sensor, RF filter and high freq micro oscillator. Compared with elctrostatically actuated and sensed capacitive silicon micro resonator, piezoelectrically transduced microresonator exhibits better power handling capacity than capacitive type since low driving-voltage of several hundreds of millivolts is enough for resonator actuation ,which facilitates the integration of microresonators with CMOS signal processing circuits. The main advantage of MEMS resonator lies in possible integration onto silicon based IC platforms.

High-mode vibration can improve mass detect sensitivity of a resonant cantilever under atmospheric pressure by suppressing the air damping effect [5].High mode vibration can be successfully achieved by the proposed structure, and greater Q-factor can be obtained as expected for the pursuit of better mass detection sensitivity. However, the measured Q-factors are still lower than the theoretical calculations. High mode vibration results in large vibration amplitude at the position where cantilever and actuator connects. It leads to large vibration amplitude in PZT actuator, which in turn induces additional energy dissipation as analyzed in reference[6]. Besides, large vibration amplitude at the actuation hinge also trends to decrease Q_{sup}, because energy may dissipate easily through substrate.

In robotics, resonance has been recognized as an important phenomenon that can be used to increase power transmission to a load, reduce the effort of actuators, and achieve a large amplitude motion for cyclic tasks, such as running (e.g., [8], [9]), flapping (e.g., [10], [11]), or fin-based swimming (e.g., [12]). Variable stiffness and resonance can be intimately connected because the ability to vary actuator stiffness provides the ability to tune a robotic system's resonant frequencies.

Quality Factor (Q) is one of the most important characteristics of MEMS resonators, especially if they are used to build sensors based on frequency monitoring. The corresponding frequency resolution, and thus the system's sensitivity, is then indeed directly linked to Q. The higher the value of Q, the higher the micro-system's performance. These MEMS resonators are indeed found in many applications were a high sensitivity is needed: inertial sensors, mass sensors. To get high Q-values, these micro-systems generally rely on the use of vacuum packaging, air damping being an important limitation to the quality factor [13].
Another possibility to get high Q-values could be to externally increase the quality factor. An interesting technique to artificially improve the quality factor is called parametric amplification and consists in modulating the structure's stiffness at a harmonic frequency of the device's resonant frequency. This modulation results in an increase of the oscillation amplitude at the device's resonant frequency and thus an increase of Q.

II. THEORITICAL CONSIDERATION

The actuator consists of a thin bar of silicon with an active piezoelectric device below the bar, and a second passive piezoelectric device on top as shown in Figure1. These devices are located at one end of the actuator. The piezoelectric material is lead zirconate titanate (PZT), and each of the devices has two electrical connections to an external circuit, realized with the Floating potential boundary condition of the Piezo Plane Strain application mode.

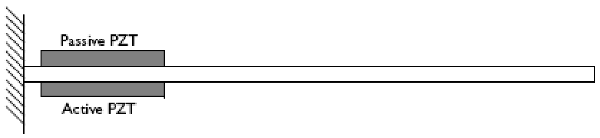

Figure1: Geometry of a Tunable Piezoelectric Actuator Based Resonator

III. MODLING OF PIEZOELECTRIC ACTUATOR

Because the fundamental resonance mode is the mode of deformation with maximum displacement and the relevant mode shapes were modeled. The results related to the various displacement with various piezoelectric material even the material of cantilever beam is fixed, which is single crystal Silicon as shown below. Thus the deformation show by displacement by varying the frequency.

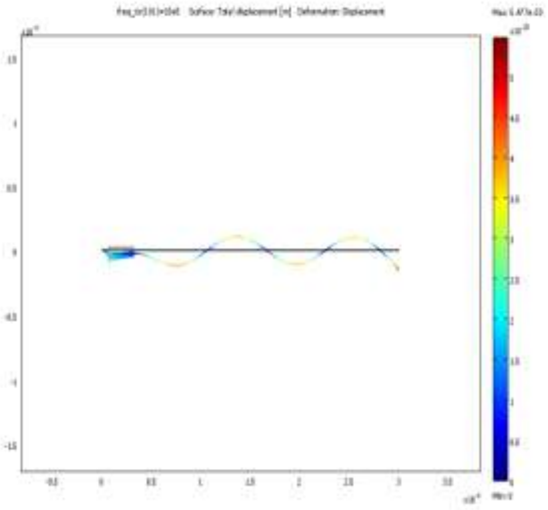

Figure2 : Simulation of displacement of Quartz

Figure 2 shows that displacement of piezoelectric actuator. In this, we use cantilever beam of silicon and piezoelectric device is of quartz material. It has the displacement of 4.842e-20 which is very low.

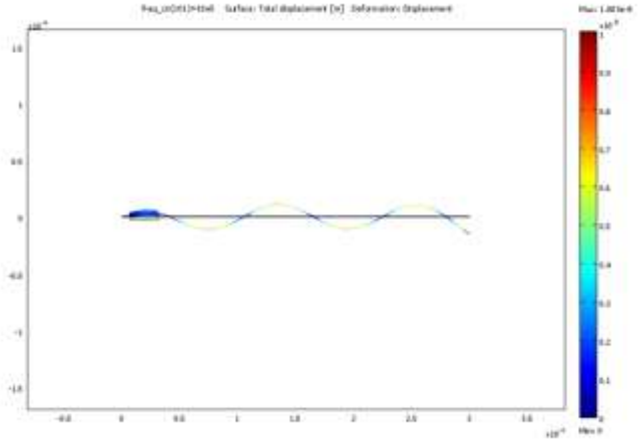

Figure3: Simulation of displacement of Zinc Oxide

Figure 3 shows that displacement of piezoelectric actuator. In this, we use cantilever beam of silicon and piezoelectric device is of ZnO material. It has the displacement of 1.003e-8 which is low.

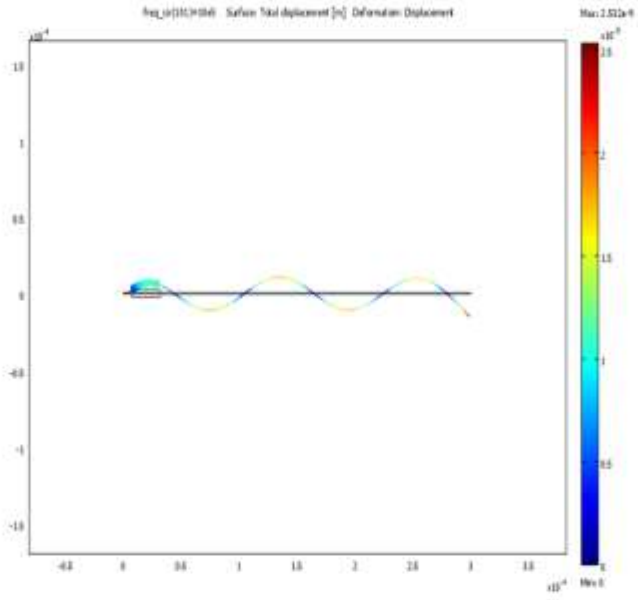

Figure4: Simulation of displacement of Aluminium Nitride

Figure 4 shows that displacement of piezoelectric actuator. In this, we use cantilever beam of silicon and piezoelectric device is of AlNi material. It has the displacement of 2.532e-9 which is low.

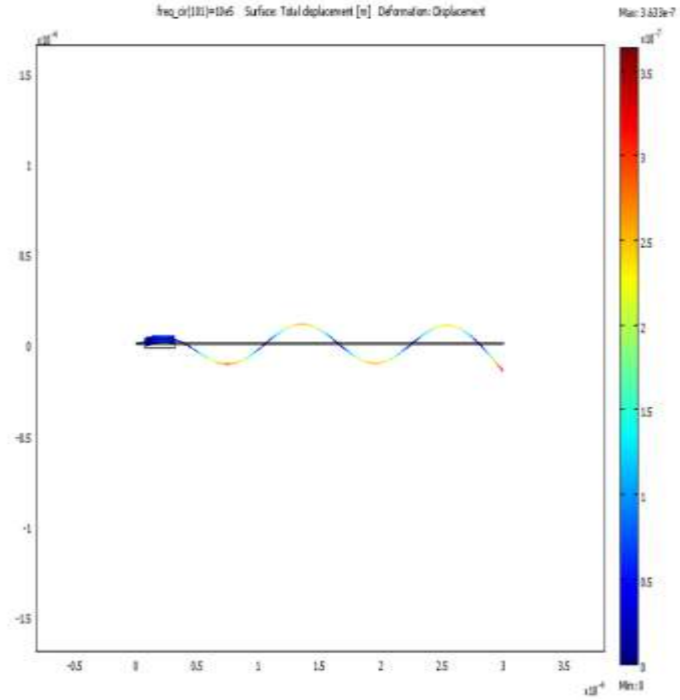

Figure5: Simulation of displacement of Lead Zirconate Titanate(PZT-5A)

Figure 5 shows that displacement of piezoelectric actuator. In this, we use cantilever beam of silicon and piezoelectric device is of PZT-5A material. It has the displacement of 3.547e-7 which is best in all materials.

All the Above Figure(1-5) shows the simulated output of piezoelectric actuator showing the variation of displacement along its boundary according to colour profile given in the plot and reported to the maximum amplitude of vibration analyzed by the lead zirconate titanate**.** Animation can also help us to show the maximum deformation of the different materials

IV. EXPERIMENTAL RESULTS

The analysis of the actuator is performed through a frequency sweep that goes from 200 kHz up to 1 MHz while logging the displacement amplitude in the *y*-direction. the vibration shows several resonance peaks in this range. The external inductance for this sweep was 50 mH.

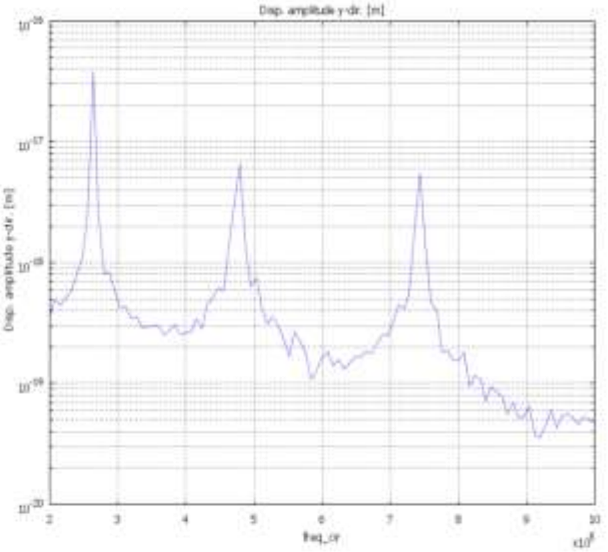

Figure6: Plot of Displacement and Frequency of Quartz material

Figure 6 shows frequency response when we used quartz material in piezoelectric device of piezoelectric actuator.

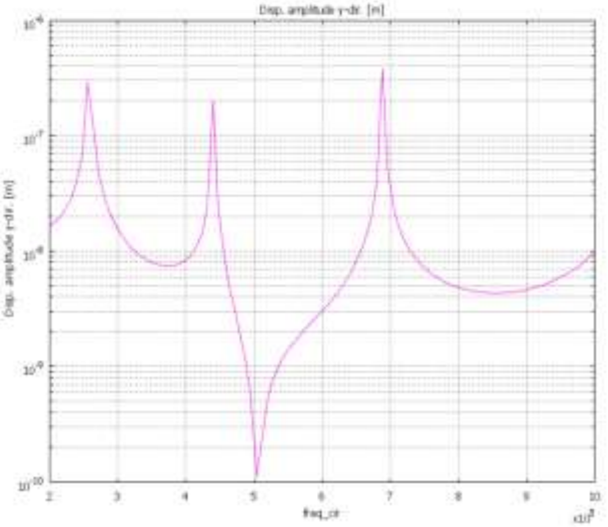

Figure7: Plot of Displacement and Frequency of Zinc Oxide material

Figure 7 shows frequency response when we used ZnO material in piezoelectric device of piezoelectric actuator.

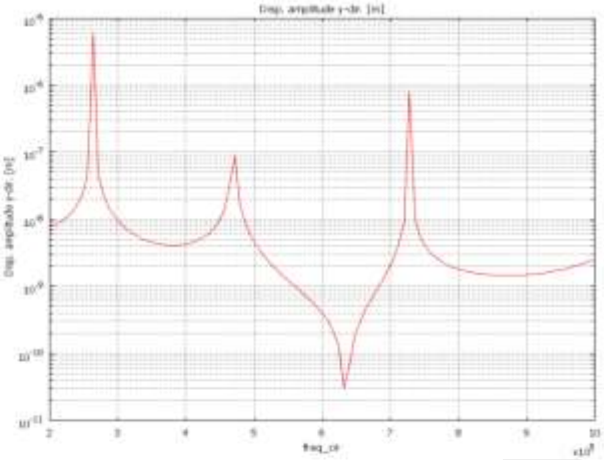

Figure8: Plot of Displacement and Frequency of Aluminum Nitride material

Figure 8 shows frequency response when we used AlNi material in piezoelectric device of piezoelectric actuator.

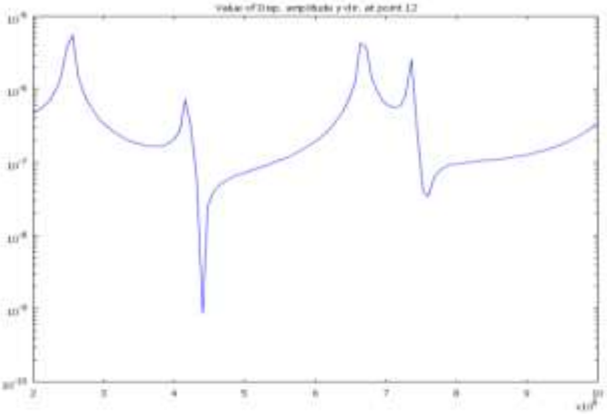

Figure9: Plot of Displacement and Frequency of Lead Zirconate Titanate(PZT-5A) material

Figure 9 shows frequency response when we used PZT-5A material in piezoelectric device of piezoelectric actuator.

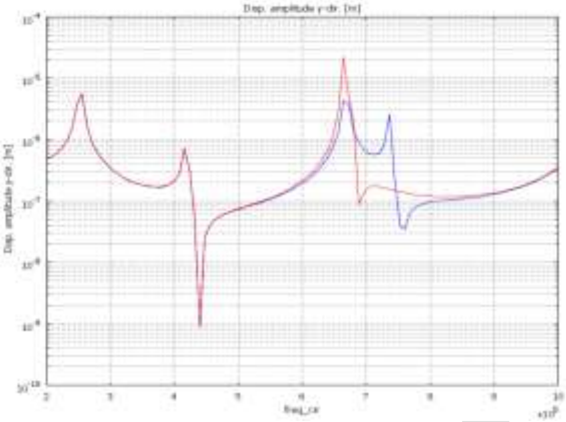

Figure10: A comparison between the amplitude versus frequency for two indunctance value in external circuit,50mH(blue curve) and 60mH(red curve).

Figure(6-9) shows frequency response of Quartz material, zinc oxide, aluminum nitride, lead zirconate titanate respectively. As the frequency increases then the displacement of cantilever beam also increases and the maximum amplitude displacement shows the resonance of the piezoelectric resonator. Figure (10) shows that tuning is possible and due to changing inductance 60mH , so only the 660kHz frequency is affected by inductance.

The spike is caused by a resonance between the capacitance of the piezoelectric device and the inductance of the external circuit. The resonant frequency for a LC-circuit is

$$f = \frac{1}{\sqrt{LC}}$$

Because the values for L and f are known, it is possible to roughly estimate the capacitance of the piezoelectric device.

$$C = \frac{1}{Lf^2} = \frac{1}{60\ \mathrm{mH} \cdot (660\ \mathrm{kHz})^2} = 40\ \mathrm{pF}$$

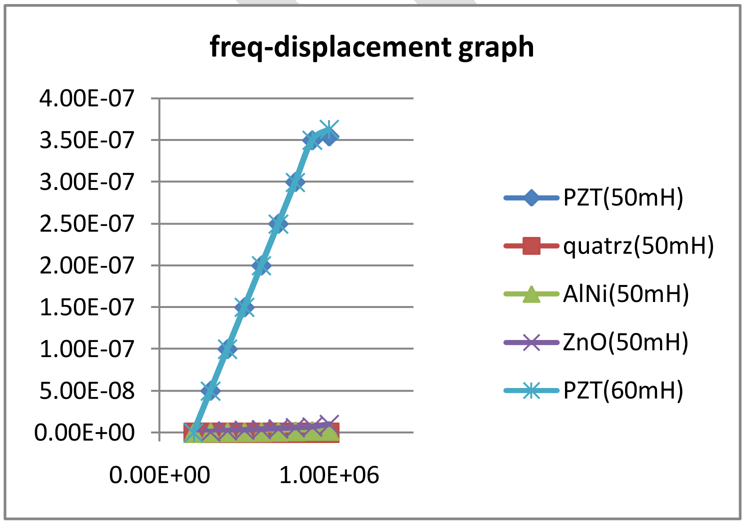

Figure11: Analyisis of frequency response of various material

In Figure 11 displacement in y-direction changes with increases in frequency . In ZnO ,quartz and AlNi material displacement is small whereas in PZT material displacement is large so that total energy stored is maximum . Also by varying inductance tuning is possible.

V. CONCLUSION

Here we concluded that all the material i.e. Quartz, Zinc Oxide, Aluminum Nitride, Lead Zirconate Titanate (PZT-5A), shows various changes in displacement when frequency changes respectively. Quartz is not used due to its low piezoelectric cofficient, but it is nevertheless an intresting material of its high Q factor. But the tunnig with external circuit is possible in the lead Zirconate Titanate by varying the inductance and also frequency will shifted towards the lower side. In order to get desired frequency range, by changing the parameter value in the solver parameter. The analysis is done by using a high end software COMSOL Multiphysics. One important parameter is to able to predict the Q factor of the structure and have accurate design guidelines to minimize the energy losses.

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