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A Comparative Analysis of Various Actuation Performance

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Abstract--In this paper the three thermal actuated technique i.e. Simple fixed fixed beam resonator, Squeezed Film Damping, Tuned Pizeoelectric Actuator are related using COMSOL Tool .In fixed beam resonator,we will study the concept of TED which is an important issue in the development of actuators.In Squeezed film damping , when two similar-shaped surfaces are close to each other and moving closer, and there is a gas or a liquid between them, that gas or liquid has to flow out. Associated with that flow is viscosity, which means that some of the kinetic energy of the moving surfaces gets dissipated. That is basically the definition of damping; it's called "squeeze film" because in this case the damping effect is associated with the "squeezing" of the fluid layer . Tunable Piezoelectric actuator , in which change in frequency by causes displacement in amplitude .

Keywords: MEMS, NEMS, PZT, TED, Poly Si, Damping. Eigen mode

I INTRODUCTION

MEMS is Micro-Electro-Mechanical System Technology[1] is a process technology in which mechanical and electro-mechanical devices and structures are constructed using special Micro-fabrication Techniques. The three major operations in MEMS are:

- Sensing: measuring a mechanical input by converting it to an electrical signal e.g. A MEMS Accelerometer or A Pressure Sensor.
- Actuation: using an electrical signal to cause the displacement (or rotation) of a mechanical structure.
- Power Generation: generates power from a mechanical input.

II SIMPLE FIXED FIXED BEAM RESONATOR

The resonator is a beam of silicon with length 400 µm, height 12 µm, and width 20 µm as shown in Fig.1. The beam is fixed at both ends, and it vibrates in a flexural mode in the *z* direction (that is, along the smallest dimension). The model assumes that the vibration takes place in vacuum. Thus there is no transfer of heat from the free boundaries. The model also assumes that he contact boundaries are thermally insulated.

A high Q value is a key factor of a MEMS resonator. It it essential that the resonator vibrates consistently at the desired frequency and that it requires as little energy as possible to maintain its vibration. These features can be characterized by the resonator's Q value, which is a measure of the sharpness of its spectrum's peak. There are several ways to define the Q value, for example: where $W0$ is the total stored vibrational energy, ΔW is the energy lost per cycle, $\omega 0$ is the natural angular frequency, δ is the damping factor (vibration decays exponentially with δt), and $\Delta\omega$ is the half power width of the spectrum

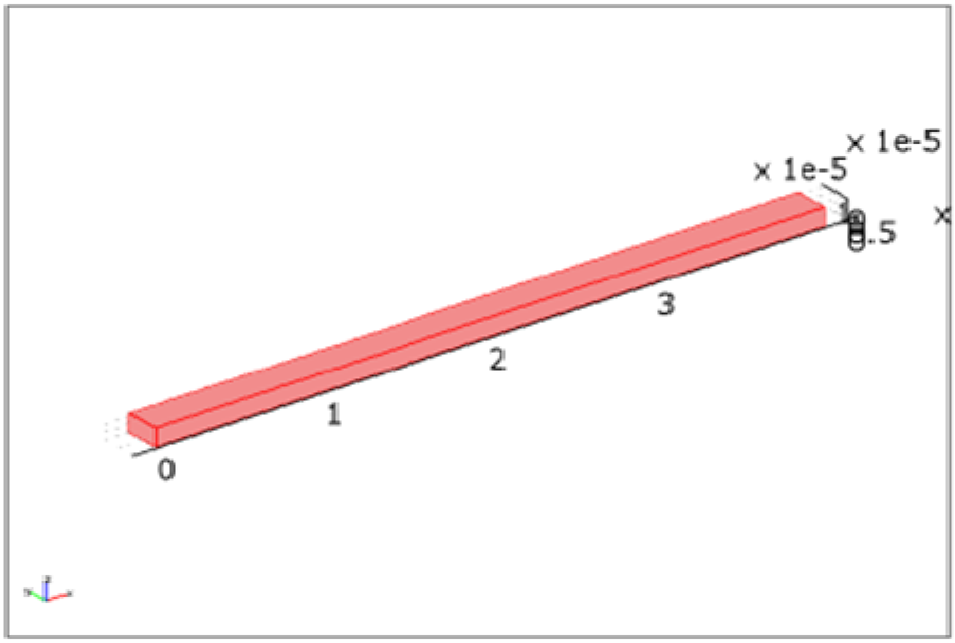

Figure 1: Geometry of a simple fixed-fixed type beam resonator.

In order to improve the resonator, the designer needs to consider all aspect that produce damping and noise to the system. For example, resonators are usually run in vacuum to minimize effects of air and squeeze-film damping. For simple structures, researchers have developed analytical expressions to estimate thermoelastic damping. According to Zener [6] and [7], you can calculate the Q value for a resonator with a single thermal mode by:

$$\frac{1}{Q} = \left(\frac{E\alpha^2 T_0}{\rho C_p}\right)\left(\frac{\omega\tau}{1+(\omega\tau)^2}\right)$$

where *E* is the Young's modulus, α is the thermal expansion coefficient, *T*0 is the resonator temperature at rest, ρ is the density, *Cp* is the heat capacity of the material, ω is the vibration angular frequency, and τ is the thermal relaxation time of the system. Thus it is easy to see that in order to have good Q value, the system needs to be designed so that ω is as far from 1/τ as possible.
The natural frequency of a beam clamped at both ends can be calculated as [2]

$$\omega_0 = a_0^2 \frac{h}{L^2}\sqrt{\frac{E}{12\rho}}$$

where *a*0 equals 4.730; *h* and *L* are the thickness and length of the beam, respectively; and *E* and ρ are material parameters.
The thermal relaxation time of the beam is given by

$$\omega_0 = a_0^2 \frac{h}{L^2}\sqrt{\frac{E}{12\rho}}$$

where κ is the thermal conductivity and other parameters are as above.

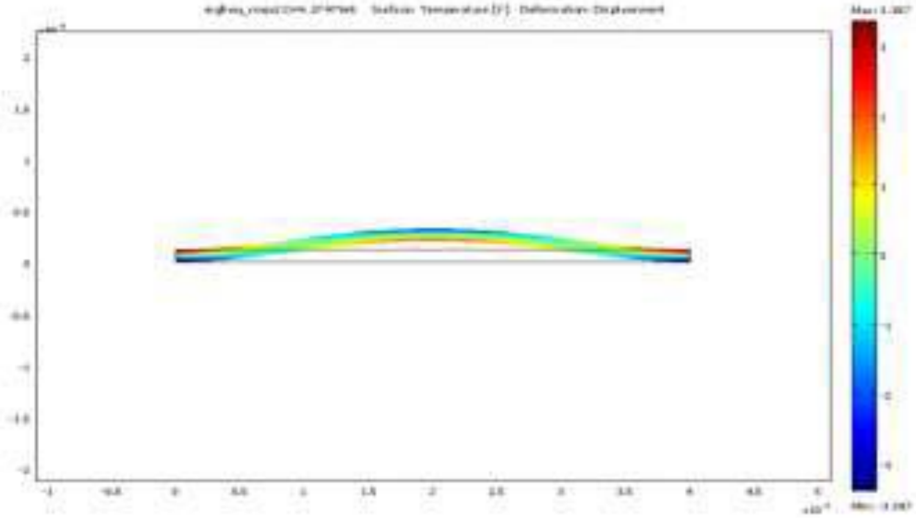

Figure 2 : First eigen mode and temperature distribution of the Poly Si.

To gain information about the quality of the resonator, it is of interest to know its natural frequency and Q value. To do this, run an eigen frequency analysis to find the eigen values for this system. For a system with damping, the eigenvalue λ contains information about the natural frequency and Q value [3]. Fig.2 shows the variation of TED factor with eigen frequency. From the analysis it is clear that at some particular frequency internal friction (TED factor) is maximum and this corresponds to the maximum dissipation of the resonator[8].

III Sqeezed Film Damping

Squeezed-film gas damping is a critical aspect of many MEMS transducers and actuators.In accelerometers, inertia produces a motion that the device detects. A typical structure connects a large proof mass, with dimensions typically in millimeters, to surrounding structures with elastic beams.

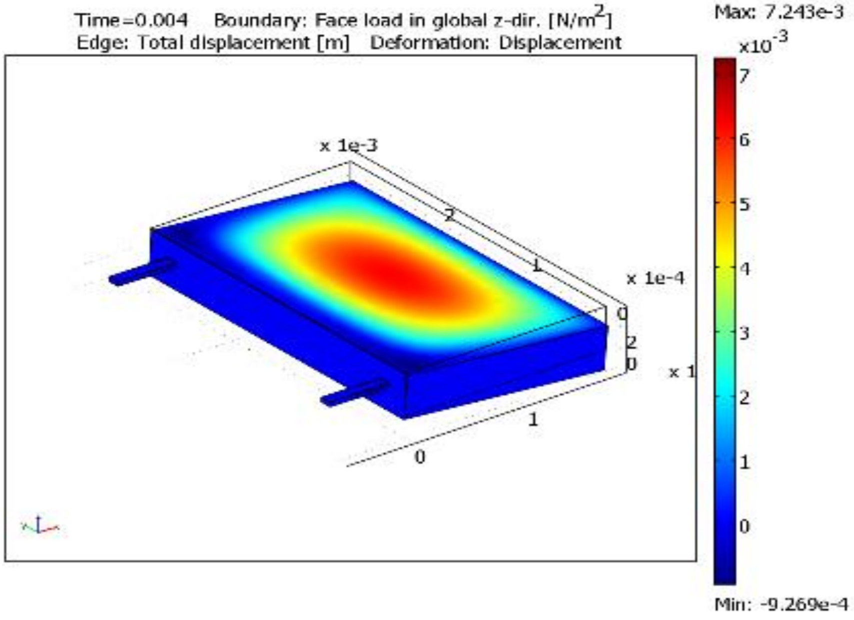

Figure 3：A load on the face of proof mass in z direction leads to deformation

This combination forms a mechanical oscillator with a specific resonance frequency. However, in accurate motion-detection applications these resonances are unwanted, and the device damps the movements to produce smooth time-step and frequency responses. Such a device can usually achieve suitable damping with a low gas pressure (100 Pa–1000 Pa) which, considering the dimensions of the device, lead to rarefied gas effect in the system [4].

A narrow gap formed by two solid horizontal plates restricts the displacement of the gas perpendicular to the surfaces. When the sensor squeezes the gap, the gas flows out from its edges. The narrow pathway restricts the flow, which causes gas pressure to increase, which decelerates the plates' movement. This model solves the squeezed-film air damping on the lower and upper surfaces using the Film Damping application mode. The model constrains the film pressure, pF, to 0 at the edges of the boundary.

The model consists of two thin silicon cantilever beams and a silicon proof mass. The cantilever beams are fixed to the surrounding structures at one end. The proof mass reacts to inertial forces and bends the cantilevers. The external acceleration, a, acts in the z direction and causes a body volume force Fz = ρsolida [5].

In this model the the pressure distribution on the surface of the proof mass after 4 ms of simulation. The ambient pressure, pA, in this case is 300 Pa, and the acceleration switches on at the beginning of the simulation. The acceleration's magnitude is half that due to gravity, g. In this figure, the maximum displacement at the tip of the proof mass is roughly 0.4 μm, or 0.1% of its thickness.

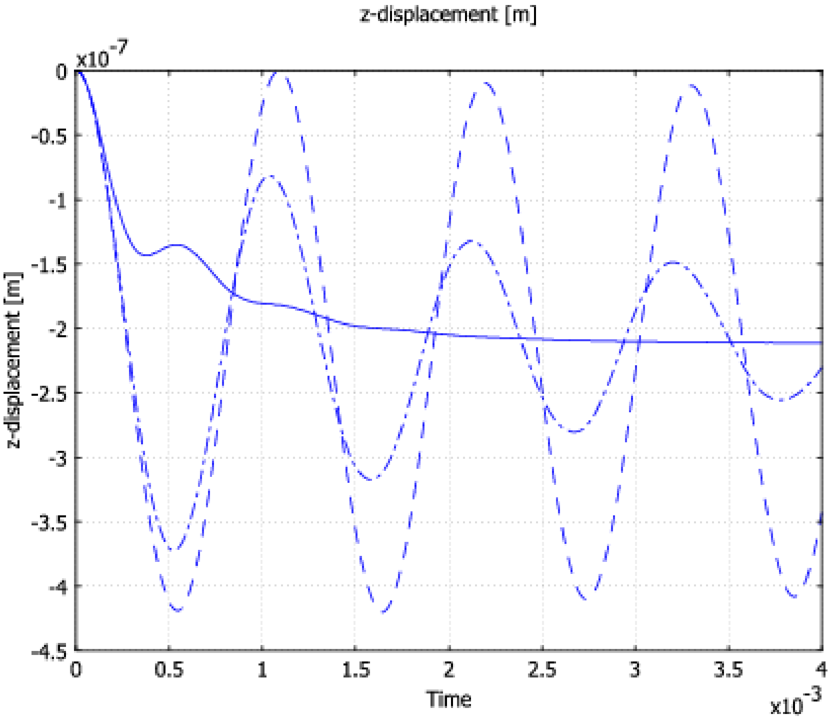

Figure 4 : Plot of Displacement the proof mass tip at ambient pressure of 3 Pa(dashed line),30 Pa (dashed-dotted line),and 300Pa(solid line).

The figure4 shows the total displacement of the proof mass tip as a function of time for ambient pressures of 3 Pa, 30 Pa, and 300 Pa. As ambient pressure increases, the film damping at the upper and lower surfaces increases through the increase in the gas' effective viscosity and density. This increased damping results in a substantial decrease in oscillation with increasing pressure. At 300 Pa, there is no apparent oscillations, and the proof mass seems asymptotically to reach the value of 0.2 μm in total displacement.

IV Tunable Piezoelectric Actuator

A piezoelectric device can actuate a cantilever beam simply by applying an AC voltage over the device. The cantilever beam itself has resonant modes that causes peaks in the vibration when the frequency of the 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. This model investigates how the external circuit influence the resonance peaks of the cantilever beam[7].

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. 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.

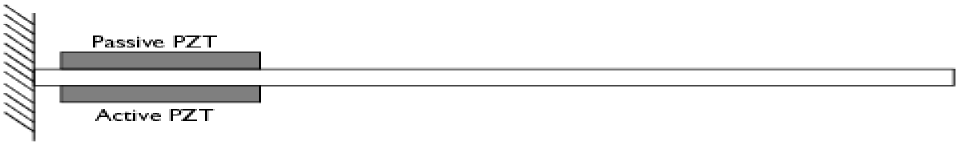

Figure 5: A piezoelectric actuator with an active piezoelectric device below and a passive piezoelectric device above the silicon bar.

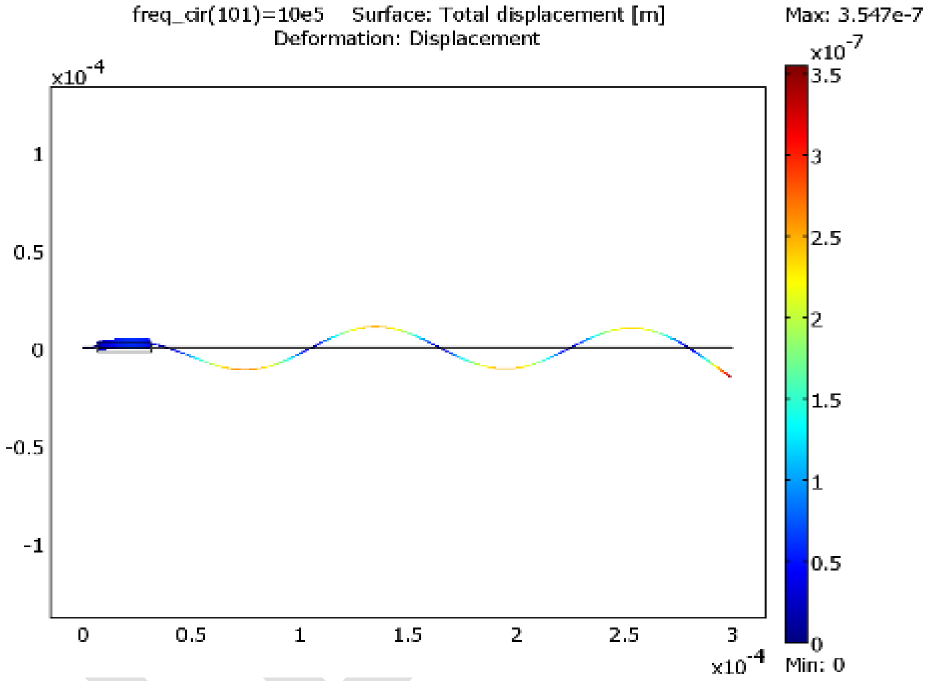

Figure 6 : First eigenmode and temperature distribution of the 3D model.

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. As shown , the vibration shows several resonance peaks in this range. The external inductance for this sweep was 50 mH.

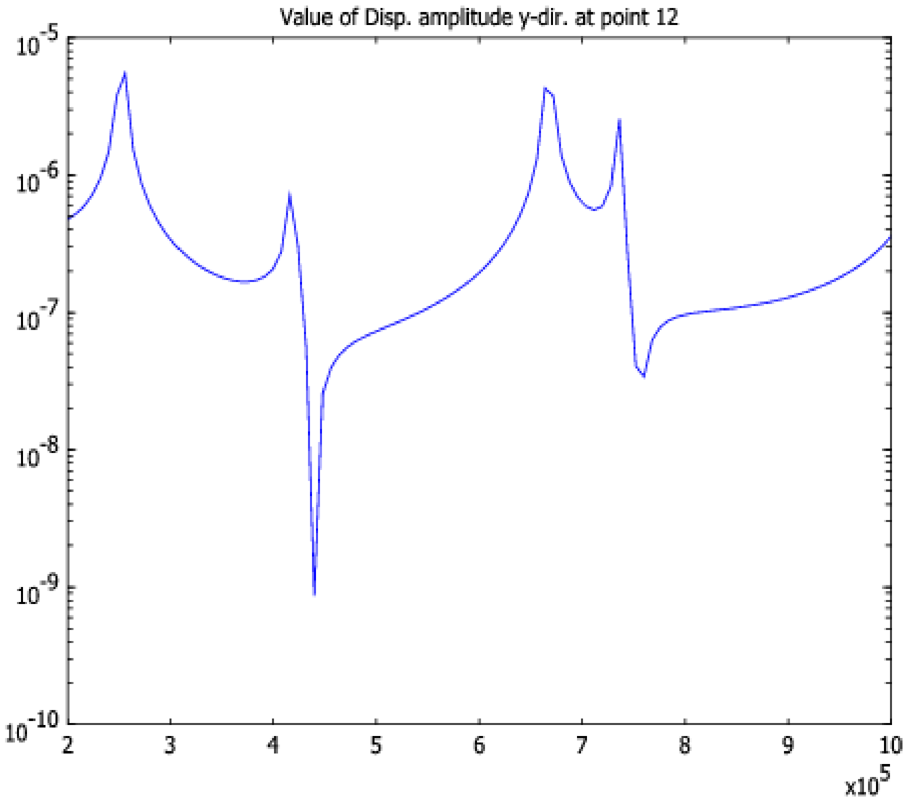

Figure 7: First eigenmode and temperature distribution of the 2D model

It is not obvious from the plot how the external circuit affects the vibration. Therefore a second sweep is performed using a higher inductance value of 60 mH. By inspecting figure it is clear that the peak around 660 kHz is affected by the change in inductance. The inductance causes a sharp spike in the spectrum that moves toward lower frequencies when the inductance increases

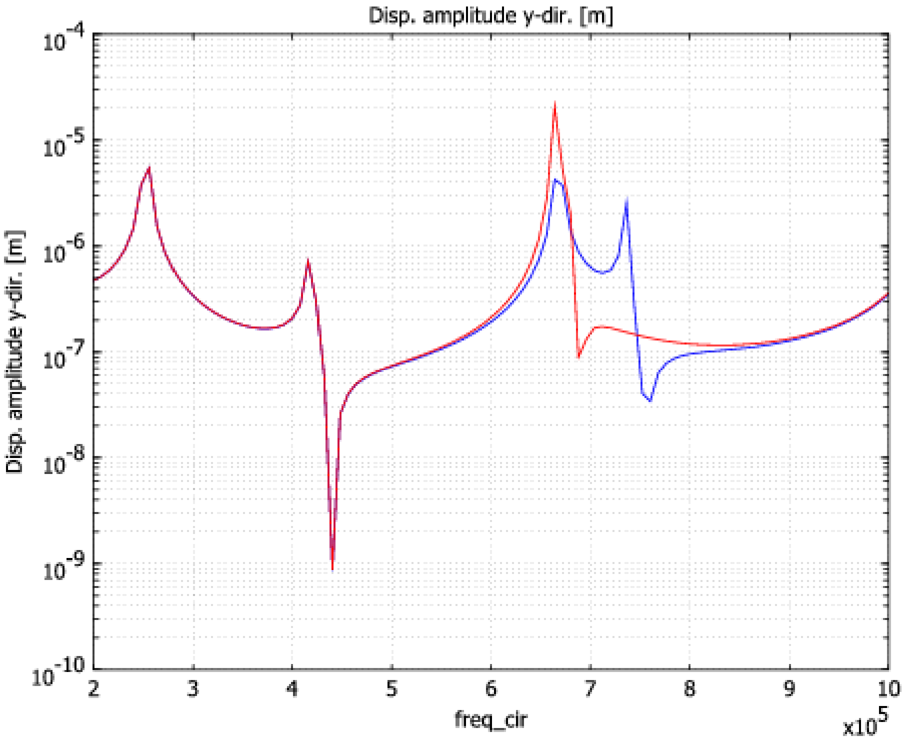

Figure 8：A comparison between the amplitude versus frequency for two inductance values in the external circuit, 50mH (blue curve) and 60 mH (red curve).

V CONCLUSION

Here we concluded that all the three devices i.e. Simple fixed fixed resonator, Sqeezed film damping, Thunable Piezoelectric actuator shows various changes when Temperature, pressure& frequency changes respectively. In simple fixed fixed resonator,as vibration increases displacement increases. In sqeezed film damping when the pressure of gas increases then it causes proof mass reacts to inertial forces and bends the cantileverist. In tunable piezoelectric actuator , peaks occur in the vibration when the frequency of the applied voltage passes the resonance frequency of each mode and varies the displacement in amplitude in y-direction.Also, we can changes displacement in amplitude by varying the inductuance value .

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