Quality Factor analysis for Nitinol based RF MEMS Resonator

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Abstract – *A paper is proposed for the study of quality factor for various materials of the cantilever beam to be used as a Micro Electro Mechanical Systems(MEMS) resonator. In order to develop such resonators the simulation of Thermoelastic Damping (TED) becomes very important. Q-factor is greatly affected by the energy dissipation mechanism in TED. The material such as Ge, GaAs, Si, Insb,Ti and Nitinol is used here. Out of all the materials the Shape memory alloy (SMA), Nitinol shows the better value of Q-factor at Eigen frequency of (0.27MHz). COMSOL Multiphysics software is used for the simulation of TED. In this study, two sided fixed beams are used and their material property effects on the Q-factor are brought out.*

***Key Words*: Cantilever beam, COMSOL, Eigen frequency, Q-factor, SMA, TED**

1.INTRODUCTION

In an MEMS resonator, TED is considered to an important loss mechanism [l]-[4]. Due to the properties such as low energy consumption, small size and less weight, MEMS resonators are often used in filters [1]. TED results in flexural vibrations of the cantilever beam. Such vibrations cause tensile and compact strains which tends to build on two different sides leading to a imbalance of the system. The dissipation of the vibrational energy is caused by the irreversible heat flow in the material [7]-[8]. Therefore, when compared to quartz crystal resonators, Silicon MEMS resonators are the best choices [5] [6]. But there are also well-established quartz technology, therefore silicon MEMS resonators should provide better performance characteristics. In achieving this, choosing of resonators having high Q-factor or a little loss in energy becomes a most important factor. The dissipation that occurs when compared to the total sytem energy in the system can be termed as Q-factor. In order to derive the energy dissipation caused by the irreversible flow of heat in oscillating structures, TED is an important factor. A high Q-factor means an system possess high signal-to-noise ratio and also there is low consumption of power, whereas low Q-factor has high dissipation resulting in reduced sensitivity and power consumption increases[6]. Therefore it is important to eliminate the dissipation as much as possible. These sources can be changed by altering the design of the model.

Shape memory alloys are activated thermally. At low temperatures the alloy is in the martensitic phase providing flexibility and thus allowing relatively large deformations. As the temperature is made higher, martensitic phase transforms to austenitic phase and in this phase the same material loses its flexibility and finally the strain is recovered. This heating of SMA actuators is based on joule's heating effect and it requires only small amount of voltage. Not only low driving voltage, SMA actuators also provides high energy density and large forces. Only drawback is that it possess high response time which is around 50ms as electrostatic actuators have a response time in the order of micro seconds.

2.THEORETICAL BACKGROUND

According to Zener, quality factor for a isotrophic beam which is vibrating in the fundamental mode can be presented with an analytical expression. Zener's expression is given by [9] and [10]:

$$\frac{1}{Q} = \frac{E\alpha T\alpha}{\rho_0 c_\rho} \frac{\omega\tau}{1+(\omega\tau)^2} \qquad (1)$$

where E can be defined as the Elastic modulus of the beam, α is thermal expansion , ω is the resonant frequency (angular) . For Q to be high, the resonant frequency should be greater when compared to the thermal relaxation time, 1/τ . And this constant τ is defined as:

$$\tau = \frac{\rho_0 c_\rho h^2}{\pi^2 \kappa} \qquad (2)$$

where h is the beam thickness and κ is the thermal conductivity of the mode. The resonant frequency of the beam can be calcualted as:

$$\omega = \frac{qh}{L^2}\sqrt{\frac{E}{12\rho_0}} \qquad (3)$$

q values differ with structure. q equals 4.73 for beams which has both ends clamped and equals π when both ends are simply supported.

3.CANTILEVER BEAM

The model consists of a single beam vibrating in its fundamental mode, perpendicular to its long axis. The model geometry is shown in Figure 1. The two ends of the beam are fixed and are assumed to be connected to a much larger body (for example a contact pad) which acts as a thermal reservoir.

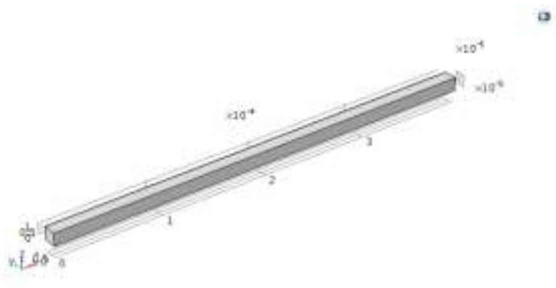

Figure 1: Model geometry of cantilever beam

The geometry consists of a cantilever beam 12 µm thick and 400 µm long. The beam width is 20 µm. Here half width of the mean is shown as the used geometry is symmetric and thus the symmetry boundary conditions are used. Two ends of the beam are clamped to a body with a large thermal mass, such as a contact pad.

4.SIMULATION RESULTS

The first Eigenmode and displacement of Germanium, Gallium Arsenide, Silicon, Indium antimonide, Titanium and Nitinol is shown in fig2, fig3, fig4, fig5, fig6 and fig7 respectively.

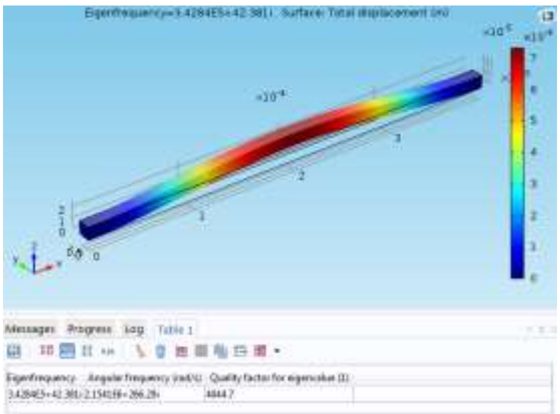

Fig 2: First Eigenmode and displacement of Germanium

From the above fig2, the quality factor is found to be 4044.7 for the first eigen frequency of 3.39E5 Hz.

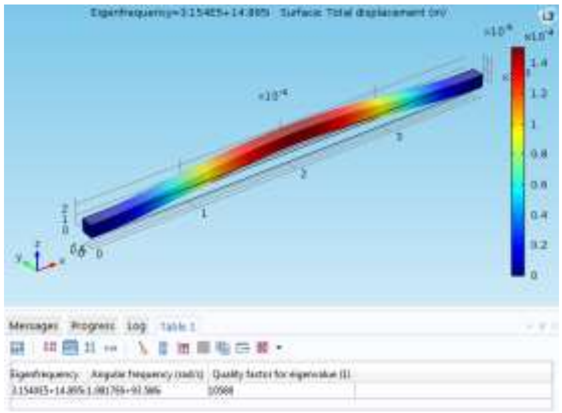

Fig 3: First Eigenmode and displacement of Gallium Arsenide

From the above fig3, the quality factor is found to be 10588 for the first eigen frequency of 3.09E5 Hz.

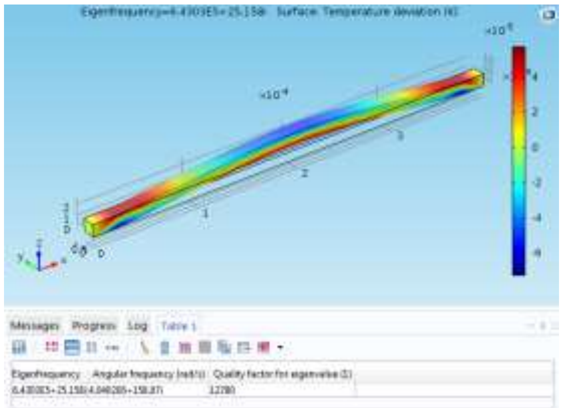

Fig 4: First Eigenmode and displacement of Silicon

From the above fig4, the quality factor is found to be 12780 for the first eigen frequency of 6.3E5 Hz.

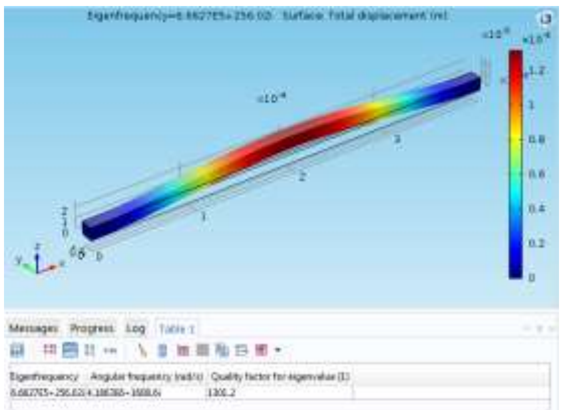

Fig 5: First Eigenmode and displacement of Indium Antimonide

From the above fig5, the quality factor is found to be 1301 for the first eigen frequency of 6.49E5 Hz.

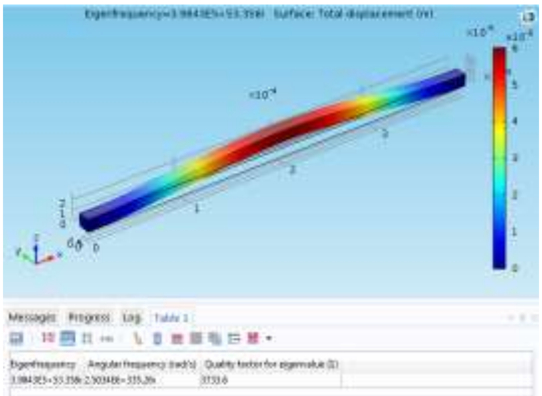

Fig 6: First Eigenmode and displacement of Titanium

From the above fig6, the quality factor is found to be 3733 for the first eigen frequency of 3.9E5 Hz.

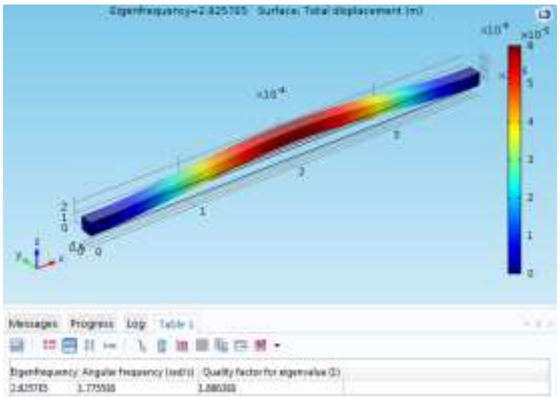

Figure 7: First Eigenmode and displacement of Nitinol

From the above fig6, the quality factor is found to be 1886300 for the first eigen frequency of 2.7E5 Hz.

The results for various materials are tabulated in Table1 and Table2.

Table1: Theoretical and simulated Quality factor for various materials.

Material	Quality factor (theoretical)	Quality factor (Simulated)
Germanium	3076	4044
Gallium Arsenide	10181	10588
Silicon	10256	12780
Indium antimonide	1316	1301
Titanium	3733	3817
Nitinol	1987896	1886300

Table2: Theoretical and simulated Eigen frequency for various materials.

Material	Eigen Frequency in Hz (theoretical)	Eigen Frequency in Hz (Simulated)
Germanium	3.39E5	3.42E5
Gallium Arsenide	3.09E5	3.15E5
Silicon	6.30E5	6.43E5
Indium antimonide	6.49E5	6.62E5
Titanium	3.90E5	3.98E5
Nitinol	2.7E5	2.82E5

In order to highlight the simulated results for both the theoretical and simulated values a graph is shown in fig8.

Figure 8: Plot of Quality factor versus Eigen frequency of all the materials for both theoretical and simulated values

In the above plot, Eigen frequency is shown along the x-axis and y-axis comprising of Quality factor. It can be seen clearly that Nitinol has the highest quality factor of 1886300.

4.CONCLUSION

A comparison between different materials has been presented. The material such as Germanium, Gallium Arsenide, Silicon, Indium antimonide, Titanium and Nitinol are studied. A summary of the same is tabulated and it shows that SMA material Nitinol has higher quality factor of 1886300. For SMA alloy the internal friction (TED factor) between 0.27 to 0.28MHz frequency is minimum and this corresponds to the minimum dissipation of the resonator. Resonance Frequency is the parameter that dominates the TED for beams. Finally it is concluded that the frequency shift ratio is in the order of 10^3 when both the ends of the beam are clamped.

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