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High Frequency Gallium Arsenide MEMS Based Disk Resonator

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Abstract:
The Microelectromechanical System (MEMS) Based On-chip resonators are greatly applicable for high frequency signal processing due to their features like small size, large frequency-quality factor product, low power consumption, low fabrication cost and etc. The Performances of the electronic device can be improved with the development of faster and lighter miniaturized devices. Here we will present an approach to solve this problem using a miniaturized semiconductor disks. These devices could produce a mechanical motion at high frequencies (Gigahertz and above) and thus will be resulting in generation of high quality factors. In this paper, we will present the eigenfrequency analysis of Disk Resonator designed in 2D using gallium Arsenide (GaAs) material to achieve a high quality (Q) factor. The maximum achieved Quality factor in this paper is 1.3927 X 10^6 at 1.356 [GHz] eigenfrequency value for Gallium Arsenide semiconducting material. The Q-factor is the most important characteristics of a resonator because it describes the frequency selectivity of the device. The high Q-factor greatly helps to implement extremely selective IF and RF filters with small percent bandwidth and low insertion loss for the devices used in RF applications.

***Keywords* – Microelectromechanical systems , Disk Resonator, gallium Arsenide (GaAs), Quality factor, Eigenfrequency, Radio Frequency Filters**

I. INTRODUCTION

The wireless communication technologies have developed to a great extent since the late 1980s. In the present day technology, there are several wireless communication technologies available such as CDMA (Code Division Multiple Access), GSM (Global System for Mobile Communication), 3G and 4G, which provides us voice, data and broadband communications. As the technology is demanding we require the devices operating at GHz range such as RF-MEMS(Radiofrequency Microelectromechanical systems) based devices. Even up to some tens of GHz frequency range, these components usually possess a high quality factor and low insertion loss and generate very low intermodulation products [1]. The MEMS devices due to their small size, low power consumption, low cost, high resistance to vibration and etc are very much applicable in the field of communication, industrial applications, consumer electronics and etc. For the upcoming communication technologies, the on-chip integrated components like oscillators and resonators are very much essential. Among all the Oscillating circuits the quartz crystal oscillator provides stable natural resonance frequencies. Even though, the quartz crystals are often used in electronic systems but usually they are off-chip. When compared to other electronic circuits, they are very large in size, not portable and difficult to integrate on a chip. Because of these reasons, we may have to go for the other oscillator device which will produce a great quality (Q) factor at natural resonance frequency with less losses to replace a quartz crystal oscillator. Vibrating devices like surface acoustic wave (SAW) and Bulk acoustic wave (BAW) with high quality factor of the range 10^3 to 10^6 are basically used to implement the high-Q oscillator and band pass filters in radio frequency and intermediate frequency stages of communication transceivers [2]. In electric circuits, to obtain a high-Q electrical resonance for designing low phase noise oscillators, acoustic resonators are generally used. The resonance frequency is determined by their geometrical structure and inversely related to their size as well.

The aim of this paper is to improve the quality factor for the MEMS based resonator by using different materials for Oscillator applications. Here, in this paper we will present the eigenfrequency analysis of Disk Resonator designed in 2D using Gallium Arsenide (GaAs) material to achieve a high quality (Q) factor. The maximum achieved Quality factor in this paper is 1.3927 X 10^6 at 1.356 [GHz] eigenfrequency value for Gallium Arsenide semiconducting material. The high Q-factor greatly helps to implement extremely selective IF and RF filters with small percent bandwidth and low insertion loss for the devices used in RF applications.

II. THE GEOMETRY OF THE DISK RESONATOR

The resonator consists of a circular disk made up of gallium arsenide (GaAs) suspended by a narrow cylindrical stem at its centre which is a nodal point for the radial contour mode vibrations. The axisymmetric model geometry of a Disk resonator is shown in the figure 1.The Disk Resonator which is at the centre of the geometry is made up of Gallium Arsenide and its supporting stem which is at the centre lying on either side of the disk resonator is made up of polysilicon. The next three layers with different radius are the layers made up of silicon substrate. The outer most layer of the geometry is perfectly matched using PML. The perfectly matched layer

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(PML) in the design is used to absorb the waves propagating in the substrate.

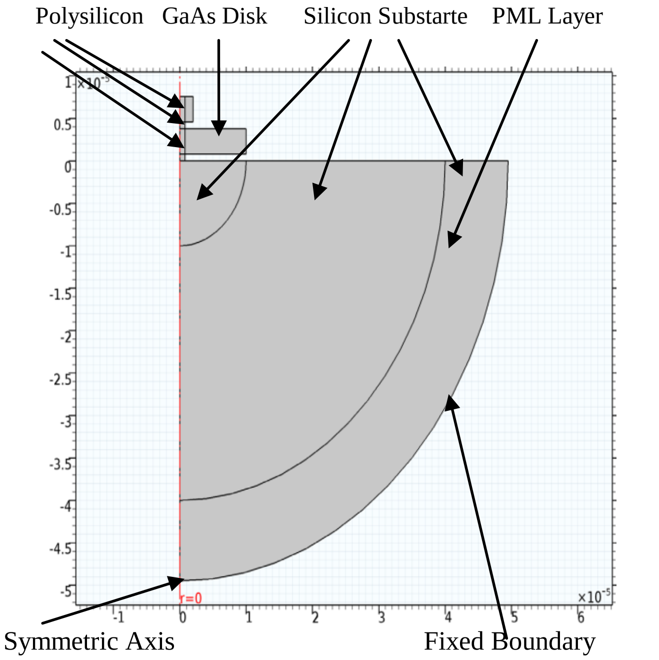

Figure 1:Axisymmetric model geometry of a Disc Resonator

This model is Modeled in 2D Axisymmetry, assuming the radius of the disk 10µm, height of the disk is 3µm, Post radius is 0.8µm , post height is 0.8µm, the radius of the substrate is 40µm, the thickness of the PML is same as the wavelength of the acoustic waves and here we are assuming the wavelength of the acoustic waves to be 9.5µm.

Table 1.Gallium Arsenide material Properties

Property	Name	Value	Unit
Density	rho	5316 Kg/m^3	Kg/m^3
Young's Modulus	E	85.9 [GPa]	Pa
Poisson's Ratio	nu	0.31	1

Table 2.Polysilicon material Properties

Property	Name	Value	Unit
Density	rho	2330 Kg/m^3	Kg/m^3
Young's Modulus	E	150 [GPa]	Pa
Poisson's Ratio	nu	0.22	1

Table 3.Silicon Substrate material Properties

Property	Name	Value	Unit
Density	rho	2230 Kg/m^3	Kg/m^3
Young's Modulus	E	130 [GPa]	Pa
Poisson's Ratio	nu	0.28	1

As the stem and disk are made from the different materials, there is an impedance mismatch between the materials. In order to suppress the energy transfer to the substrate, this mismatch is designed. Which results in the enhancement of the quality factor of the device [3]. The applied physics to the resonator is the solid mechanics. The materials used in the model and their properties are as given in the table (1), (2) and (3) are provided by the COMSOL Software.

III. DISK RESONANCE FREQUENCY AND ITS OPERATION

The radial-bulk mode disk resonator's resonance frequency can be derived in terms of Bessel functions [3], [4] as follows.

$$\frac{J_0 \frac{\zeta}{\xi}}{J_1 \frac{\zeta}{\xi}} = 1-\sigma^2 \qquad (1)$$

Where,

$$\zeta = \omega_0 R\sqrt{\frac{\rho(2+2\sigma)}{E}}, \qquad \xi = \sqrt{\frac{2}{1-\sigma}} \qquad (2)$$

Here J_α is Bessel function of the first order α, ω_0 is the angular resonance frequency, R is the radius of the disk and ρ, E and σ are the mass density, young's modulus and poisson's ratio of the material of the disk resonator. The resonant frequency for the particular mode of operation can be obtained by simplifying the above equations as

$$\omega_0 = \frac{\lambda_i}{R}\sqrt{\frac{E}{\rho(1-\sigma^2)}} \qquad (3)$$

Where, λ_i is the frequency parameter for that particular mode of operation.

The ratio of the energy stored in the system to the energy lost per cycle is defined as the quality factor (Q).The Q-factor is the most important characteristics of a resonator because it describes the frequency selectivity of the device. The following mechanisms like thermo elastic damping (Flexural Modes), material losses, and anchor losses could limit the obtainable quality factors of MEMS based resonators [4]. Usually, anchor losses occur when the vibrations of the structure and its supporting anchors excites acoustic waves propagating in the substrate. These waves radiating away from the resonator results in a damping (or loss of mechanical energy). In most of the cases, the anchor damping can represent the limiting loss mechanism that determines the resonator quality factor. This model shows how to determine the anchor damping limited resonant quality factor of a gallium arsenide disc resonator. The perfectly matched layer (PML) in the design is used to absorb the waves propagating in the substrate.

IV. RESULTS AND DISCUSSION

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The Disk resonator is analyzed at several eigenfrequency values using COMSOL Multiphysics. Some of the modes which have exhibited a greater Quality factor and its corresponding 3-D mechanical displacement is provided in table 4. The figure 2(a) shows the 3-Dimension resonator displacement in the mode 1 of the resonator, which occurs at a frequency of 1.351 GHz. The resonators quality factor is related to the ratio of the real and imaginary parts of the eigenfrequency value of the mode. In this case the evaluated quality factor is 7561.4 which is shown in the fig. 2(b).

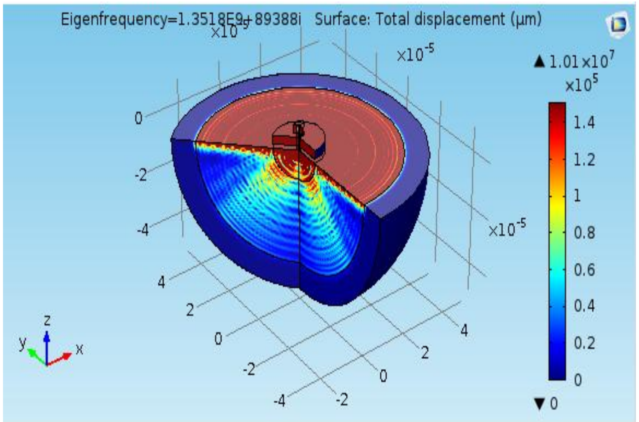

Figure 2(a).The 3-D displacement of the structure to emphasize the waves propagating in the substrate of mode 1 at 1.351 GHz

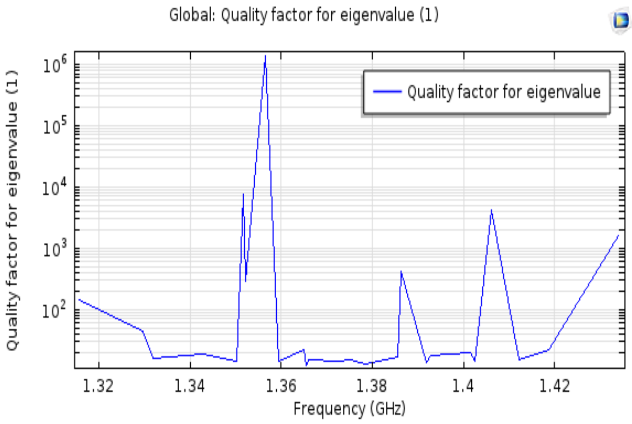

Figure 2(b).The measured Quality Factor of mode 1 at 1.351 GHz

The figure 3(a) shows the 3-Dimension resonator displacement in the mode 3 of the resonator, which occurs at a frequency of 1.351 GHz. In this case the evaluated quality factor is 9574.6 which is shown in fig 3(b).

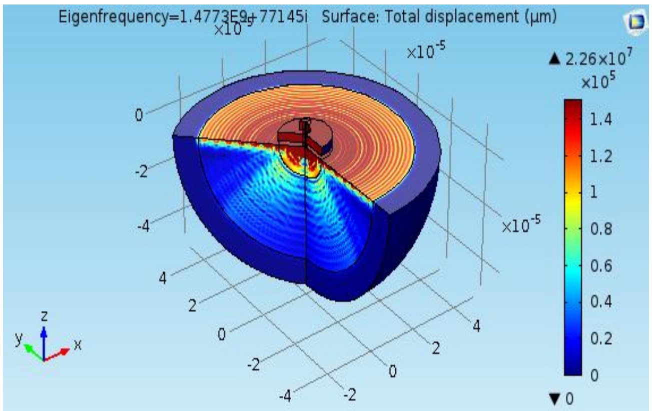

Figure 3(a).The 3-D displacement of the structure to emphasize the waves propagating in the substrate of mode 3 at 1.477 GHz

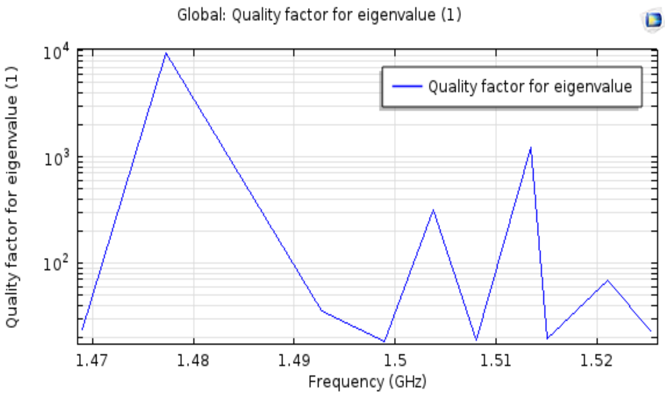

Figure 3(b).The measured Quality Factor of mode 3 at 1.477 GHz

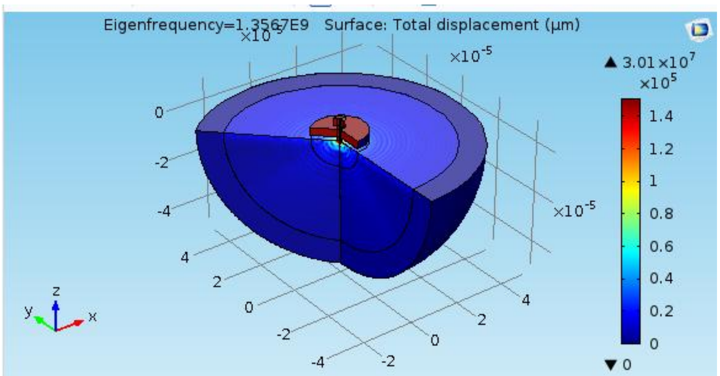

Figure 4(a).The 3-D displacement of the structure to emphasize the waves propagating in the substrate of mode 2 at 1.356 GHz

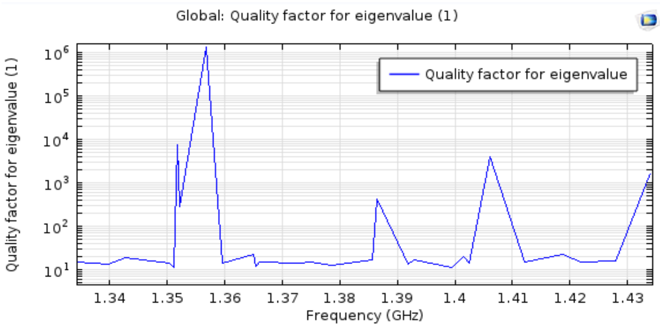

Figure 4(b).The measured Quality Factor of mode 2 at 1.356 GHz

The figure 4(a) shows the 3-Dimension resonator displacement in the mode 2 of the resonator, which occurs at a frequency of 1.3567 GHz. In this case the evaluated quality factor is 1.3927 X 10^6 which is shown in the fig.4 (b). This compares well and finds a slight improvement with the measured values of Lin et.al 2004a [6], which has produced a quality factor of 48,000 at 60 MHz, with the values of Vikram Kumar Singh et.al 2012 [5], which has produced a quality factor of 10,000 at 200.2 MHz and with the values of Li et.al 2004[7], which has produced a quality factor of 15,000 at 1.2 GHz. The table.4 given below shows the evaluated Quality factor and its corresponding 3-D mechanical displacement values for some of the modes.

Table 4. The Evaluated Quality Factor for various Eigenfrequencies values

S.No	Eigenfrequency (GHz)	Displacement (Micro meters)	Quality Factor
1	1.3518E9+89388i	1.01 X 10^7 X 10^5	7561.4
2	1.3567E9	3.01 X 10^7 X 10^5	139270 0
3	1.4773e9+77145i	2.26 X 10^7 X 10^5	9574.6

V. CONCLUSION

In this work, the disk resonator has simulated at several modes of frequencies and found that it is exhibiting a good Quality factor of 1.3927 X 10^6 at 1.3567 GHz and thus these can be used for IF and RF filters with small percent bandwidth and low insertion loss. Further, the Quality factor of the resonator can be enhanced by changing its dimesion values and varying the materials for the disk and stem.

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AUTHORS DETAILS

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