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Design and simulation of µdisk resonator for high frequency 5G bands

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Abstract

Radio frequency microelectromechanical system (RF MEMS) resonating devices have made remarkable progress during the past decades in modeling, design and fabrication. These developments have led to prevalent use of such micro-resonators in various applications. Micro-resonators are considered a workable alternative to the well-established quartz crystal technology with improvement in drawbacks like size, cost and compatibility. This paper presents the simulation results of one such micro-resonator in fundamental, second and third mode of resonance indicating the efficient operation in ultra-high frequency (UHF) range.

Keywords : Resonator, µresonator, RF MEMS, 5G communication, UHF.

1.Introduction

The requirement of frequency selective elements and RF filters has seen a steady rise in the past decades. The major impact being on consumer electronics, automation, healthcare and telecommunications. Microelectromechanical systems (MEMS) are proving to be a promising technology towards realizing the vision of growing market of electronics and today's IoE (internet of everything). µresonators introduced in early 1960s, are mechanical structures which resonates due to electrical, thermal, optical etc. actuation (Abdolvand *et al*., 2016). MEMS resonators are the good alternative to the quartz resonators having some drawbacks relating to size, cost and compatibility with CMOS technology (Basu & Bhattacharya, 2011; Deshpande *et al.*, 2020; Deshpande & Pande, 2019; Joshi *et al.*, 2020). The development of micromachining technologies for silicon through the miniaturization of transmission lines proved promising and is marked as the start of research in this field in 1990s (Iannacci 2019).

Wireless communication technology is widely researched field and is exploring the requirement of small size, high speed, low-cost wireless devices such as antennas, filters, channelizers etc. preferably using MEMS technology which shows efficient electrical performance along with high quality factor (Q) (Chorsi & Chorsi, 2018; Hao *et al.*, 2004; Clark *et al.*, 2005). The new generation mobile network such as 5G are operating at very high frequency for transmission and reception of data compared with 1G, 2G, 3G, 4Gtechnologies. Also, 5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices (Figure 1) (Chorsi & Chorsi, 2018; Hao *et al.*, 2004; Clark *et al.*, 2005). The hardware and power requirement are said to reduce with 5G technology, RF-MEMS is considered the most promising candidate to support the smooth operation of the 5G smartphones, MS (Main station), BS (Base Station) (Joshi *et al.*, 2020; Iannacci 2019).

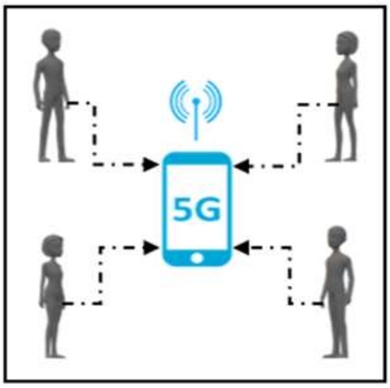
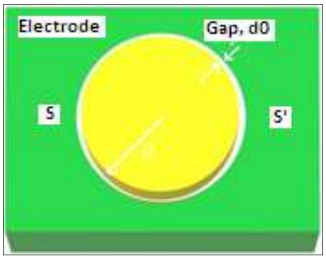


Figure 1 Connectivity enhancement through 5G technology

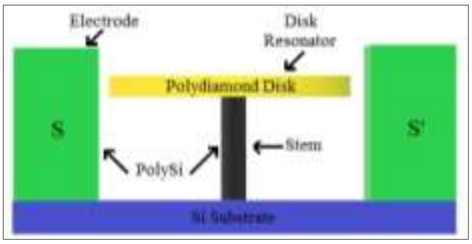
One of the important elements in high-speed wireless device is a µresonator. Radial-contour micro-disk resonators can achieve very high resonance frequencies even with larger structures. Disk resonators can achieve high quality factor too even at UHF range (Chorsi & Chorsi, 2018; Chaudhari & Bhattacharya, 2013). Therefore, they are considered as best candidates for television transmission, mobile phones and many other broadcasting radio services. This work presents the dynamic analysis and simulation of a vibrating micro-disk resonator operating in the UHF range.

2.Materials & Methods

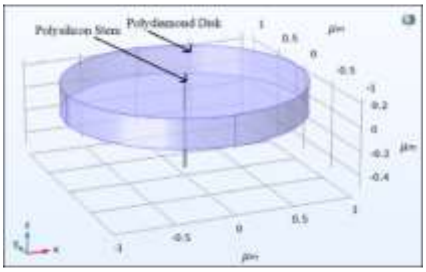
The physical design of µdisk resonator mainly depends on its performance parameters including quality factor (Q) (Clark *et al.*, 2005), resonance frequency (f_r) etc. (Hao *et al.*, 2004). A design of a contour mode µdisk resonator has been structured in Comsol Multiphysics; shown in Figure 2 and its analytical study has been presented in our previous work (Joshi *et al.*, 2020). Polydiamond and polysilicon material have been considered for the disk structure and for the stem respectively. The use of polydiamond is addressed high acoustic velocity which can further produce high frequency with less loss (Chorsi & Chorsi, 2018; Chaudhari & Bhattacharya, 2013).



(a) design perspective



(b) cross-section view



(c) 3D view

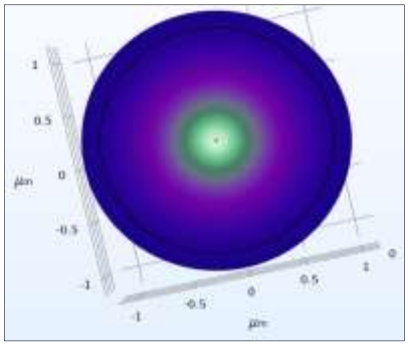
Figure 2 A design of contour mode µdisk resonator Connectivity

After application of a small actuating dc bias, the disk starts vibrating in the plane perpendicular to the stem at its equilibrium position (Joshi *et al.*, 2020). The polydiamond-based structure shown in Figure 2, was designed, simulated and optimized using Comsol Multiphysics 5.5 simulation software. The structural mechanics module of Comsol was considered to investigate the eigen frequencies at three vibrational modes. The device dimensions and material properties are tabulated in Table 1.

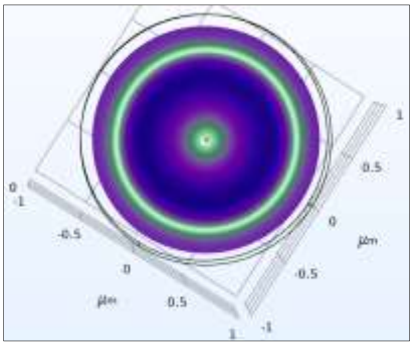
Table 1. The dimensions (Joshi *et al.*, 2020) and material properties (Huang 2008) of µdisk resonator

Parameters / Specifications	Value
Disk radius	1μm
Disk thickness	0.25μm
Stem radius	0.01μm
Stem length	0.75μm
Modulus of elasticity (polydiamond)	1144 GPa
Density (polydiamond)	3500Kg/m^3
Poisson's Ratio (polydiamond)	0.069
Modulus of elasticity (polysilicon)	150GPa
Density (polysilicon)	2300Kg/m^3
Poisson's Ratio (polysilicon)	0.226

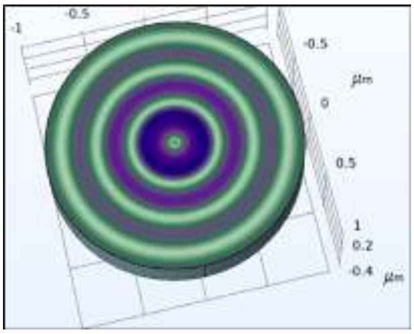
Figure 3 shows the various resonant modes that determine the respective resonance frequency. The 3 resonant modes such as fundamental, second and third can be seen with the resonance frequency of 5.22 GHz, 14.67 GHz, and 22.88 GHz respectively. The simulation results show that higher the mode of operation higher is the resonance frequency.



(a) Fundamental mode: wavelength $\lambda 1$ = 1.99 (Joshi *et al.*, 2020), resonance frequency = 5.25 GHz



(b) Second mode: wavelength $\lambda 2$ = 5.37 (Joshi *et al.*, 2020), resonance frequency = 14.67 GHz



(c) Third mode: wavelength $\lambda 3$ = 8.42 (Joshi *et al.*, 2020), resonance frequency = 22.88 GHz

Figure 3: Comsol simulation showing contour plots of

radial contour mode disk resonator in fundamental, second and third resonant modes.

In a fundamental mode of operation, the whole disk undergoes in-plane vibrations along the radius with maximal displacement at edges and a stationary node at center. In second mode of operation, a stationary circumference node gets created in addition to the central stationary node where the resonator vibrates as well as becomes steady and reverses the vibrations increasing the frequency. And in the third mode, another circumference node is created similar to second mode and vibrations reverse and become steady alternatively thus increasing the frequency of operation to more extent.

3.Result and Discussion

A radial disk vs resonance frequency plot is depicted in Figure 4. The plot represents the resonance frequency for the fundamental, second and third mode of vibration w.r.t to the disk radius. The radial contour mode disk resonators have higher values of stiffness and subsequently the quality factor reduces due to increase in losses at the central stem (Chorsi & Chorsi, 2018).

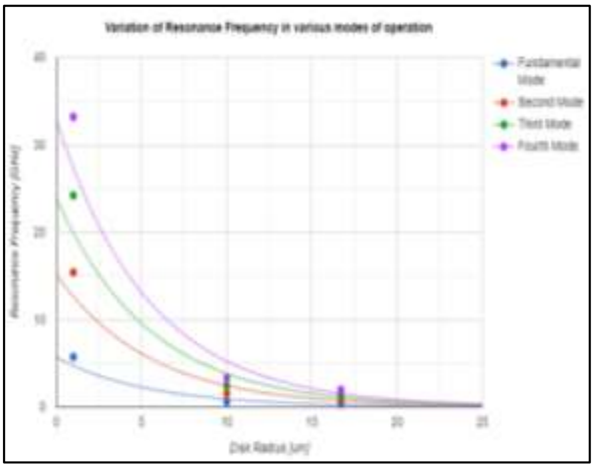


Figure 4 Disk radius vs resonance frequency plot

From Figure 4, it can be predicted that for small device dimensions achieving high resonance frequency is possible and vice-versa. The device structure was simulated in Comsol Multiphysics 5.5 to determine the resonance frequency were similar to the analytical results presented in (Joshi et al., 2020). This shows that the resonator design is suitable to operate in UHF range that will further be helpful for the 5G communication technology.

4.Conclusion

RF MEMS are being considered as promising candidates to enable futuristic technologies such as 5G communication technology, RF filters, channelizers etc. In this work, a radial contour disk resonator is analyzed and the working is simulated with the help of COMSOL Multiphysics 5.5. The resonator being electrostatically actuated vibrates at different frequencies in various modes suitable for high frequency applications. The structural dimensions of the resonator should have a very accurate aspect ratio. The materials used should have high acoustic velocity and should also support frequency reproducibility. The simulation results presented in this paper show that polydiamond material is suitable for achieving high frequencies in a radial micro-disk resonator. The resonance frequency seen through simulation is 5.25 GHz, 14.67 GHz and 22.88 GHz in fundamental, second and third mode respectively which will be suitable for the operation of futuristic 5G technological devices in the ultra-high frequency (UHF) range. These resonators will create a path for the use and application of such devices in various defense and medical sectors where miniaturization is a developing concept. The simulation and analysis presented in this work showcase the impact of various design constraints and the applications of such devices which will be helpful for further research and optimization of μdisk resonators.

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