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# Q factor Comparison of Various Ring Resonator Configurations

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*Abstract—* ***A ring resonator consists of a closed loop which is made up of non-magnetic material like copper. Ring resonators are commonly used to determine microwave substrate properties like dielectric constants and loss tangents. The ring resonators can be configured as band pass filters, notch filter etc. It can be used to construct sensors for different applications. The ring resonator operates in various modes like wineglass mode, contour mode, waveguide modes etc. Ring resonator exists in various geometries like single ring resonator, single split ring resonator, double split ring resonator etc. The performance of a ring resonator is mainly characterized by its Q factor. In this paper, Q-factor of the ring resonator is compared based on its mode of operation and geometry.The Q factors in the Ultra high frequency and Super High Frequencies are also compared***

***Index Terms— Contour mode, Q factor, Ring resonator, Q factor, Wine glass mode.***

## I.INTRODUCTION

MEMS based RF components can be used to enhance the system performance by reducing the signal delay time and noise effects through the applications of on chip components. RF MEMS devices include switches, tunable capacitors and filters. Electromechanical resonators and filters are widely used in signal processing and communication applications. Radio Frequency communication based on MEMS resonators is having a great demand especially for wireless communication devices. The resonators operating at GHz frequencies with a high Quality factor can greatly simplify wireless communication devices. The piezoelectric Aluminium Nitride contour mode ring resonator [1] uniquely combines multiple frequencies with the ability to interface directly with 50Ω systems. This is possible since it has low motional resistance ranging from 50Ω to 700Ω. It also achieves high Q factor as high as 4300 at 230 MHz in air [1].

A micromechanical extensional wine glass mode ring resonator [2] operating in a compound (2,2) mode is capable of achieving higher frequency and lower impedance. This design provides a Q factor of 3700 at 1.2 GHz with a motional resistance of 560 KΩ at DC bias of 20V and a Q factor of 2800 is obtained at 1.52 GHz [2]. This structure generally provides motional resistances 2.2 times lower than that in radial contour mode disk resonator. A compact silicon ring resonato fabricated on an Silicon On Insulator (SOI) wafer with a 220nm thick core layer on a buried oxide under cladding is presented in [3]. A compact wine glass mode coupled ring resonator with a ring geometry to achieve high mechanical frequencies and high capacitive actuation areas is presented in [4]. An ultra high frequency spoke suppoted ring resonator is presented in [6]. It operates in frequencies ranging from 10's of MHz upto 3GHz which makes it suitable to be used in high frequency reference oscillators to very high frequency and ultra high frequency oscillators.

## II. PERFORMANCE PARAMETERS

### *A. Quality Factor*

Quality Factor (Q) is one of the most important characteristics of MEMS resonators, especially for vibrating structures where the resonant frequency variation is monitored.

Quality factor is defined as the ratio of resonant frequency divided by bandwidth. In terms of energy, it is expressed as,

$$Q=\frac{2\pi\times \text{Energy stored in the circuit}}{\text{Energy dissipated per cycle}}$$

Quality factor is a dimensionless quantity that gives the quality of the resonator.

As the Quality factor increases its coupling rate increases along with low power consumption. The Q factor and the coupling coefficient has a direct relationship with each other.

### *B. Motional resistance*

The motional resistance Rx is estimated based on

$$Rx = 100 \,(1/Tmax - 1)$$

## III. . PERFORMANCE COMPARISON OF VARIOUS METHODS

A piezoelectric Aluminum Nitride contour mode ring resonator [1] consists of an AlN elastic body which is in the form of a ring. The ring can be of circular shape or square shape. The resonator is made by sandwiching this ring between Aluminum and Platinum electrodes. When an electric field is applied to it, the resonator vibrates in breathing mode across its width. The structure of a piezoelectric Aluminum ring resonator is as shown in Fig.1.[1].

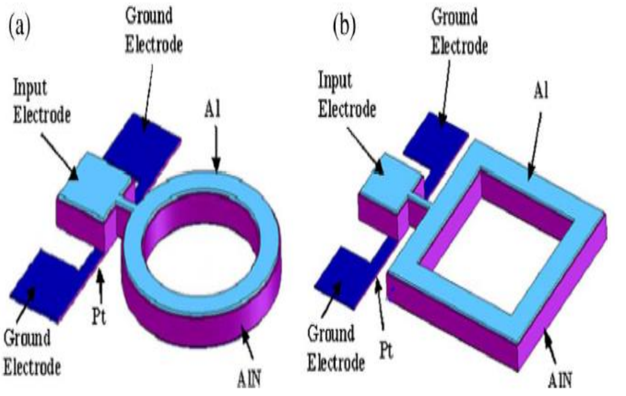


Fig.1. Piezoelectric Aluminium Nitride ring resonator (a) Circular ring (b) square shaped ring

For a circular ring resonator with a single unnotched support, the Q factor is 2400 for a resonant frequency of 223.9MHz. At this frequency the motional resistance is as low as 56Ω. For a circular ring resonator with notched supports, the Q factor is 2900 at a resonant frequency of 472.7 MHz and at this frequency the motional resistance is 84Ω. For a square shaped ring resonator, the Q factor is 1600 at a frequency of 475.3 MHz and the motional resistance is 130Ω.

For a vibrating polysilicon micromechanical ring resonator [2], a high Q factor occurs when it is in extensional wine glass mode shape. This ring resonator structure operates in a compound (2,2) mode. Due to this it achieves higher frequency and lower impedance. The structure of an extensional wine glass mode ring resonator is as shown in Fig.2.[2].

At a pressure of 200 µtorr vacuum, The Q factor is 7700 at a resonant frequency of 220MHz and Q factor is 6500 at a resonant frequency of 435 MHz. The motional resistance is 9.83 KΩ and 701 KΩ respectively. This ring resonator wth a single electrode yields a Q factor of 4650 and 4550 in vacuum and air respectively.

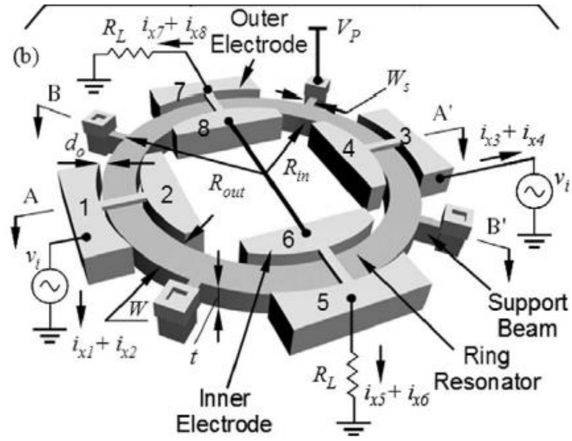


Fig.2. Structure of extensional wine glass mode ring resonator

At a pressure of 200 µtorr vacuum, The Q factor is 7700 at a resonant frequency of 220MHz and Q factor is 6500 at a resonant frequency of 435 MHz. The motional resistance is 9.83 KΩ and 701 KΩ respectively. This ring resonator wth a single electrode yields a Q factor of 4650 and 4550 in vacuum and air respectively.

A compact silicon ring resonator [3] is fabricated on an Silicon On Insulator (SOI) wafer with a 220nm thick core layer on a buried oxide under cladding. The waveguides were designed to be 500nm in width. It is then cladded with a 900 nm thick $SiO_2$ layer. The optical micrograph of a silicon microring resonator is as shown in fig.3[3]. At the critical coupling point, the loaded Q factor of the resonator is 57000[3].

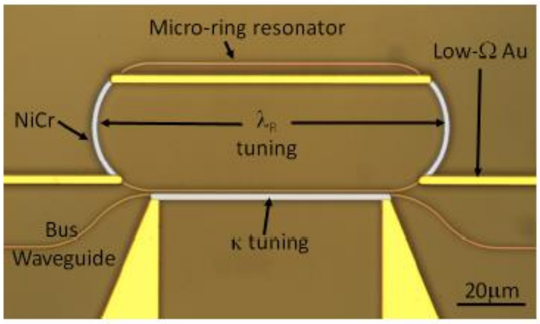


Fig.3. The optical micrograph of a silicon microring resonator

A compact wine glass mode coupled ring resonator[4] has a ring geometry to achieve high mechanical frequencies and high capacitive actuation areas. The mechanical mode shapes of the fundamental compound wine glass mode is as shown in fig.4[4]. For this configuration the optical Q factor of 75,150.

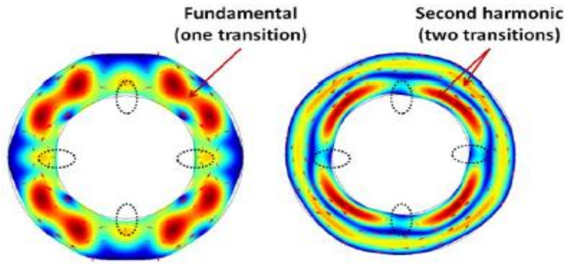


Fig.4. The mechanical mode shapes of the fundamental compound wine glass mode [4]

A split ring resonator operating at microwave frequencies is as shown in Fig.5. [5].At 2.367 GHz, this split ring resonator exhibits a Q factor of 1900 and at 1.85 GHz it exhibits a Q factor of 1710.

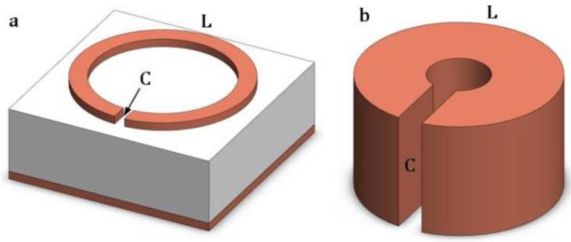


Fig.5. Split ring resonator operating in microwave frequency [5]

A spoke supported ring resonator is presented in [6]. The spoke suppoted rings are constructed using both polysilicon and poly diamond. The schematic of the spoke supported ring resonator for two different electrode configurations are as shown in Fig.6. [6].

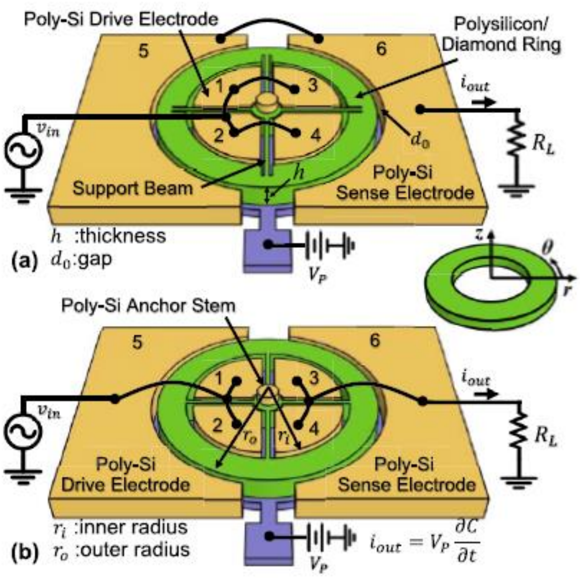


Fig.6. Spoke supported ring resonator for two different electrode configuration[6]

The device consists of a ring structure suspended by spokes. A centrally located anchor and quarter wavelength support beams are also included to provide degree of balance and to suppress anchor loss. This helps the resonator to achieve high Q factor values. The spoke supported ring is surrounded by capacitive transducer electrodes. A DC bias is applied to conducting ring and an AC signal is applied to inner electrodes to excite the device. The 1st contour mode and the 2nd contour mode of the spoke supported ring resonator is as shown in Fig.7.[6].

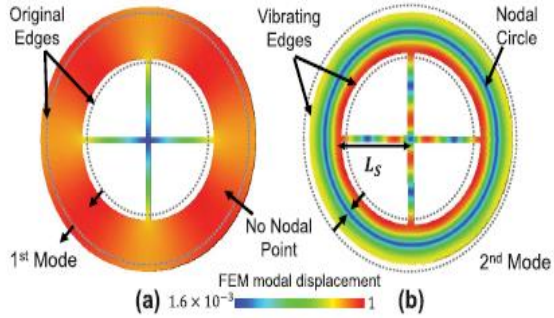


Fig7. Spoke supported ring resonator modes (a) 1st contour mode (b) 2nd contour mode [6]

For an unnotched spoke supported polysilicon ring resonator in first contour mode, the Q factor is 67,700 at a frequency of 24.37 MHz when a bias voltage of 3V is applied and the Q factor is 42,800 at a frequency of 72.07 MHz when a bias voltage of 7V is applied.

For spoke supported ring fabricated using microcryatalline diamond, the Q factor is 77,200 at a resonant frequency of 900 MHz and at 2.97 GHz the Q factor is 42900 which is the highest for this range of frequencies. The motional resistance at this frequency is 81 KΩ. The motional resistance can further be reduced by arranging seven such resonators in a mechanically coupled array with 30nm gap spacing. This can reduce the motional resistance to 300Ω.

## IV. CONCLUSION

The performance parameters of various ring resonator structures in different modes are compared in this paper. In Contour mode, the circular ring gives a higher Q factor value than the square shaped ring. The vibrating polysilicon microring resonator exhibits a Q factor of 3700 at 1.2 GHz with a motional resistance of 560KΩ. A compact silicon ring resonator exhibits a Q factor of 5700 that operates in optical domain. A compact wine glass mode coupled ring resonator exhibits a Q factor of 75000 at 9.82GHz. The spoke supported ring resonator exhibits a Q factor of 42900 at 2.97 GHz with a motional resistance of 81KΩ. Among all these structures, the spoke supported ring resonator is superior since it achieves the highest Q factor at ultra high frequency range with low motional resistance which makes it a suitable candidate for channel select applications. At super high frequency, the compact wine glass mode coupled ring resonator is having high Q factor and hence it is preferable for super high frequencies.

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