Design and Optimization of BAW Resonator for Biomedical Applications

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Abstract

MEMS devices have found a broad usage in biomedical field. Remote handling of biomedical data of implantable requires wireless transmission. The radiofrequency (RF) filter plays an important role in wireless communication. In this paper, an optimized MEMS resonator is designed. The design and optimization of SMR resonator utilizes piezoelectric thin-film material viz. AlN, ZnO, PZT, BaTiO3 and LiNbO3. Each of them is appropriate for RF filters due to their distinct material characteristics. For low noise and extremely sensitive communication systems require high Q factors. By evaluating the various piezoelectric materials, the Quality factor of SMR resonator is calculated. The performance of a SMR in relation to the stages of Bragg's reflector arrangement and its material is studied. W/SiO2-based Bragg's reflector configurations based on AlN gives good performance in terms of Quality factor.

Keywords: MEMS, Piezoelectric, SMR, BAW, Quality Factor

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1. Introduction:

Applications of biomedical devices range from neural [1]to endoscopic capsule systems [2] with video transmission.Micro technologies development, which permitted the shrinking of sensors and actuators and their subsequent integration with readout and communication electronics[3], to be credited in part for the creation of such systems.The radiofrequency (RF) chips can be useful for this purpose.The role of RF filters in communication networks is crucial[4,5].With the evolution of integrated circuit technology in recent years, new filters based on Micro electromechanical systems (MEMS) have addressed the aforementioned restrictions.

MEMS devices are widely used in biomedicalapplications [6,7].Some of these uses include:

a) Precise ophthalmic surgery
b) Bio molecular recognition
c) Micro pumps for drug administration in autonomous therapy management systems
d)DNA detection[8]

The resonators are the most important component of MEMS filters. Resonances with low internal loss, low launch, high quality factor, and high frequency stability are critical in MEMS filter design[9]. Thus, MEMS filters need the design of simple and inexpensive resonators. There are different types of Resonators out of that Bulk acoustic are the devices used for 5G application.

Numerous sensing applications have made use of bulk acoustic resonators due to its high sensitivity, quick measurement speed, simple construction, and inexpensive design cost.[10]. Bulk acoustic waves (BAWs) devices have been under development since 1980 [11]. The bulk micro-machining approach has often been used to create BAW devices on silicon substrates by sandwiching a piezoelectric layer between thin metal layers [12]. In BAW resonators, the resonance is produced by the piezoelectric action. Acoustic waves are created when an ac electric signal is applied to a BAW device, and they propagate in the longitudinal direction toward the electric field [13]. Backside, reflection of longitudinal acoustic waves is measured using the bottom electrode. The acoustic wave confinement inside the piezoelectric layer may come from the perfect confinement of an acoustic wave inside a BAW device.The acoustic wave can be completely contained because of the reflection coefficient's unity magnitude.[14]. The resonance frequency of the BAW device is calculated using the acoustic velocity and piezoelectric layer thickness. The resonance frequency is provided by [11,15]

$$f = \frac{\vartheta}{2t_p} \qquad (1)$$

here, ϑ is acoustic wave velocity andtp denotes the piezoelectric layer thickness.

According to equation (1), in BAW devices, the fundamental resonance frequency and piezoelectric layer thickness are inversely proportional to one another.When an out-of-phase state occurs inside the resonator for SMR devices, the acoustic wave is subjected to both mechanically induced and dielectric polarizations, which results in parallel resonance. [11, 16].

Two broad categories of BAW resonators are distinguished:

1. Thin Film bulk acoustic resonator (FBAR) and
2. Solidly mounted resonator (SMR)

Design of Thin Film Bulk AcousticWave Resonator(FBAR)is shown in Figure 1 and design of Solidly Mounted Resonator (SMR) is shown in Figure 2.

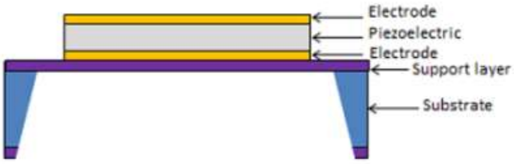


Figure.1. Thin Film Bulk Acoustic Wave Resonator(FBAR)

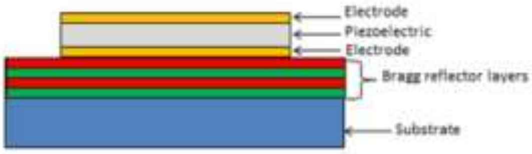


Figure.2. Solidly Mounted Resonator (SMR)

Solidly mounted resonators are preferred due to their great durability, low risk of mechanical damage during the dicing process, low layer tensions, and good power handling capabilities. As a result, the following major issues are resolved in order to design SMR that can operate more effectively and efficiently:

- The piezoelectric layer material
- its thickness
- brag reflectors material

Downshifting in SMR's resonant/antiresonant frequency is caused by changes in any of these characteristics [11].

Sections of the paper are organized as follows. In Section II, the novel contribution to the work is highlighted.Section III displays the results of the FEM simulation of the SMR and the micro-fabrication process of the proposed SMR with discussion on results in section IV. Section V states the conclusion of the proposed research.

2.Proposed Work

Novel Contribution of the Paper

We are very driven to use different piezoelectric materials to address the aforementioned obstacles. The different materials are used in the bragg reflectors along with the SiO2 layer.AlN, BaTiO3, LiTaO3, PZT, and ZnO are some of the different piezoelectric materials utilised, and W, AlN, Mo, Ta2O5, and ZnO are some of the different materials used in brag reflectors alongside the SiO2 layer. The performance analysis of SMR by varying different piezoelectric material and the different materials used in brag reflectors along with SiO2 layer is compared.andDue to the high resistance of tungsten (W), which provides strong isolation and energy confinement in SMR, it has been discovered that SMR employing AlN as the piezoelectric material and Tungsten (W) as one of the layers in the brag reflector give good value of Quality Factor.

3.SMR Design, FEM Simulation and Fabrication

The SMR is designed as shown in Figure2 with top and bottom electrodes of aluminium with thickness 100nm and 200 nm respectively. A 100nm thick different materials and SiO2 layer is grown to create a high-low acoustic impedance layer for the Bragg reflector.

The SMR design with specificationsare given in the table 1 below.

Table 1: SMR designwith specifications

Material		Length (L) (um)	Width (W) (um)	Thickness (um)					Frequency (GHz)	Quality Factor
Piezo	Brag			Si	Brag Layers	bottom electrode	piezo	top electrode		
AlN	SiO2/W	0.9	0.35	0.5	0.1	0.2	0.12	0.1	5.34	3325
BaTiO3	SiO2/W	1.1	0.35	0.5	0.1	0.2	0.14	0.1	5.345	2010
LiTaO3	SiO2/W	0.9	0.35	0.5	0.1	0.2	0.22	0.1	5.35	1376
PZT	SiO2/W	0.9	0.35	0.5	0.1	0.2	0.17	0.1	5.355	1007
ZnO	SiO2/W	0.8	0.4	0.5	0.1	0.2	0.3	0.2	5.34	2335
AlN	SiO2/AlN	0.9	0.35	0.5	0.1	0.2	0.12	0.1	5.35	3210
AlN	SiO2/Mo	0.9	0.35	0.5	0.1	0.2	0.12	0.1	5.35	3210
AlN	SiO2/Ta2O5	0.9	0.35	0.5	0.1	0.2	0.12	0.1	5.35	3210
AlN	SiO2/ZnO	0.9	0.35	0.5	0.1	0.2	0.12	0.1	5.35	3210

3.1 Quality Factor Analysis of SMR

Finite element simulations are carried using COMSOL Multiphysics MEMSCAD tool. A 3Dmodel of FBAR is designed using AlN, BaTiO3, LaTaO3, PZT, and ZnO piezoelectric material. Firstly, the resonator is designed using 2D work planes withspecificdimensions.Thefirsttwoplanes are usedtomakesiliconsubstrate and oxide layers whereas other one is used as Bragg reflectorlayers.Theverynextwork plane is used to design the entire resonator design with top andbottom electrode sandwiching the piezoelectric material. Allthe work plane is then extruded with the thickness mentioned intable 1. All the domains of the geometry are assigned withsolid mechanics physics and piezoelectric material is assigned with electro staticphysics.Thebottomandtopelectrode act as ground and potential terminal for resonator as shownin Figure 2. For the actuation of resonator, 1mV of electricpotential is applied to the top electrode and the geometry starts resonating at a certain frequency which is calculated by eigen frequency analysis. The frequency of the firsteigen mode is found as 5.34GHz where maximum performance is achieved by the resonator.

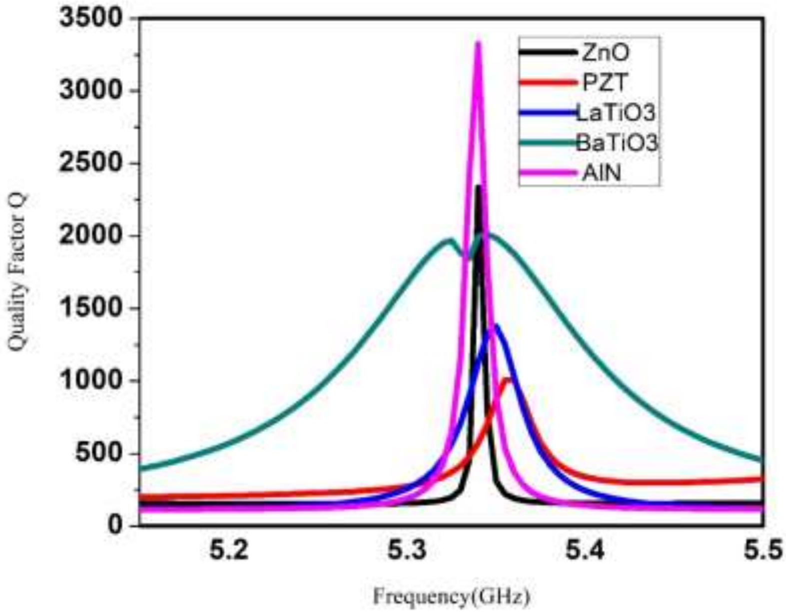


Figure 3. Quality factor (Q) vs different piezoelectric materials

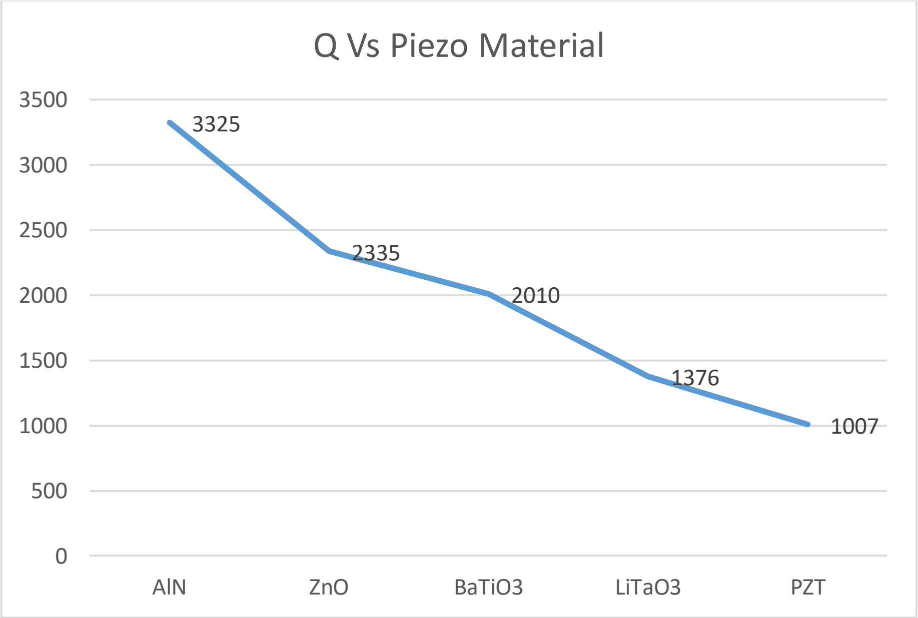


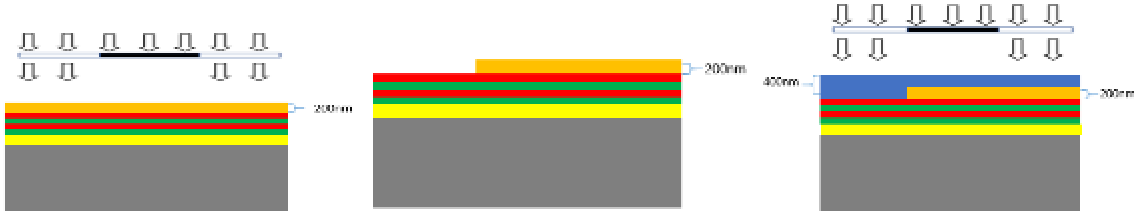
Figure 4. Quality Factor Q Vs Piezo materials

The Quality factor (Q) of the modelled resonator is depicted in Figure 3 and 4 in relation to the thickness of the piezoelectric layers and the resonant frequency using various piezoelectric materials.

3.2 Micro-Fabrication Process Steps

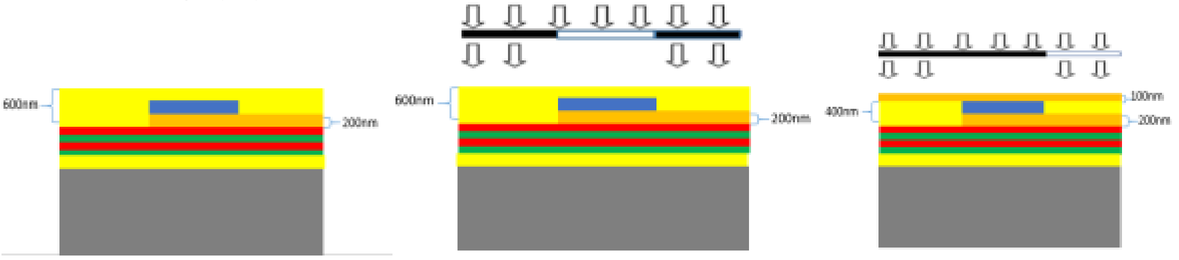
The deposition of films on the substrate and lithographic patterning of those films are the processes used to build micromechanical devices. This manufacturing technique is a typical form of surface micromachining. The fabrication process begins with the deposition of an isolation layer of brag reflector silicon dioxide (SiO2)/W (2 steps) of 100 nm on top of a p-type<100> orientation 2"silicon wafer (4–7 ohm-cm resistivity). For first time deposition of SiO2 Wet oxidation is used and rest CVD is used. Metal deposition (Al) for the formation of bottom electrode – Thermal Evaporation (200nm) is used.Then 1st level Electron Beam Lithograph-MASK1 bottom electrode is performed.After Etching – with Aluminium etchant, Piezoelectric deposition (AlN)- Sputter Deposition (200nm). 2nd level Electron Beam Lithography– MASK 2. Etching of AlN. Deposition of SiO2(spacer layer 600 nm).3rd level Lithography (Mask 3). Etching of SiO2. Metal deposition (Al) for the formation of top electrode – Thermal Evaporation (100nm). Metal deposition (Al) for the formation of top electrode – Thermal Evaporation (100nm).

RCA,WetOxidation,Deposition of TungstenDeposition of SiO2, Tungsten Sputtering of
Aluminium



1st level Lithography (Mask 1) Etching of Aluminium Deposition of
Piezoelectric layer

2nd level Lithography (Mask 2)



Etching of Piezolayer , 3rd level Lithography (Mask 3) Sputtering of
Aluminium
Deposition of SiO2 (Spacer Layer) 4th level
Lithography (Mask 4)

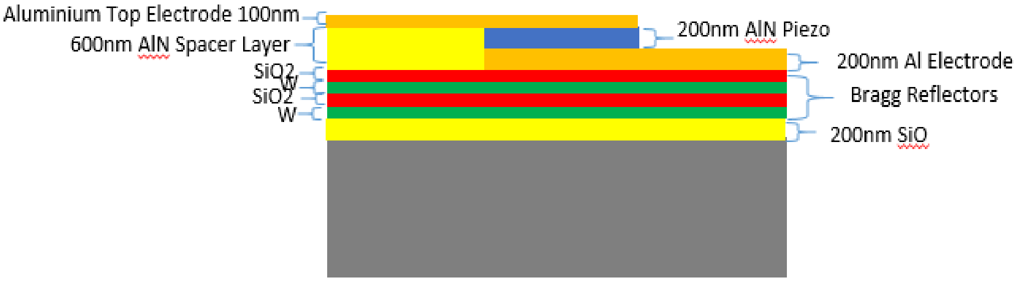


Figure 6. Process Flow for Fabrication

4. Results and Discussions

This work briefly describes SMR simulation using different piezoelectric thin-film materials, including AlN, ZnO, PZT, BaTiO3, and LiNbO3. Each of these materials has distinct material features that make it suited for a particular purpose.For low noise, extremely sensitive communication systems, high Q Factor is required.Analyzing the various piezoelectric materials allows for the optimization of the Quality Factor of FBAR resonators. The performance of a FBAR in relation to the stages of Bragg's reflector arrangement and its material is studied.A few examples of the high and low acoustic impedance layers used to construct the Bragg's reflector configuration include SiO2/W, SiO2/AlN, SiO2/Mo, SiO2/Ta2O5, and SiO2/ZnO. The FBAR Resonator was simulated using COMSOL 5.6 Multiphysics, simulation and it was found that AlN piezoelectric material has a better Quality factor than ZnO, PZT, BaTiO3, and LiNbO3 piezo materials.

5. Conclusion

The current research asserts that W/SiO2-based Bragg's reflector configurations based on AlN are best suited to give increased performance in terms of Quality Factor. Aiming to improve SMR's Quality Factor, optimization was carried out.The thickness of the top metal electrodes, the piezoelectric layer, and the low and high acoustic impedance layers of the brag reflector were determined to be best optimized at 0.1 nm, 0.12 nm, and 0.1 nm, respectively. The designed and optimized SMR can be used in RF filters for wireless implantable in biomedical applications.

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