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# Aluminium Scandium Nitride Thin Film BAW Resonators (FBAR) for 5G Applications

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***Abstract: -*** With the growing impact of 5G communication system, Radio-Frequency Micro-Electro-Mechanical-Systems (RF MEMS) technologies are becoming increasingly important in our daily lives. Development of filters in the 5G frequency range is being carried out tremendously. The rapid rise in smartphone usage, heightened data demands, congestion in the frequency spectrum, and advancements in technology have posed numerous challenges for the development of RF filters. The ultimate goal is to simplify the RF Front End Module used in smart phones, thereby achieving better selectivity. In this paper, a high frequency - high Q thin film bulk acoustic wave resonator of piezoelectric material Aluminium scandium nitride (AlScN)based FBAR is designed for 5G Application. Finite element analysis conducted using the COMSOL Multiphysics software assess the characteristics of the constructed FBAR. The outcomes indicate that the device resonates effectively at 5 GHz, exhibiting commendable return loss and a Q-factor of 1490. A high-resonance-frequency FBAR device offers advantages for 5G mobile technology.

***Keywords:*** RF MEMS, Aluminium Scandium Nitride, FBAR (Thin Film Bulk acoustic wave Resonator) Quality Factor,5G

## I. INTRODUCTION

The realm of 5G communication has experienced significant transformation in recent years. With the surge in smartphone numbers, rising data usage, spectrum frequency congestion, and technological advancements, designing RF filters has become increasingly challenging. Key hurdles include designing resonators with enhanced out-of-band (OoB) rejection, minimal insertion losses, and compact dimensions. Moreover, for wearable devices, these filters need to be flexible. Thin film bulk acoustic wave resonator (TFBAR) technology offers answers to these issues.

A reference periodic electronic signal, for example, is used to regulate the function of a conventional digital device. Converting mechanical vibration to a periodic electrical signal is one approach to generate this oscillatory signal [1]. A MEMS resonator comprises of a resonant mechanical structure and an electronic circuit that drives the resonance. The resonator is excited to one of its natural resonance modes at a single frequency, and the response periodic vibration of the resonator generates a voltage signal. The resonator response is defined by a frequency and a quality factor (Q), which determines the rate of decay of the vibration amplitude as well as temperature and other operating parameters sensitivities [2]. Bulk acoustic resonators (BAW) find extensive application in sensing tasks due to their elevated sensitivity, rapid measurement capabilities, simple design, and cost-effectiveness [3]. The development of devices utilizing bulk acoustic waves began in the late 1980[4]. Typically, BAW devices are fabricated on silicon substrates using bulk micro-machining methods, incorporating a piezo layer sandwiched between thin metal layers [5]. The resonance of BAW resonators is created by the piezoelectric effect. The FBAR consists of a thin piezoelectric film placed between two electrodes. The inverse piezoelectric effect causes the structure to deform when an electric field is induced between the electrodes [6]. As a result, a resonant standing wave also known as an acoustic wave is generated. The natural frequency of an FBAR

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is dependent on the thickness of the piezoelectric thin film [7]. The wavelength of these waves is twice as long as the thickness of the piezoelectric film. That is, the overall thickness of the piezoelectric film is equivalent to the half-wavelength. As shown in equation (1), the thickness, tp of the piezoelectric layer has a significant impact on the resonance frequency of an FBAR [8].

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

Here, tp is piezoelectric layer thickness and $\vartheta$ is the acoustic wave velocity, respectively. Parallel resonance in a solidly mounted resonator (SMR) device arises from the combined effects of dielectric polarization and acoustic waves when there is an out-of-phase condition within the resonator [9]. Piezoelectric material is placed between two electrodes in the piezoelectric MEMS resonator. It features a low motional resistance and a robust electromechanical coupling capability [1].

## II. Piezoelectric MEMS Resonator

There are two main modes of propagation: within the bulk of the material (BAW)and at the surface of the material (SAW), according to the underlying physical principle. The pace of propagation of surface waves is slower than that of bulk waves. The modes of propagation of SAW and BAW devices differ significantly, making them suited for distinct types of applications. SAW RF resonators are less expensive than BAW RF resonators and are used in RF Filter applications with frequencies below 1.5 GHz. Because of the low Q-factor of SAW RF filters, a temperature compensation technique is required. The charges building on the bottom electrode strain the piezoelectric material, causing an elastic or acoustic wave to flow through it and be reflected by the top electrode.

BAW resonators are classified as

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

2. SMR (Solidly Mounted Resonator)

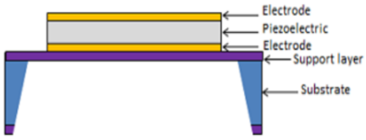



**Fig.1. Thin FBAR**

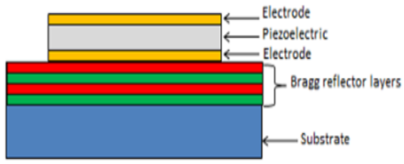



**Fig.2. SMR**

FBAR as shown in Fig. 1 the edge structure is etched to create a cavity in the substrate where the total energy is confined inside the structure and in Solidly Mounted Resonator (SMR) Fig.2, Additional layers beneath the primary framework serve as Bragg reflectors and offer structural support. These reflectors effectively reduce the acoustic wave leakage from the primary structure. Both types of BAW consist of a configuration involving metal-piezoelectric-metal layers. The FBAR features a micro-machined air gap designed to reduce the electromechanical coupling to the substrate below. In contrast, the SMR device utilizes a series of reflective components, referred to as a reflecting mirror or Bragg's reflector. [10]. AlScN is a material that can be deposited using the same techniques as AlN and demonstrates an enhanced piezoelectric coefficient. [11]

## III. COMSOL Multiphysics Simulation

COMSOL Multiphysics software is employed to model and simulate various designs and procedures across engineering, manufacturing, and scientific investigations. Serving as a comprehensive simulation platform, COMSOL Multiphysics offers both fully integrated multiphysics and individual physics modeling functionalities [12]. The Model Builder encompasses the entire modeling process, starting from defining geometries and material attributes to specifying the relevant physics for addressing particular phenomena, followed by solving and analyzing models to yield precise outcomes. In the simulation, the FBAR featured top and bottom aluminium electrodes each with a thickness of 100nm.AlScN with thickness of 250nm was used as a piezoelectric material.

The device active area measures 1x1 μm$^2$. A 500nm-thick oxide layer positioned at top of the silicon substrate serves both as an insulator and to reinforce the membrane. A cavity of 2 μm x 1.5 μm x 0.5 μm was created in the oxide layer. The three layers are stacked on top of each other and have the same dimensions, making fabrication easier. The design structure is depicted in Fig.3

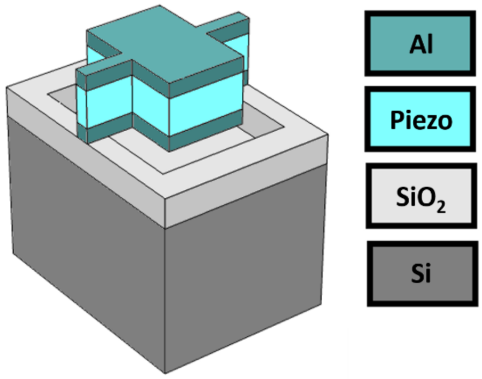
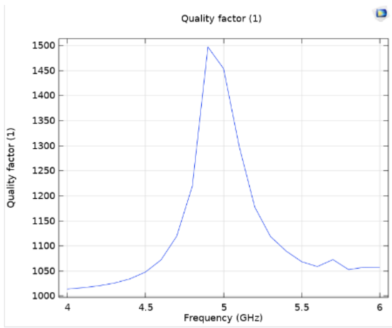
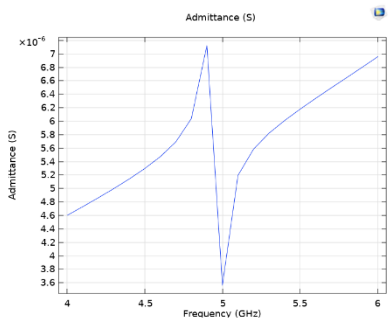
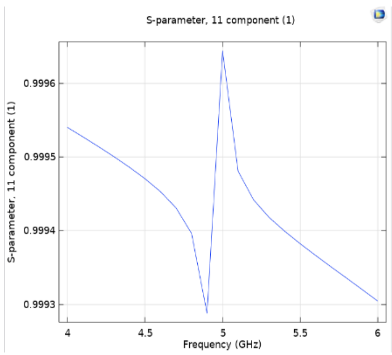


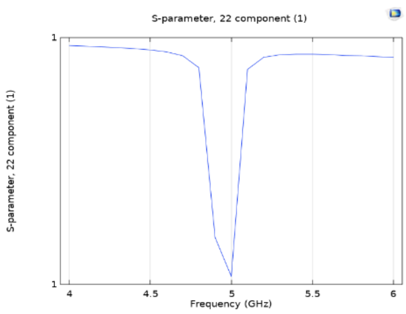

**Fig. 3. COMSOL Multiphysics FBAR geometrical structure**




**(a)Quality Factor Vs Frequency** **(b) Admittance Vs Frequency**




**(c) S11 Vs Frequency** **(d) S22 Vs Frequency**

**Fig.4 COMSOL Multiphysics FBAR Simulation Result**

The peak resonance in the admittance curve shown in Figure (4)(b) was determined using the eigen-frequency. The fundamental resonance, mode shape, S11 Fig (4)(c), S22, Fig (4)(d) and finally the quality factor was obtained using COMSOL to simulate the chosen dimensions and materials [2]. Aluminium scandium Nitride (AlScN) based FBAR devices with fundamental frequency of 5 GHz was simulated. COMSOL Multiphysics generated a quality factor plot Fig (4)(a) was extracted using the Eigen-frequency. The fundamental resonance, mode shape, S11, Q with a value of around 1490. The admittance curve was used to confirm the resonant frequency. Figures 4(c) and 4(d) show these plots in relation to frequency, respectively.

To calculate the BVD model parameters, FBAR parameters such as the series resonant frequency, parallel resonant frequency, quality factor, and dimensions were extracted as shown in fig 3. Table 1 Illustrates the component values within the MBVD model of the designed FBAR, with parameter values extracted through the use of ADS software. The tuning of circuit component values in ADS was performed to achieve a resonant frequency of 5 GHz.

**Table 1** Circuit parameters of MBVD model for proposed FBAR

| Parameter | Values |
|---|---|
| Rm | 0.0718 [fF] |
| Lm | 17.912 [µH] |
| Cm | 387.04 [Ω] |
| C0 | 1.274 [fF] |

Scattering parameters were plotted using ADS. They are displayed in fig. 5 given below.

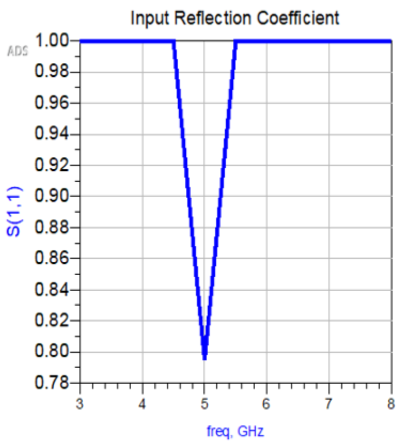



**Fig. 5. (a)Simulated S11 of proposed FBAR**

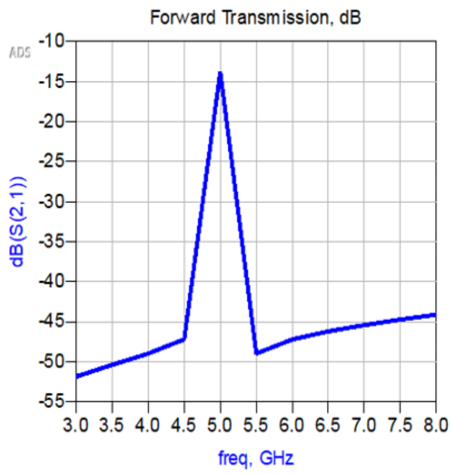



**Fig. 5 (b) Simulated S21 of proposed FBAR**

## IV. MICRO-FABRICATION PROCESS STEPS

P-type silicon wafer of <100> orientation with 4-7 Ω-cm. Preparation of 2% HF:192 ml DI water+8 ml of (49%) HF.RCA 1: Take 180 ml of DI water+25 ml $NH_4OH$+50 ml $H_20_2$, Heat for 5 minutes. Add 50 ml $H_20_2$ and heat for 8 minutes, cool for 12 minutes and give 30 seconds HF Dip. RCA 2: Take 180 ml of DI water+25 ml HCl+50 ml H202 Heat for 5 minutes Add 50 ml $H_20_2$ and heat for 3 to 6 minutes, cool for 12 seconds HF Dip. On RCA Cleaned wafer first level lithography for cavity followed by TMAH etching, deposition of SiO2(200nm) using Dielectric sputtering in the cavity. Sputtering of Al-AlScN-Al of 100nm-150nm-100nm followed by etching. A spacer layer is deposited using SiO2.At the end Removal of SiO2 from Cavity using BHF dip as shown in fig.6.

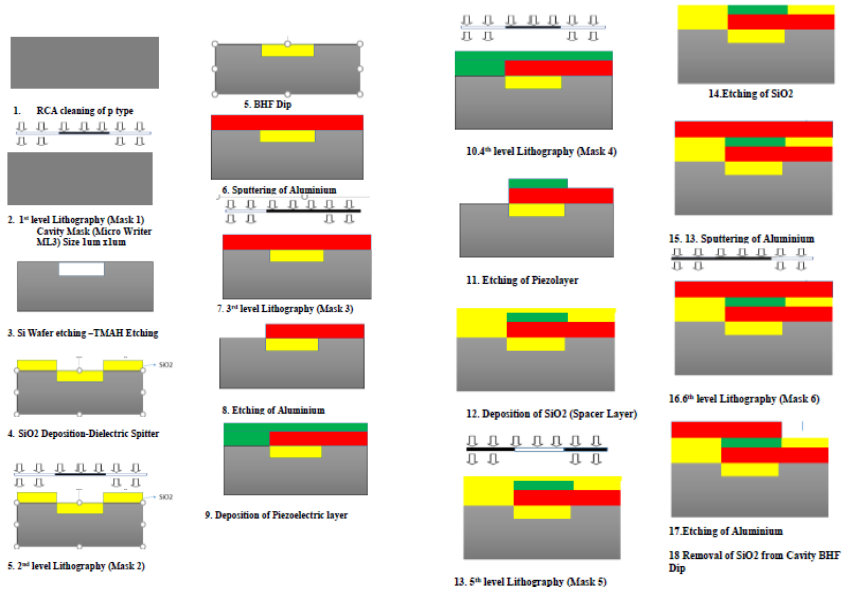



**Fig. 6. Process Flow for Fabrication of FBAR**

## V. Results and Discussions

In this work, a thin film bulk acoustic resonator is designed and simulated to operate at a resonant frequency of 5 GHz. The modeling and simulation of the resonator is carried out using COMSOl Multiphysics and Advanced Design System (ADS) software. Aluminium scandium Nitride (AlScN) is used for the piezoelectric film because of its high acoustic velocity, with an aim to achieve a high-quality factor. The Q factor is found to be 1490 for the proposed design.

RF circuit designs must provide efficient power transfer from source to load. The circuit must be created to be stable even in the worst-case scenarios. In RF networks, it is important to optimize the power flow from source to load so that there are as few power losses as possible under operational conditions. Through the examination of scattering parameters (S-parameters), the stability of an RF circuit is determined. The results obtained using ADS show that the input port radiates ideally at 5 GHz, where S11 = -1.94dB Thus, all the power at port 1 is reflected at 5 GHz. Hence, the achieved results show that the designed FBAR can act as a high selectivity filter at 5 GHz.

## VI. Conclusion

Significant efforts are carried out to advance filter technology within the 5G frequency spectrum. The primary objective is to simplify the RF Front End Module utilized in smartphones, thereby enhancing selectivity. This study introduces a high-frequency, high-Q thin film bulk acoustic wave resonator, utilizing Aluminum Scandium Nitride (AlScN) piezoelectric material, designed specifically for 5G applications. The results indicate efficient resonance of the device at 5 GHz, demonstrating a Q-factor of 1490. Such a high-resonance-frequency FBAR device presents promising advantages for 5G mobile technology.

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