# Effects of Thick Bottom Electrode on ZnO-based FBAR Devices

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## ABSTRACT

In this paper, the resonance characteristics of ZnO-based film bulk acoustic resonator (FBAR) devices with thick bottom electrode are investigated. The ultra-thin Cr film (300 Å-thick) between $SiO_2$ film and W film is formed by a sputtering-deposition in order to enhance the adherence at their interfaces. The resonance frequency of three different resonator devices was observed to be ~2.7 GHz, and the resonance characteristics ($S_{11}$) of the FBAR devices were found to have a strong dependence on the thickness of bottom electrode.

Keywords
FBAR, Bragg reflector, adhesion layer, quality factor

## Ⅰ. Introduction

The huge growth of wireless market has demanded more advanced mobile communication devices and systems. Also, the increasingly sophisticated electronic circuitry has needed various forms of aggressively scale-downed devices to meet the rigorous design requirements. With the rapid advancement of integrated circuits (ICs) technology, even more number of devices and components could be integrated together. This allows the printed circuit boards and other substrates to be further reduced in size. More recently, the ICs technology has been developed to the degree to which virtually entire systems can be integrated in one die or chip [1]. Furthermore, the dramatically rapid development of the wireless communication area has demanded more advanced brand-new filters with higher performance to protect receivers from undesirable adjacent channel interferences and noises. In general, the typical filters used in RF front-end of the commercial wireless handsets have mostly exploited the ceramic or surface acoustic wave (SAW) resonators. Unfortunately, neither of them is fully compatible with the standard IC-technology [2]-[3].

On the other hand, the film bulk acoustic resonator (FBAR) filter has recently attracted much attention as a promising next-generation novel filter technology mainly because it can be fully integrated with other CMOS/RFIC circuitry, potentially allowing for the realization of a single-chip radio or a transceiver in the future. With the use of this technology, not only the filter size can be further reduced but also the higher filter performance can be obtained. In other words, the film bulk acoustic wave resonator (FBAR) devices and their technology are expected to play an important role for the fabrication of the next generation radio-frequency (RF) filters. The FBAR devices basically exploit the acoustic resonant characteristics of the piezoelectric materials (AlN or ZnO films). Acoustic waves are about 5 to 8 orders of magnitude smaller than electromagnetic waves and thus, this allows for 5 to 8 orders of magnitude decrease in device size as compared to ceramic resonators without any significant sacrifice of device performances. Compared with the so-called surface acoustic wave (SAW) filters, the FBAR device filters are known to have smaller size and higher performance especially in power handling capability [4].

The typical FBAR device is composed of a thin piezoelectric film sandwiched between top and bottom conductors (electrodes). The devices must have the two acoustically reflecting surfaces in order to trap energy and produce a resonating characteristic. According to the type of reflecting surfaces, the FBAR devices can be classified into three groups. The first group is membrane structure back-etched type supported by the edge of the structure. The second one is an air-gap type with an air gap type under the resonator. The last is the solidly mounted-type which has a Bragg reflector part generally made up of multiple alternating layers of both low and high acoustic impedance materials [5].

In this paper, the effects of thick bottom electrode on the ZnO-based FBAR devices were investigated. Also, their resonance characteristics ($S_{11}$) and performance evaluations are presented.

## II. Experiment

The ZnO-based FBAR devices are made up of a piezoelectric ZnO film sandwiched between top and bottom electrodes (aluminum) deposited on 5-layer W/$SiO_2$ Bragg reflectors. Each layer of the Bragg reflectors has around quarter-wavelength thickness of the resonance frequency in order to acoustically isolate the piezoelectric layer part from the substrate. Moreover, the ZnO films, which play an important role in determining the characteristics of the FBAR in term of the piezoelectric property of piezoelectric films, were deposited to be a half-wavelength thickness of the resonance frequency. In accordance with the fabrication of each layer, various fabrication equipments were employed such as P5000 TEOS CVD, Metal Sputter, and E-gun evaporator. A 3-dimensional schematic of one-port 5-layer FBAR device is shown in Fig. 1. The 5-layer W/$SiO_2$ Bragg reflectors were fabricated by alternately depositing the tungsten (W) of high acoustic impedance material and $SiO_2$ films of low acoustic impedance material on a 4-inch Si wafer. With P5000 TEOS CVD, the $SiO_2$ films (0.6 μm-thick) were deposited at 390 °C, under the operation pressure of 9 Torr and RF power of 350 W. On the other hand, the tungsten (W) films (0.57 μm-thick) were also deposited at room temperature and with RF power of 250 W by Metal Sputter. In addition, the Cr films (300 Å - thick) between $SiO_2$ film and W film were formed by deposition in a metal sputter in order to enhance the adherence at their interfaces. After depositing five layers ($SiO_2$/W/$SiO_2$/W/$SiO_2$) of Bragg reflectors, the Al bottom electrodes (1.2 μm-thick) were deposited on the 5-layer Bragg reflectors in an E-gun evaporator with power supply of 5 kW. Furthermore, 1.2 μm-thick ZnO piezoelectric films were deposited on the bottom electrodes at room temperature for 100 minutes under an argon/oxygen gas mixture (2:1) of 10 mTorr and RF power of 260 Watts. Next, the top electrodes were patterned on the piezoelectric film using a conventional photolithography technique and Al (Al) top electrodes (0.2 μm-thick) were deposited. The three different top electrode patterns were completed by the lift-off processing to strip off the remaining PR layers. A cross-sectional SEM image of the thick bottom electrode on 5-layer Bragg reflectors of FBAR device and the resonator patterns of top electrode are shown in Fig. 2(a), (b). The return losses ($S_{11}$) of three resonators were measured by using the Network Analyzer-System Agilent HP 8510C and a probe station.

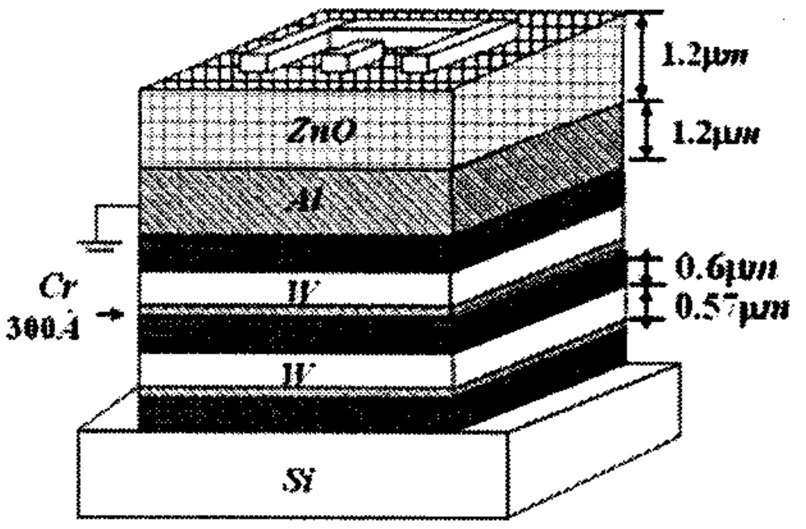

Fig.1 A 3-dimensional schematic of one port 5-layer FBAR device

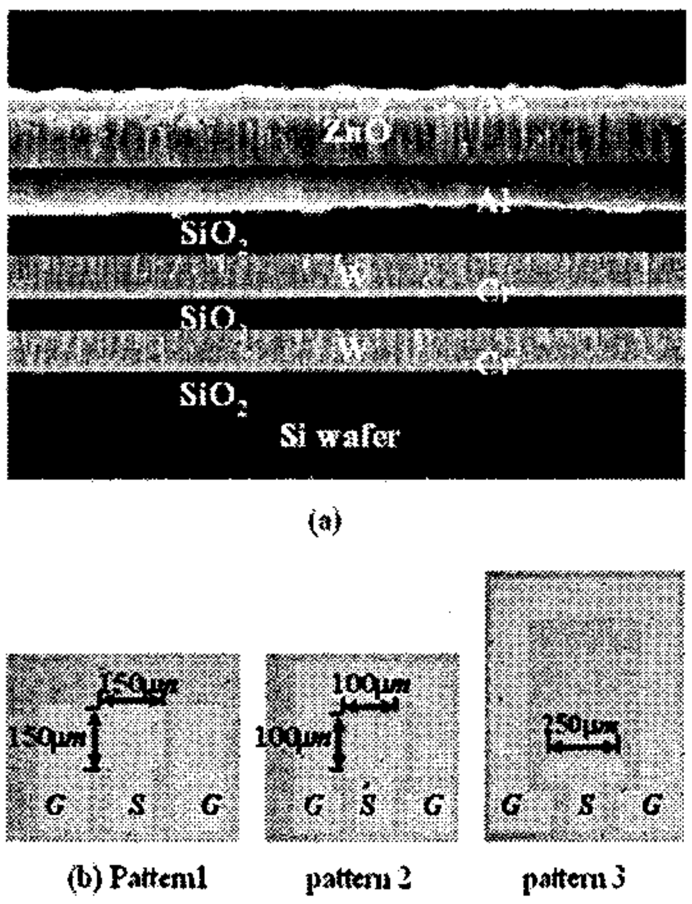

Fig.2 (a) Cross-sectional SEM image of Al-thick bottom electrode layer on 5-layer Bragg reflectors of FBAR device (b) Three different top electrode patterns of FBAR device

## III. Results and Discussion

For the different resonator patterns, the return losses ($S_{11}$) of 5-layer FBAR devices were shown in Fig. 3 and Table 1. The return losses of 5-layer Bragg reflectors were around -24.45 dB, -24.67 dB, -26.63 dB for patterns 1, 2, and 3 of top electrodes, respectively. The resonance frequency of three different FBAR devices was around 2.725 GHz.

Previously, the resonance characteristics of the ZnO-based FBAR devices have been investigated for various thermal-annealing conditions, ref. [7], where the thinner bottom electrode (0.3 μm-thick) was deposited on the 7-layer Bragg reflector. In case of non-annealing process (meaning that no thermal annealing treatment are used), the return losses of three different devices were below -10 dB and their resonance frequency was around 1.78 GHz. Based on this finding, the use of the thick bottom electrode in FBAR devices appears to further improve the resonance characteristic ($S_{11}$) and increase the resonance frequency.

The measured S-parameters indicate that the FBARs may be used for the application of 2.7~3 GHz broadband WiMAX (worldwide interoperability for microwave access) that has been demonstrated to have its high potential not only to bridge the gap between fixed and mobile access but also to offer the same subscriber experience whether on a fixed or a mobile network. Currently, the 2.3~3.6 GHz band assignment for the WiMAX application is being considered as one of the best choices for mobile broadband deployments as it has been widely reserved for mobile services [8].

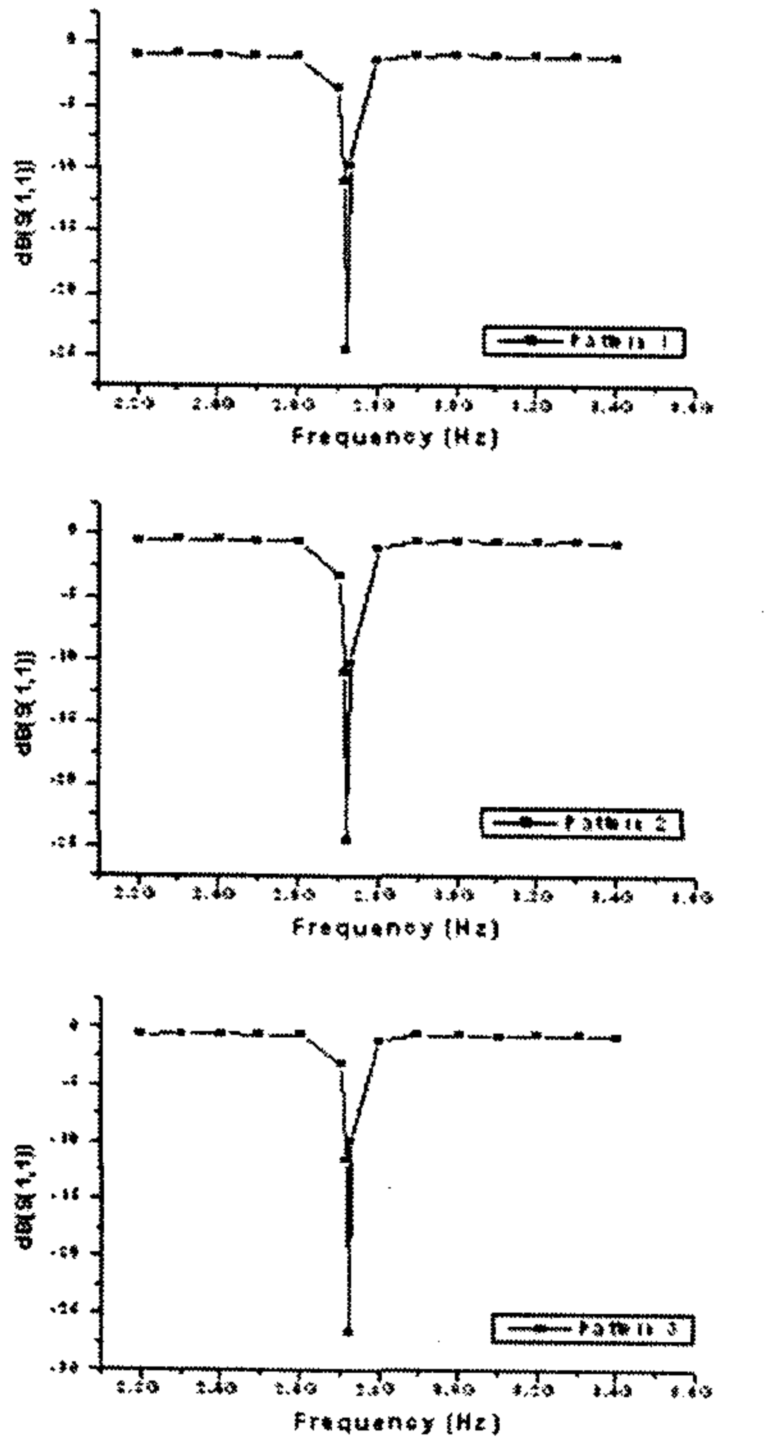

Fig. 3 Return loss $S_{11}$ measurement results for three different resonator patterns

On the other hand, the Cr adhesion layer between $SiO_2$ and W layers was formed by deposition to enhance the adherence between the tungsten (W) and $SiO_2$ films. In spite of the additionally formed Cr layers, no significant deterioration in device performance was observed. From this perspective, FBAR devices without adhesion layers may have some imperfect adhesions at the interface between the physically deposited films, possibly leading to the degradation in the device performance. However, the use of Cr adhesion layers seems to enhance the adhesion quality between $SiO_2$ and W layers in the Bragg reflectors, eventually leading to improvements of resonance characteristics [6].

In order to estimate the resonator performance, $Q_{s/p}$ is used as a figure of merit (FOM). The series/parallel quality factor ($Q_{s/p}$) is a measure of loss within the device. This 'loss' can result from various reasons such as ohmic resistance in the electrodes, acoustic loss within the acoustic stack, scattering of the acoustic waves from rough surfaces or grain boundaries, and acoustic radiation into the surrounding area of the device. Therefore, quality factor impacts the insertion loss and the width of the transition band. In accordance with the empirical definition that uses the local extrema in the slope of the input impedance phase ($\angle Z_{IN}$), the series/parallel resonance frequency and the slop of $\angle Z_{IN}$ versus frequency are obtained.

$$Q_{s/p} = \frac{f_{s/p}}{2} \left| \frac{d\angle Z_{IN}}{df_{s/p}} \right| \qquad (1)$$

where the $\angle Z_{IN}$ is the input impedance phase and $f_{s/p}$ are the series and parallel resonance frequencies, respectively [6]. The calculated series and parallel Q-factor values for FBAR resonators with three different patterns are tabulated in Table 2. Fig. 4 represents the slope of input impedance phase ($\angle Z_{IN}$) as a function of the frequency, plotted for the resonator pattern 1, 2, and 3 of 5-layer Bragg reflector on the FBAR devices.

Table 1. Return loss measurement results for three different patterns

| Return loss | $S_{11}$[dB] |
|---|---|
| Pattern 1 | -24.45 |
| Pattern 2 | -24.67 |
| Pattern 3 | -26.63 |

Table 2. Series and parallel Q factors for three different patterns

| Q-factor | $Q_s$ | $Q_P$ |
|---|---|---|
| Pattern 1 | 5724 | 5520 |
| Pattern 2 | 7195 | 5232 |
| Pattern 3 | 6204 | 5678 |

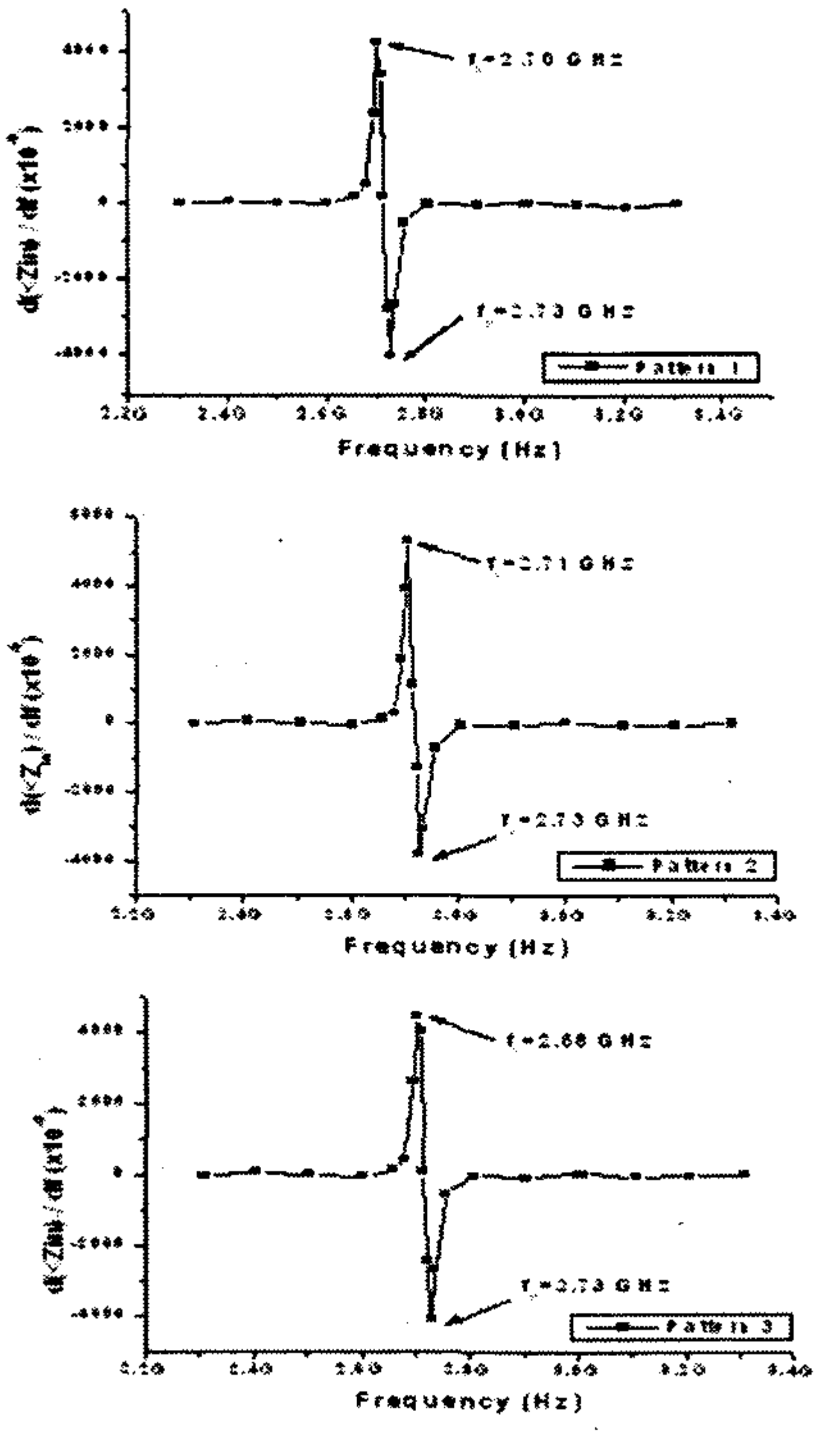

Fig. 4 Slope of $\angle Z_{IN}$ as a function of the frequency for the resonator pattern 1, 2, and 3.

## Ⅳ. Conclusion

The resonance characteristics of the SMR-type ZnO-based FBAR resonators were investigated for various resonator patterns. Based on comparison of the return loss ($S_{11}$) and $Q_{s/P}$ factors for different resonator devices, the resonance characteristics ($S_{11}$) appear to have a strong dependence on the thickness of bottom electrodes. The use of thick bottom electrode will be helpful to fabricate the FBAR devices for the mobile broadband WiMAX applications.

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