Effects of Multi-layer Bragg Reflectors 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 high-quality multi-layer reflectors are proposed. The ultrathin 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 was observed to vary with the number of the reflectors. This seems to be attributed to the change in the effective thickness of the ZnO film. Also, increasing the number of layers has led to a significant improvement of the series/parallel quality factor.

KEYWORDS

FBAR, adhesion layer, resonance characteristic, return loss(S_{11}), quality factor(Q)

Ⅰ. INTRODUCTION

The rapid expansion of the wireless market has led to a huge growth of more advanced mobile communication systems. Especially, miniaturized mobile phones have been developed that have multi-functions with higher operating frequencies. Complying with the recent trends, there has been a great demand particularly for ultra-miniaturization and monolithic integration of RF filters as one of core components in mobile communication systems. Typical filters used in RF front-end for commercial wireless handsets are ceramic or surface acoustic wave (SAW) resonators. However, neither of them is compatible fully with standard IC-technology [1].

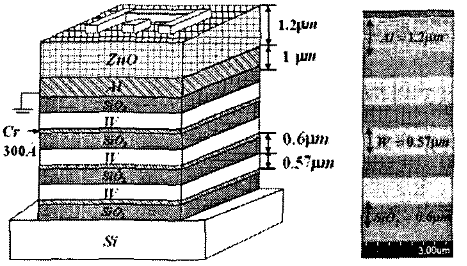
Film bulk acoustic wave resonator (FBAR) devices and their technology can play an important role for the fabrication of the next generation radio-frequency (RF) filters. FBAR devices basically utilize the acoustic resonant characteristics of piezoelectric materials such as AlN or ZnO. Acoustic waves are about 5 to 8 orders of magnitude shorter than electromagnetic waves, thus resulting in significantly reduced device sizes. 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, FBAR device filters also have smaller size and higher performance especially in power handling capability [2, 3].

The typical FBAR device is composed of a thin piezoelectric film sandwiched between two top and bottom conductors (electrodes). The devices must have two acoustically reflecting surfaces in order to trap energy and produce a resonating characteristic. According to the type of reflecting surfaces for FBAR devices, the solidly mounted-type is having a Bragg reflector part which is made up of alternating layers of both low and high acoustic impedance materials.

In this paper, we present the effects of the multi-layer Bragg reflectors on the ZnO-based FBAR devices. As a result, the resonance characteristics (S_{11}) of the ZnO-based FBAR devices were found to have a strong dependence on the number of layers of Bragg reflectors.

Ⅱ. EXPERIMENT

The ZnO-based FBAR devices are made up of piezoelectric ZnO film sandwiched between the top (Co) and bottom electrodes (Al)



(a) (b)

Fig. 1 (a) 3-dimensional schematic of one port 7-layer FBAR device (b) Cross-sectional SEM image of Al bottom electrode layer on 7-layer Bragg reflectors of FBAR device

deposited on the multi-layer W/SiO_2 Bragg reflectors. Each layer of 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 were deposited to be half-wavelength thickness of the resonance frequency. According to the fabrication of each layer, various machines were employed such as P5000 TEOS CVD, Metal Sputter, and E-gun evaporator. The multi-layer W/SiO_2 Bragg reflectors were fabricated by alternately depositing tungsten (W) and SiO_2 films on a 4-inch Si wafer. With P5000 TEOS CVD, the SiO_2 films of 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 of 0.57 μm-thick were also deposited at room temperature, RF power of 250 W by Metal Sputter. In addition, the Cr films of 300 Å-thick between SiO_2 film and W film were deposited by Metal Sputter in order to enhance the adherence at their interfaces. After depositing three layers (SiO_2/W/SiO_2) of Bragg reflectors, the substrate wafer was divided into two pieces in order to go through different processes. That is, one of them is used for 3-layer (SiO_2/W/SiO_2), the other is used for 7-layer (SiO_2/W/SiO_2/W/SiO_2/W/SiO_2). It was to figure out the effects of the number of layers on Bragg reflectors. Then, the Al bottom electrodes of 1 μm-thick were deposited on the 3-layer and 7-layer Bragg reflectors, respectively, in an E-gun evaporator with power supply of 5 kW. A 3-dimensional schematic of one-port 7-layer FBAR device and a cross-sectional SEM image of Al bottom electrode on 7-layer Bragg reflectors of FBAR device are shown in Fig. 1. 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 0.2 μm-thick of Cobalt (Co) top electrodes were deposited. The four different top electrode patterns were completed by the lift-off processing to strip off the remaining PR layers. For experiment measurements, the return losses (S_{11}) of four resonators were measured by using Network Analyzer-System Agilent HP 8510C and a probe station.

III. RESULTS AND DISCUSSION

In this work, according to the number of layers of Bragg reflectors, the return losses (S_{11}) between 3-layer Bragg reflectors and 7-layer Bragg reflectors were compared in Fig. 2 and Table 1. A significant improvement of the return loss is shown in the 7-layer Bragg reflectors. The return losses of 7-layer Bragg reflectors were around -21.92dB, -20.44dB, -20.02dB, and -24.32dB, while those of 3-layer Bragg reflectors were around -17.63dB, -16.31dB, -14.08dB, and -14.31dB. The return losses of 7-layer Bragg reflectors are around 4.29dB, 4.13dB, 5.94dB, and 10.01dB better than those of 3-layer Bragg reflectors for patterns 1, 2, 3, and 4 of top electrodes. In case of 3-layer Bragg reflectors, the resonance frequency of four different FBAR devices was around 2.893GHz. However, the resonance frequency increased to around 2.9GHz in 7-layer Bragg reflectors. It is shown that the number of layers of Bragg reflectors could affect the resonance frequency. From the above measurement results, it is believed that the resonance characteristics of FBAR devices can be significantly improved in terms of return loss (S_{11}) by 7-layer Bragg reflectors.

On the other hand, the Cr adhesion layer between SiO_2 and W was deposited to enhance the adherence between the tungsten (W) and SiO_2 films. In spite of the additional Cr layer, there has been no significant deterioration in device performance. As a result, it is speculated that FBAR devices without adhesion layers may have some physical imperfections in the film microstructures and some imperfect adhesions at the interface between the physically deposited films, possibly degrading the device

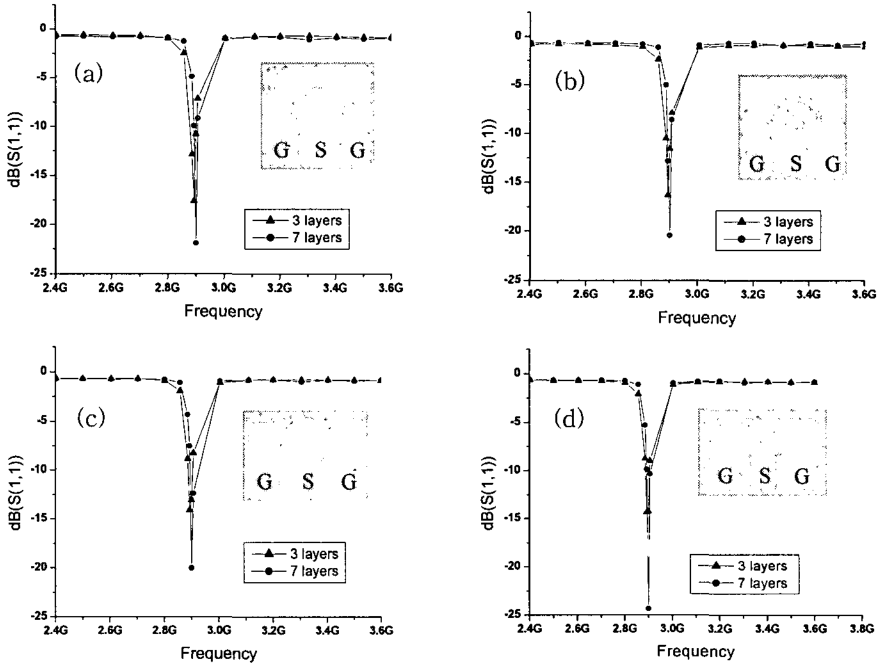


Fig.2 Top electrode patterns and return loss S_{11} measurement results for the comparison between 3-layer and 7-layer Bragg reflectors.
(a) Pattern 1 (b) Pattern 2 (c) Pattern 3 (d) Pattern 4

performance. However, Bragg reflectors, which accompany the adhesion layers, may reduce any possible existing imperfect microstructures in the Bragg reflectors, eventually leading to improvements of resonance characteristics [4].

In order to estimate the resonator performance, $Q_{s/p}$ is used as a figure of merit (FOM). Series/parallel quality factor ($Q_{s/p}$) is a measure of loss within the device.

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

where, the $\angle Z_{iN}$ is the input impedance phase and $f_{s/p}$ are the series and parallel resonance frequencies, respectively [5]. The calculated series and parallel Q-factor values for FBAR resonators with four different patterns are tabulated in Table 2. Series and parallel quality factors of 7-layer Bragg reflectors were significantly improved.

Ⅳ. CONCLUSION

The resonance characteristics of the ZnO-based SMR-type FBAR resonators were comprehensively investigated for various multi-layer Bragg reflectors. Return loss (S_{11}) and $Q_{s/p}$ factors could be considerably improved, especially in the devices with 7-layer Bragg reflectors. This approach will be very useful for the future FBAR device applications.

Table 1. Return loss measurement results for four different patterns

S_{11}	3-layer	7-layer
Pattern 1	-17.63dB	-21.92dB
Pattern 2	-16.31dB	-20.44dB
Pattern 3	-14.08dB	-20.02dB
Pattern 4	-14.31dB	-24.32dB

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

	3-layer		7-layer	
	Q_s	Q_P	Q_s	Q_P
Pattern 1	5044	4396	7054	11220
Pattern 2	4163	4988	11292	12086
Pattern 3	2795	3006	10746	11383
Pattern 4	3456	3259	13208	10436

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