Thermal Improvements for 2.75 GHz-FBAR Devices

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ABSTRACT

In this paper, we studied a ZnO-based film bulk acoustic wave resonator (FBAR) device fabricated on top of a novel multi-layered Bragg reflector with chromium adhesion layers (0.03μm-thick) inserted. The performance of FBAR device could be significantly improved using proper thermal treatments. At ~2.75 GHz, we could achieve good return loss and quality factor (Q). This device fabrication technique will be useful for the future mobile WiMAX applications.

Keywords

FBAR, Bragg reflector, adhesion layer, post-annealing, quality factor, WiMAX

I. Introduction

Recent technological innovations have shown a great promise for mobile broadband users. The WiMAX broadband wireless access technology, based on the IEEE 802.16 standard, is at the origin of great promises for many different markets covering fixed wireless internet access, backhauling and mobile cellular networks. Currently, the 2.3-3.6 GHz band assignment for WiMAX is considered as one of the best choices for the transmission of multimedia services (voice, Internet, email, games and others) at high data rates [1]. Therefore, new bandpass filters may be required that are smaller, consume less power, have lower insertion loss and operate at higher frequencies. The thin film bulk acoustic wave resonator (FBAR) technology has the capabilities needed to achieve these requirements simultaneously. The FBAR are one of the resonant piezoelectric devices, similar to the bulk acoustic resonators such as quarts, but scaled down to resonate at few GHz frequencies. Typical FBAR comprises a piezoelectric film sandwiched between top and bottom electrodes. When RF signal is applied across the device, it produces a resonance [2]. Based on the thin film techniques, FBAR devices are classified into three groups [3]. The first is membrane structure back-etched type supported by the edge of the substrate, the second one is an air-gap type having an air gap under the resonator, and the last is a solidly mounted resonator (SMR)-type with a Bragg reflector (BR). In SMR-type, the BR can act as a mirror to isolate a possible energy loss from piezoelectric layer into the substrate, enabling the FBAR device to have high quality factor (Q). A high quality BR fabrication will be critical to yield high-Q devices. Conventionally, the BRs for the SMR-type FBAR devices have been fabricated by alternatively depositing both high and low impedance materials. Even though some studies [4, 5] have been done to improve the FBAR characteristics, few have been reported on the methods to improve the quality of the tungsten/silicon dioxide (W/SiO_2) multilayer BRs, and also to the best of our knowledge, no studies have been reported on the effects of the thermal annealing on the resonator performances at ~2.75 GHz regime.

In this paper, we present a combined technique to improve the resonance characteristics by inserting Cr adhesion layers into W/SiO_2 multilayer and performing thermal annealing treatments. As a result, the resonance frequency peaks were observed to improve at ~2.75 GHz and also excellent resonance characteristics were obtained in terms of return loss and Q-factors.

II. Experiment

Fig. 1 shows the schematic structure and cross-sectional SEM image of the FBAR device fabricated in this work. The FBAR device consists of a multi-layered BR on Si substrate and a piezoelectric (ZnO) film positioned between the top and bottom Al electrodes. The bottom electrode was also designed to act as a floating ground plane with a thickness of 1.2μm. The FBAR devices were prepared as follows. First, a multi-layered BR was prepared by sequentially depositing several thin film layers of SiO_2, Cr, W, SiO_2, Cr, W, and SiO_2. SiO_2 layers (0.6μm-thick) were deposited by a chemical vapor deposition technique. Cr (0.03μm-thick) and W (0.6μm-thick) layers were deposited using a sputtering technique. Then, 1.2μm-thick Al bottom electrode was deposited on Si wafer, followed by 1.2μm-thick ZnO film deposition. Subsequently, the Si wafer was divided into five samples (S1 to S5). In order to investigate the thermal treatment effects, four samples (S2 to S5) were thermally treated under various annealing conditions, whereas the sample S1 was not thermally treated in order to use it as a reference sample. The deposition and patterning of the top Al electrodes (0.2μm-thick) on the ZnO film completed device fabrication. Then, four samples (S2 to S5) were post-annealed at 220, 240, 260, and 280℃, respectively for 120 minutes in argon (Ar) ambient of an electric dehydrate furnace. Here, two different resonator layout patterns (1 and 2) were designed for second order resonance at ~2.7 GHz. The return loss (S_{11}) characteristics were extracted from all the fabricated resonators by using a probe station and Hewlett Packard 8722D network analyzer.

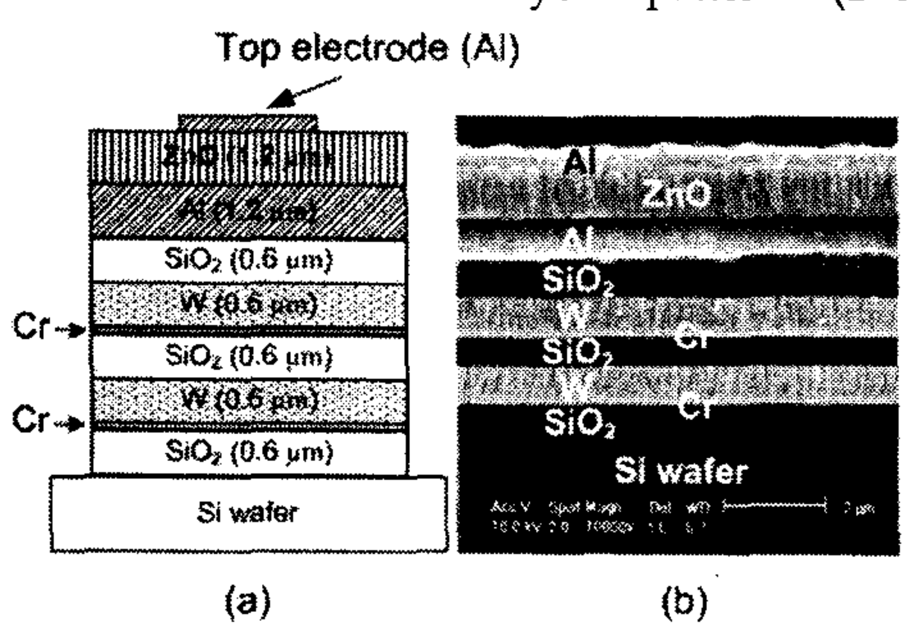

Fig. 1 FBAR device structure
(a) Schematic view
(b) Cross-sectional view of SEM image

III. Results and Discussion

Fig. 2 illustrates the comparison of return loss characteristics measured from two resonator patterns 1 and 2 for various thermal annealing conditions. The S_{11} values of the post-annealed resonator samples (S2 to S4) samples show the same increasing trend in comparison with the S_{11} of the resonator sample (S1) up to 260℃ annealing temperature. But at higher temperatures (> 260℃), the S_{11} values of all those resonators were quickly dropped (resonators on S5 sample case). Clearly, there is an optimum post-annealing temperature (260℃/120 minutes) for the enhancement of the S_{11} value. At the optimum post-annealing condition, the S_{11} values were -35.52 dB and -37.55 dB for the resonator patterns 1 and 2, respectively. All the extracted S_{11} values were summarized in Table 1. Reportedly, the quality of the multi-layered Bragg reflector may have an impact on the FBAR characteristics [4, 5]. In the as-deposited

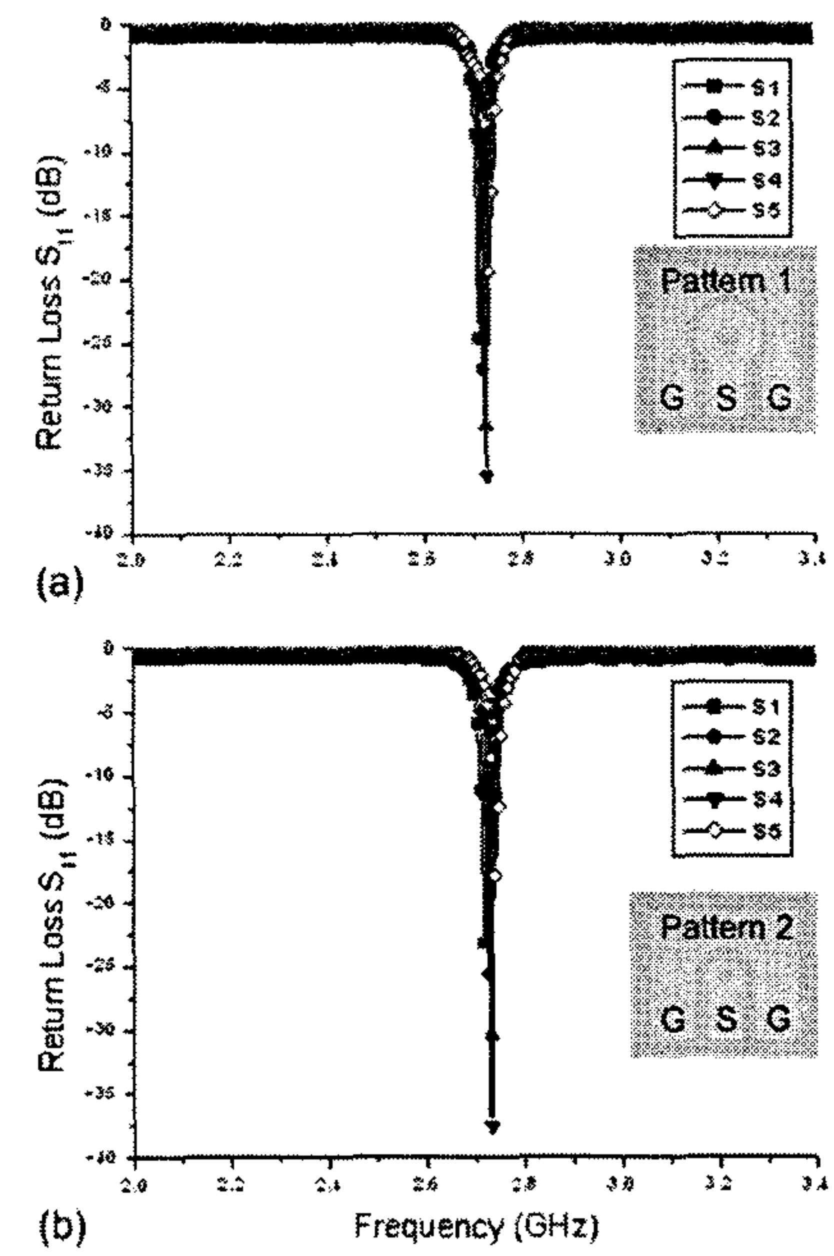

Fig. 2 Return loss characteristics versus frequency for various post-annealing conditions.
(a) Pattern 1 (b) Pattern 2

Table 1. Return loss values of five resonator samples with different patterns

Sample	Return loss S_{11} (dB)	
	Pattern 1	Pattern 2
S1 (non-annealing)	-24.67	-23.20
S2 (post-annealing 220℃)	-27.05	-25.59
S3 (post-annealing 240℃)	-31.59	-30.40
S4 (post-annealing 260℃)	-35.52	-37.55
S5 (post-annealing 280℃)	-19.41	-17.84

SiO_2/W multi-layered BR, some physical defects may exist and/or some poor adhesions may occur at interfaces between the physically deposited films, hence degrading the device performance. The adhesion issues here can be resolved by inserting very thin adhesion layers between W and SiO_2 layers in the multi-layered BR. The adhesion layers were additionally deposited films to enhance the adhesion property between W and SiO_2 layers, and they were observed to have no deleterious effects on the BR structures or properties. The chromium (Cr) is one of the most widely used materials for the adhesion enhancement in thin-film technology [6]. In this work, the Cr adhesion layer is considered a reasonably good choice for the improvement of the adhesion between the W layer and SiO_2 layer, sputter-deposited. The Cr layer is deposited not only due to its good bond-forming abilities, but also due to its having the same crystal structure as W material of the body-centered cubic (bcc) structure. Thus, the additionally inserted Cr layer with very thin films (0.03 μm-thick) is expected to considerably improve the multi-layered BR quality.

Post-annealing processes clearly appear to improve the resonance characteristics of the three samples (S2 to S4). It is speculated that the sandwiched structure of the as-deposited multilayers (Al/ZnO/Al) may have some physical imperfections, such as incomplete adhesions and micro-defects in the film itself. The proper post-annealing process is believed to eliminate or reduce the physical imperfections occurring during the thin-film depositions, leading to the improvement of the FBAR device performances.

Performance of FBAR devices can be

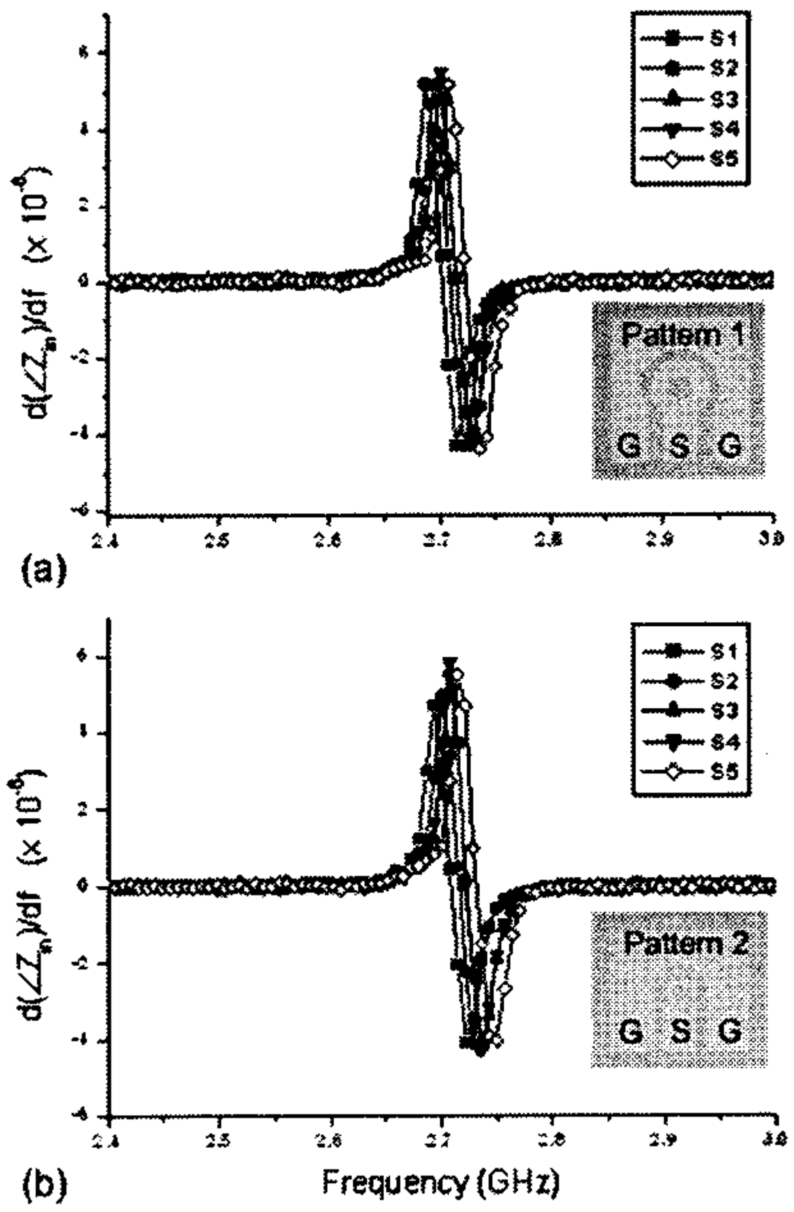

Fig. 3 Slope of input impedance phase (∠ Z_{in}) versus frequency. (a) Pattern 1, (b) pattern 2

determined by the figure of merit (FOM) in terms of Q-factor [7]. Based on the definition reported [8], the series/parallel resonance Q-factors ($Q_{s/p}$) can be calculated and shown in Table 2. Fig. 3 represents the slopes of the input impedance phase (∠ Z_{in}) as a function of frequency for the two resonator patterns. Finally, the fabricated FBAR devices were observed to resonate at 2.75 GHz with excellent return loss and high Q-factors. Thus, the FBAR devices can be used for the broadband mobile WiMAX applications.

Table 2. Series/parallel $Q_{s/p}$-factors for the resonator samples

Sample	Pattern 1		Pattern 2	
	Q_s	Q_p	Q_s	Q_p
S1	6946	5817	6359	5540
S2	6945	5857	6727	5595
S3	7207	5841	7537	5590
S4	7429	5785	7899	5895
S5	7008	5983	7468	5549

Ⅳ. Conclusion

In this paper, we present the FBAR devices fabricated on top of the SiO_2/Cr/W multilayer Bragg reflector. Their resonance characteristics were investigated for various post-annealing treatments. With a process optimization, excellent return loss and Q-factors were achieved at the resonance frequency of ~2.75 GHz.

Acknowledgement

This work was supported by the ERC program of MOST/KOSEF (Intelligent Radio Engineering Center)

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