Improvement of Resonance Characteristics by Post-Annealing in FBAR Devices

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Abstract**—**This paper presents the resonance characteristics of the ZnO-based FBAR devices with multi-layered Bragg reflectors with Cr adhesion layer inserted between SiO_2 and W layers. Due to the post- annealing, the return loss (S_{11}) and series/parallel quality factor are significantly improved when compared with the non-post annealing. This post-annealing method seems to be a very efficient way to improve the resonance characteristics of FBAR devices.

Index Terms—FBAR, return loss, quality factor, annealing.

I. INTRODUCTION

Recently, the rapid development of wireless communication area has demanded more advanced brand-new filters with higher performance to protect receivers from undesirable adjacent channel interferences and noises. The currently existing communication components need to be further scaled down and more compatibly integrated into a small chip. On the other hand, film bulk acoustic resonator (FBAR) filter has attracted much attention as a possible next-generation novel filter technology mainly because it can realize a high performance as well as a smaller size, and also 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 [1].

The typical FBAR device is composed of three basic parts such as two electrodes, a thin film piezoelectric, and two acoustically reflecting surfaces. The reflecting surface is an important factor to affect the resonance characteristic of the FBAR devices. According to the reflecting surface, the FBAR is classified into three types. First one is a back-etched type supported by the edge of the substrate. Second one is a surface-micro-machined type with an air-gap under the resonator part. Last one is solidly mounted-type having a Bragg reflector part which may acoustically isolate piezoelectric material from the substrate [2, 3].

Several studies in order to improve resonance characteristics have been done by thermal annealings on Bragg reflectors just before the deposition of bottom electrode [4, 5] and also on the resonator immediately after the deposition of top electrode [6]. In this paper, three kinds of processes such as non-annealing, post-annealing (200 °C/1 hour), and the other post-annealing (200 °C/2 hours) are used. As a result, the thermal annealing was found to improve the resonance characteristic (S_{11}) of the ZnO-based FBAR devices with 5-layered Bragg reflectors.

II. EXPERIMENT

In this experiment, the ZnO-based FBAR devices are composed of the piezoelectric ZnO film sandwiched between the top and bottom electrodes (Al) deposited on 5-layered W/SiO_2 Bragg reflector. In order to fabricate each layer, various kinds of machines were employed such as P5000 TEOS CVD, Metal Sputter, and E-gun evaporator. The 5-layered W/SiO_2 Bragg reflectors were fabricated by alternately depositing tungsten (W) and SiO_2 films on a 4-inch Si wafer. Each layer has around quarter wavelength thickness of the resonance frequency in order to acoustically isolate the piezoelectric layer part from the substrate. By using P5000 TEOS CVD with deposition rate of 153 Å/sec, the SiO_2 films of 0.6 µm-thick were deposited at 390 °C, under 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, RF power of 250 W and deposition rate of 100 Å/min 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. Then, the Al bottom electrodes of 1 µm-thick were deposited on the 5-layered Bragg reflector in an E-gun evaporator with power supply of 5 kW and deposition rate of 10 Å/sec. Then, 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. The ZnO films were deposited to be half wavelength thickness of the resonance frequency. A 3-dimensional schematic of one-port FBAR resonator is shown in Fig. 1(a). For device fabrications, the substrate wafer with the bottom electrode on Bragg reflector was segmented into three

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small samples. The top electrodes were patterned on the piezoelectric film using a conventional photolithography technique and the deposition of 0.3 µm-thick top electrode (Al). The three different kinds of the top electrode patterns were completed by the lift-off processing to strip off the remaining PR layers. The top electrode patterns of FBAR resonators are shown in Fig. 1(b). For the non-annealed samples, the return losses (S_{11}) of three resonators from one of the three samples were measured by using Network Analyzer-System Agilent HP 8510C and a probe station.

On the other hand, one of the remaining two samples on Bragg reflector was annealed in electronic dehydrate furnace at 200 °C for one hour and the other one was annealed at the same temperature for two hours. Thus, for the three FBAR devices fabricated under three different conditions, all the return loss (S_{11}) values were also extracted.

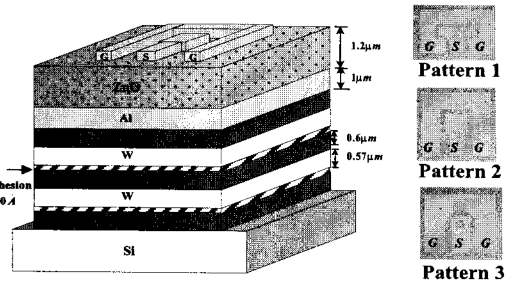

Fig. 1 (a) 3-dimensional structure of one-port FBAR resonator (b) top electrode patterns

III. RESULTS AND DISCUSSION

The return losses (S_{11}) of three FBAR devices after post-annealing were measured, respectively. In Fig. 2, 3 and Table 1, the return loss (S_{11}) measurements were plotted for the comparison of the annealing effects according to three different methods. In other words, measurement results of FBAR devices were obtained from the three different samples with non-annealing of sample 1, post-annealing (200 °C/1hour) of sample 2, and the other post-annealing (200 °C/2hours) of sample 3. First, the return losses (S_{11}) of three patterns were compared between sample 1 and sample 2 in Fig 2. A significant improvement of the return loss is shown in the sample 2. The return losses of sample 2 were around -22.69 dB, -28.28 dB, and -30.61 dB, while those of sample 1 were around -18.45 dB, -26.35 dB, and -26.68 dB. The return losses of sample 2 were around 4.24 dB, 1.95 dB, and 3.93 dB better than those of sample 1 for pattern 1, 2, and 3 of top electrodes. Also, the resonance frequency of three different FBAR devices was ~1.71 GHz. There was no significant variation in the resonance frequency in spite of post-annealing. Fig. 3 also shows the considerable improvement in return loss S_{11} of sample 3 by post-annealing (200 °C/2 hours) than sample 2. Return losses of the sample 3 were around -26.6 dB, -30.31 dB, and -31.31 dB, while those of sample 2 were around -22.69 dB, -28.28 dB, and -30.61 dB. That is, the return losses of sample 3 were around 3.91 dB, 2.03 dB, and 0.8 dB improved possibly due to the post-annealing at 200 °C for two hours. In spite of the post-annealing, there was no variation in the resonance frequency at 1.709 GHz. From 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 post-annealing at 200 °C for two hours.

Furthermore, 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 the non-annealed FBAR devices without adhesion layers may have some physical imperfections in the film.

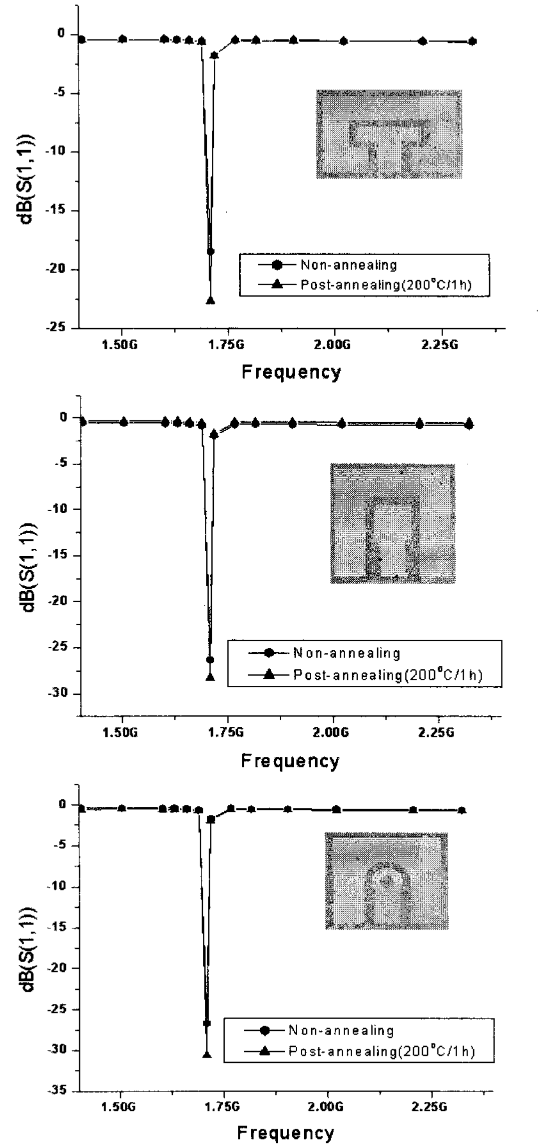

Fig. 2 Return loss S_{11} measurement results for the comparison between sample 1 and sample 2. (a) Pattern 1, (b) Pattern 2, (c) Pattern 3

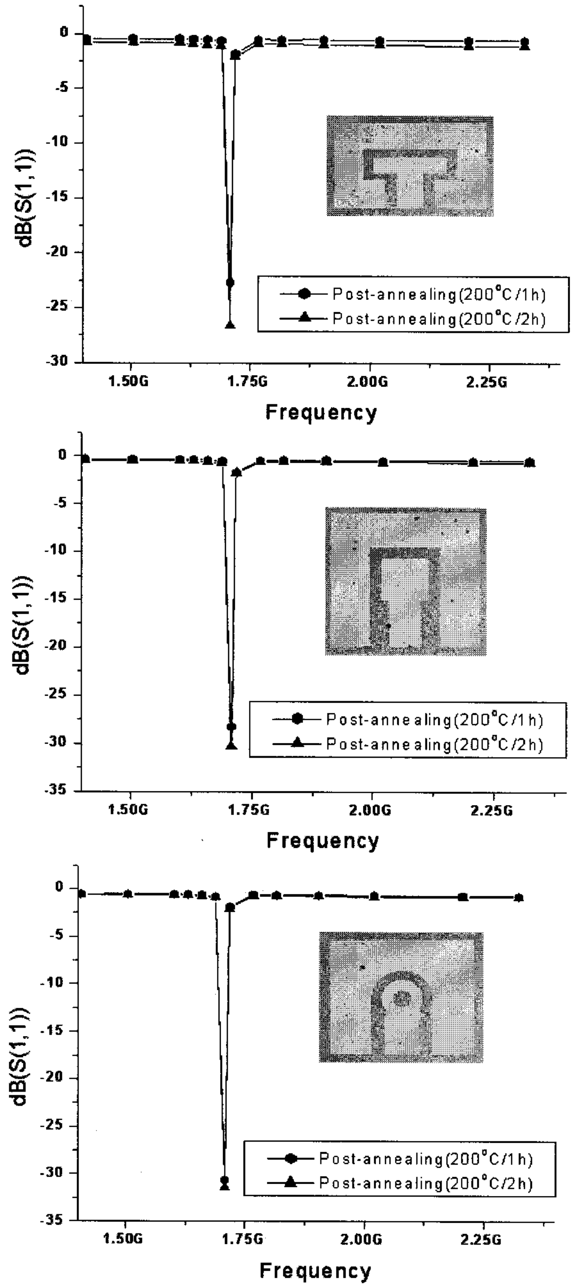

Fig.3 Return loss S_{11} measurement results for the comparison between sample 2 and sample 3. (a) Pattern 1, (b) Pattern 2, (c) Pattern 3

microstructures and some imperfect adhesions at the interface between the physically deposited films, possibly degrading the device performance. However, Bragg reflector, which accompanies adhesion layers as well as post-annealing process, may eliminate any possibly exiting 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 [7]. The calculated series and parallel Q-factor values for FBAR resonators with three different patterns are tabulated in Table 2. Series and parallel quality factors of three resonators annealed by post-annealing at 200 °C for two hours were significantly improved.

In [4], the effects of thermal annealing of W/SiO_2 multilayer Bragg reflectors of the ZnO-based FBAR devices are presented. Even though almost all steps of FBAR device fabrication were similar, the series and parallel quality factors of FBAR devices are very different. The use of Cr adhesion layer and 1 μm-thick Al electrode in this work seems to further improve the quality factors.

Table 1 Summary of the return loss measurement results for three different patterns.

Name	Pattern 1	Pattern 2	Pattern 3
Sample 1	-18.45dB	-26.35dB	-26.68dB
Sample 2	-22.69dB	-28.28dB	-30.61dB
Sample 3	-26.60dB	-30.31dB	-31.41dB

Table 2 Series and parallel Q factors for three patterns.

Sample Name	Pattern 1		Pattern 2		Pattern 3	
	Q_s	Q_p	Q_s	Q_p	Q_s	Q_p
Sample 1	6608	6405	6350	6214	6748	6469
Sample 2	7009	6608	6611	6227	6970	6574
Sample 3	7013	6745	6942	6339	7077	6587

IV. CONCLUSION

The resonance characteristics of the ZnO-based SMR-type FBAR resonators were investigated for various annealing methods such as non-annealing, post-annealing (200 °C/1h), and the other post-annealing (200 °C/2h). Return loss (S_{11}) and $Q_{s/p}$ factors could be considerably improved, especially by the post-annealing at 200 °C for two hours. This efficient approach will be very useful for the future FBAR device applications.

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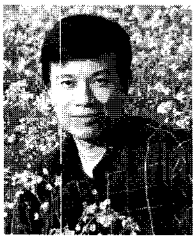

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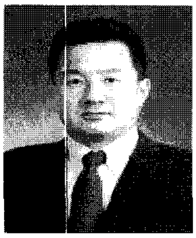

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