A New Technique to Improve ZnO-based FBAR Device Performances

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ABSTRACT

This paper presents the improvement of the resonance characteristics of film bulk acoustic-wave resonator (FBAR) devices fabricated on multilayer Bragg reflectors (BRs) based on inserting ultra-thin chromium (Cr) adhesion layers into BRs and post-annealing processes. The measurements show excellent improvement of return loss (S_{11}) and Q-factor by the combined use of Cr adhesion layers and thermal treatments particularly for 120 minutes at 200℃.

KEYWORDS

FBAR device, Bragg reflector, post-annealing, return loss S_{11}, Q-factor.

Ⅰ. INTRODUCTION

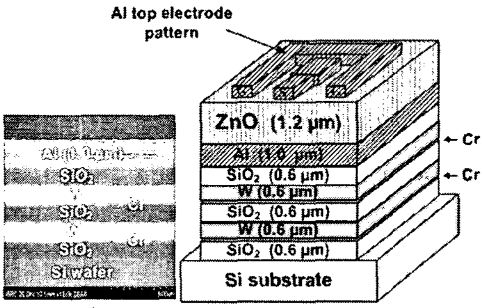
Wireless communications in the range from 0.5 GHz to 6 GHz has thrived in the last decade, leading to an explosion of demand for integration of frequency devices on a silicon wafer. FBAR devices seem very suitable for microwave monolithic integrated circuits (MMICs) mainly due to their high potential of being integrated with conventional Si or GaAs substrates [1]. FBARs are resonant piezoelectric devices, similar to bulk acoustic resonators such as quarts, but scaled down to resonate at GHz frequencies. Basic FBAR comprises a piezoelectric film sandwiched between a top and bottom electrodes. When an RF signal is applied across the device it produces a resonance [2]. Based on the thin film techniques, FBAR devices are classified largely 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 this SMR-type, the BR acts as a mirror to isolate a possible energy loss from piezoelectric layer to the substrate, enabling a FBAR device to have high quality factor (Q). A high quality BR fabrication may become critical to yield high-Q SMR-type FBAR devices. Conventionally, the BR for the SMR-type FBAR devices have been fabricated by alternatively depositing both high and low impedance materials. Despite some efforts [4-7] to improve the FBAR characteristics, few studies have been reported on the method to improve the quality of the tungsten/silicon dioxide (W/SiO_2) multilayer BR.

In this paper, based on the SMR-type ZnO-based FBAR devices, we proposed a new technique to improve the quality of W/SiO_2 multilayer BR on the resonance characteristics by inserting Cr adhesion layers into W/SiO_2 multilayer. In addition, several post-annealing processes were deployed to further enhance the FBAR device performances.

Ⅱ. EXPERIMENTS

In this work, the FBAR devices are prepared as follows: the multilayer BR of the FBAR device was formed by depositing thin film layers of SiO_2, Cr, W, SiO_2, Cr, W, and SiO_2 on

4-inch p-type (100) silicon wafer. The SiO_2 layer (0.6 μm-thick) was deposited by chemical vapour deposition (CVD) technique. The Cr (0.03 μm-thick) and W (0.6 μm-thick) layers were deposited by using a sputtering technique. Then, 1.0 μm-thick aluminum (Al) bottom electrode (as floating ground) was deposited on the wafer with the BR, followed by 1.2 μm-thick ZnO film deposition. Finally, the deposition and patterning of the top electrodes (0.2 μm-thick Al) on top of the ZnO film completed the FBAR devices fabrication. Fig. 1 shows the schematic structure of FBAR device and three resonator layout patterns (1, 2, and 3), in which the pattern 3 was used in [6] for comparison.



(a) (b)

Fig. 1 FBAR device structure
(a) cross section view SEM image of BR
(b) three-dimensional schematic

To investigate the thermal treatment (called post-annealing process) effects, the 4-inch wafer was divided into three samples (namely R1, R2, and R3). The two samples (R2 and R3) were thermally treated under different annealing conditions, while keeping the remaining one (R1) non-annealed in order to use it as a reference sample. The first post-annealing process was carried out on the R2 sample for 60 minutes at 200℃ in the ambient argon (Ar) using an electric dehydrate furnace (EDF). Similarly, the second post-annealing process was applied for R3 sample with the same thermal condition, but for 120 minutes.

The return loss (S_{11}) characteristics were extracted from three resonance patterns (Fig. 1(a)-1(c)) on each of the three samples (R1-R3) by using a probe station and Hewlet Packard/HP 8722D network analyzer.

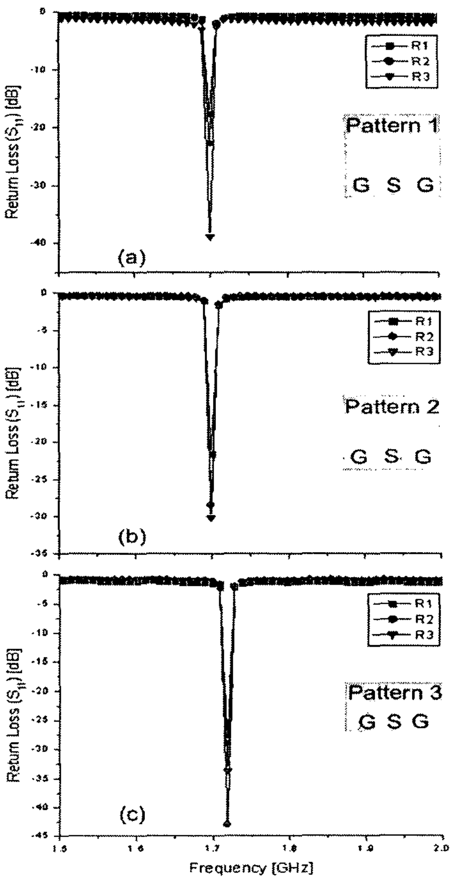


Fig. 2 Return loss characteristics versus frequency for various thermal processes.
(a) Pattern 1 (b) Pattern 2 (c) Pattern 3

III. RESULTS AND DISCUSSION

Fig. 2 shows the return loss characteristics versus frequency for various thermal annealing conditions. Fig. 2a compares the return loss characteristics of the FBAR devices with the resonator pattern 1 experienced non-annealing, the first post-annealing, and the second post-annealing processes. Similarly, Fig. 2(b) and 2(c) show the return loss characteristics of the FBAR devices with the resonance pattern 2 and 3, respectively. The S_{11} values of the two resonator patterns fabricated on R2 and R3 samples show the same increasing trend in comparison with that of resonators on R1. Undoubtedly, the post-annealing appears to be one of the most important factors to enhance the return loss characteristics. From Fig. 2(a), at the resonant point, the resonator on R1 sample has the smallest return loss value (S_{11} = -17.62 dB). Meanwhile, the return loss values of R2, R3 samples are -22.62dB and -38.51dB, respectively. All the extracted values S_{11} of the three resonator patterns are summarized in Table 1.

Table 1 Return loss values of three resonator samples with different patterns

Pattern \ Sample	Return loss S_{11} [dB]			
	R1	R2	R3	Ref. [6]
Pattern 1@1.69GHz	-17.62	-21.62	-28.88	—
Pattern 1@1.69GHz	-22.63	-28.41	-33.70	—
Pattern 1@1.72GHz	-38.51	-30.13	-43.06	-23.43

Reportedly [4, 7], the quality of BRs influences the FBAR characteristics. Within the as-deposited W/SiO_2 multilayer BR, there may exist some physical imperfections in the film microstructures and/or some imperfect adhesions at interfaces between the physically deposited films, thus degrading the device performances. The Cr adhesion layers were inserted into multilayer BR to enhance the adhesion between W and SiO_2 layers as well as the uniformity of the thin-films layers deposited for BR fabrication. The combination of both Cr adhesion layers and post-annealing is believed to effectively suppress any possibly existing imperfect microstructures and incomplete adhesions in the multilayer reflectors, eventually improving the resonance characteristics. In the FBAR devices, the use of Cr adhesion layers in Bragg reflectors seems to further improve device performances as compared to those without Cr adhesion layers [6].

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

Sample	Pattern 1		Pattern 2		Pattern 3	
	Q_s	Q_p	Q_s	Q_p	Q_s	Q_p
R1	6760	6696	6929	6738	6936	6897
R2	6846	6712	7073	6822	7039	6911
R3	7173	6979	7101	6845	7156	6981
Ref.[6]	—	—	—	—	4264	4961

The performance of FBAR devices can be determined by the figure of merit (FOM) [8] in term of Q-factor. Based on the definition reported in [9], the series/parallel resonance Q-factors ($Q_{s/p}$) were calculated and shown in Table 2. The resonators on the R3 sample, post-annealed for 120 minutes at 200℃, have the largest Q-factor values.

IV. CONCLUSION

In this paper, the combination of inserted Cr adhesion layers into multilayer BR and post-annealing processes was presented to improve the resonance characteristics of ZnO-based FBAR devices. The measurements show that the new technique appears to be very promising to enhance FBAR device performance.

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