

A Method to Improve Bragg Reflectors Quality in FBAR Devices

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Abstract—This paper presents some methods to improve the resonance characteristics of film bulk acoustic-wave resonator (FBAR) devices. The FBAR devices were fabricated on multilayer Bragg reflectors (BR) into which very thin chromium (Cr) adhesion layers were inserted, followed by several kinds of thermal annealing processes. These methods resulted in an excellent device improvement in terms of return loss and Q-factors.

Index Terms—Bragg reflector, FBAR, Q-factor, resonator, return loss

I. INTRODUCTION

With the rapid growth of wireless communications in the range from 0.5 GHz to 6 GHz, there has been a strong demand for the integration of high 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]. Basic FBAR structure consists of a piezoelectric thin-film sandwiched between top and bottom electrodes where a resonance occurs when an electric field is applied onto electrodes [2]. Solidly mounted resonator (SMR) [3] has a Bragg reflector acting as a mirror to prevent a possible energy loss into the substrate from the resonating piezoelectric region. A high-quality BR fabrication may become critical to improve the resonance characteristics in 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. In spite of some efforts to improve the FBAR device characteristics [4-7], few studies have been reported on the method to improve the quality of the tungsten/silicon dioxide (W/SiO₂)

multilayer BR.

In this work, we, for the first time, present a novel technique to improve the quality of W/SiO₂ multilayer Bragg reflectors on the resonance characteristics of ZnO-based FBAR devices by inserting Cr adhesion layers into W/SiO₂ multilayer. In addition, several thermal annealing processes were employed to further enhance the FBAR device performances.

II. EXPERIMENT

Fig. 1a-d shows the schematic structure of the FBAR device and three resonator layout patterns (1, 2, and 3), in which the pattern 3 was used in [6] for comparison. The multilayer BR of the FBAR device was formed by depositing thin film layers of SiO₂, Cr, W, SiO₂, Cr, W, and SiO₂ on 4-inch p-type (100) Si wafer.

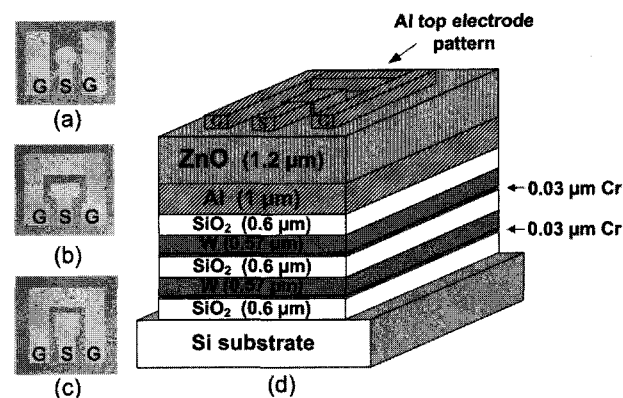


Fig. 1 FBAR device structure and three patterns
a Three-dimensional schematic of FBAR device,
b Pattern 1, c Pattern 2, d Pattern 3

The SiO₂ layer (0.6 μm-thick) was deposited by chemical vapour deposition (CVD) technique. The Cr (0.03 μm-thick) and W (0.57 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. Then, the 4-inch wafer was divided into four samples (namely R1, R2, R3, and R4). To investigate the thermal treatment effects, two thermal annealing processes were carried out in this work. The first thermal annealing process (called inter-fabrication annealing), was used to anneal the samples prior to the deposition of top electrodes. The second one, called post-annealing process, was applied for the samples immediately after the top electrode

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deposition (0.2 μm -thick Al). The R1 sample remains non-annealed at all in order to use it as a reference sample while the others (R2, R3, R4) were thermally treated as follows: the R2 sample was only post-annealed and the R3 sample was merely inter-fabrication annealed. Meanwhile, the R4 sample was firstly inter-fabrication annealed, then post-annealed. Here, the inter-fabrication annealing and post-annealing were done at 200 °C for 60 minutes and for 120 minutes, respectively, in ambient argon (Ar) using an electric dehydrate furnace (EDF). Annealing treatment conditions for the four samples R1 to R4 are summarized in table 1. Finally, all FBAR devices were measured in order to extract the return loss (S_{11}) by using a probe station and HP 8722D network analyzer.

Table 1 Thermal processes

Samples	R1	R2	R3	R4
Thermal steps				
Inter-fabrication annealing 200°C/60min.	-	-	Ar	Ar
Post-annealing 200°C/120min.	-	Ar	-	Ar

III. RESULTS AND DISCUSSION

The return loss characteristics versus frequency were extracted from four samples where each sample has three different resonator patterns, as shown in Fig. 1b-d. And the extracted S_{11} parameters were plotted in Fig. 2a-c and also summarized in table 2.

Table 2 Return loss values of the resonator samples with different patterns

Samples	Return loss S_{11} [dB]				
Patterns	R1	R2	R3	R4	Ref. [6]
Pattern 1	-20.41	-26.43	-23.14	-32.28	-
Pattern 2	-18.62	-27.84	-21.04	-31.68	-
Pattern 3	-26.88	-33.10	-28.62	-38.13	-23.43

The S_{11} values of the three resonator patterns fabricated on R2, R3, and R4 show the same increasing trend in comparison with those of resonators on R1 sample. In particular, the most significant improvement of the return loss characteristics was observed at resonators of the R4 sample with the combined-thermal processes. From Fig. 2c, among 4 resonator samples, R1 have smallest return loss values ($S_{11} = -28.88$ dB). Meanwhile, the respective return loss values for samples R2, R3, and R4 are $S_{11} = -43.10$ dB, -36.62 dB, -47.13 dB, respectively. The reason why return loss value of sample R1 is smaller than R2, R3, and R4, can be explained detail in [6] and [7].

Within the as-deposited W/SiO₂ 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 to enhance the adhesion between W and SiO₂ layers as well as the uniformity of the thin-film layers deposited for BR fabrication. The combination of both Cr adhesion layers and thermal 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].

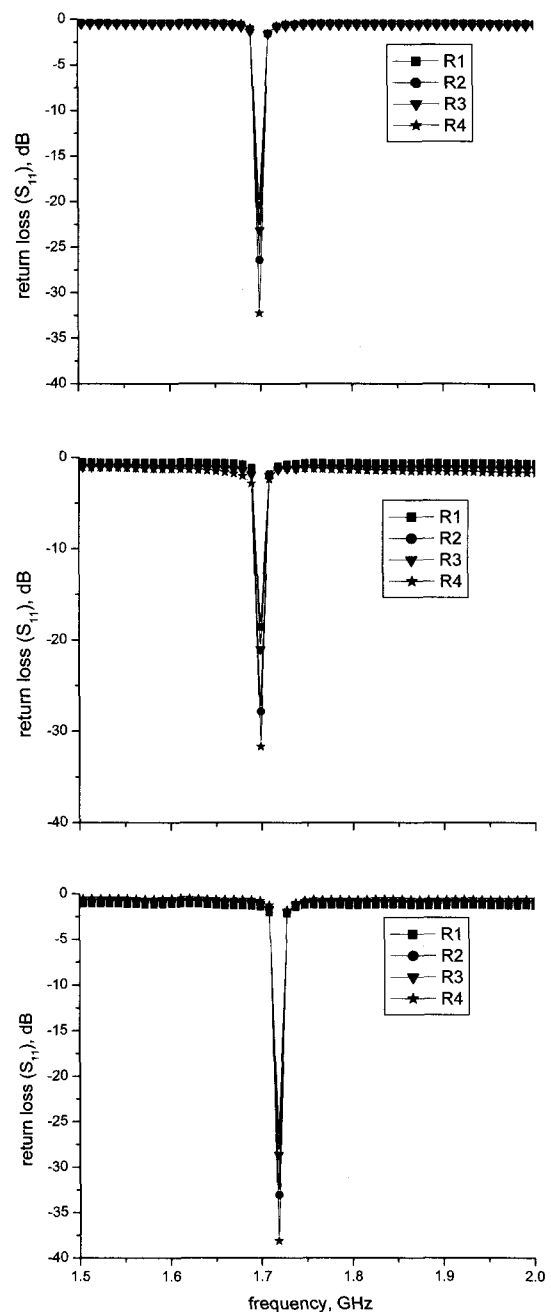


Fig. 2 Return loss characteristics versus frequency for various thermal processes
a Pattern 1, b Pattern 2, c Pattern 3

The performance of the FBAR devices can be determined by the figure of merit (FOM) [8] in term of Q factor. Based on an empirical definition [9], the series/parallel resonance Q-factors ($Q_{s/p}$) were calculated as shown in Table 3. The resonators on the R4 sample, both inter-fabrication annealed and post-annealed, have the largest Q-factor values.

Table 3 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	6019	6008	5981	5916	6430	6257
R2	6401	6245	6473	6223	6696	6481
R3	6307	6106	6173	6042	6366	6296
R4	6753	6284	6713	6196	6991	6438
Ref. [6]	-	-	-	-	4264	4961

IV. CONCLUSION

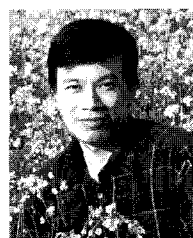
In this paper, the resonance characteristics of ZnO-based FBAR devices were considerably improved due to the combination use of inserted Cr adhesion layers into multilayer Bragg reflector and thermal treatments (inter-fabrication and post-annealing processes). The proposed technique appears to be very promising for FBAR device applications.

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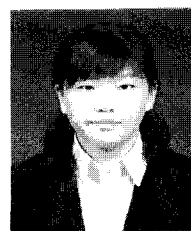
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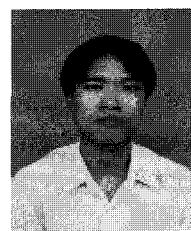
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