Realization of FBAR Devices for Broadband WiMAX Applications

Linh Mai, Jae-young Lee, Van Su Pham, and Giwan Yoon, *Member, KIMICS*

Abstract—Effects of the addition of Cr adhesion layer to W/SiO_2 multilayer Bragg reflectors on the resonance characteristics of film bulk acoustic wave resonator (FBAR) devices are presented. Main resonance peaks could be significantly shifted to higher frequency, mainly due to the addition of Cr adhesion layer to multilayer Bragg reflectors and control of the bottom electrode thickness as well. The FBAR devices with the Cr adhesion layer in Bragg reflectors could result in much more improved resonance characteristics at about 3 GHz in terms of return loss and Q-factor.

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

I. INTRODUCTION

Recent technological innovations have shown a great promise for mobile broadband users. New technologies such as WiMAX (worldwide interoperability for microwave access) have been demonstrated its possibility to bridge the gap between fixed and mobile access and to offer the same subscriber experience whether on a fixed or a mobile network. Currently, the 2.3-3.6 GHz band assignment for WiMAX is considered as one of the best choices for mobile broadband deployments as it has been widely reserved for mobile services [1]. Therefore, device manufacturers may need new bandpass filters that are smaller, consume less power, have lower insertion loss and operate at higher frequencies. Thin Film Bulk Acoustic Resonators (FBARs) technology has the necessary capabilities to achieve these requirements simultaneously. 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 mainly 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 the SMR-type, the BR can act as a mirror to isolate a possible energy loss from piezoelectric layer into 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 BRs for the SMR-type FBAR devices have been fabricated by alternatively depositing both high and low impedance materials. Despite some efforts [4-7] made 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 BRs, and also to the best of our knowledge, no comprehensive studies have been reported on the effects of the bottom electrode thickness on the resonator performances.

In this paper, we proposed a novel technique to improve the resonance characteristics by inserting Cr adhesion layers into W/SiO_2 multilayer. In addition, the FBAR device performances were studied based on variation of bottom electrode thickness in the devices.

II. EXPERIMENT

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 three 4-inch p-type (100) silicon wafers (named S1, S2, and S3). 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, 0.3; 0.8 and 1.2 μm-thick aluminum (Al) bottom electrode (as floating ground) was deposited on the three wafers S1, S2, and S3, respectively, followed by 1.2 μm-thick ZnO film deposition on these wafers. Finally, the deposition and patterning of the top electrodes (0.2 μm-thick Al) on top of the ZnO film on the three wafers completed the FBAR devices fabrication. Fig. 1 shows cross-sectional SEM image of the Bragg reflector and the schematic structure three-dimension of FBAR device.

Three resonator layout patterns (1, 2, and 3) were designed for testing the resonance characteristics in this work. The return loss (S_{11}) characteristics were extracted from the resonance patterns on each of the three wafers

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(S1-S3) by using a probe station and Hewlett Packard/HP 8722D network analyzer.

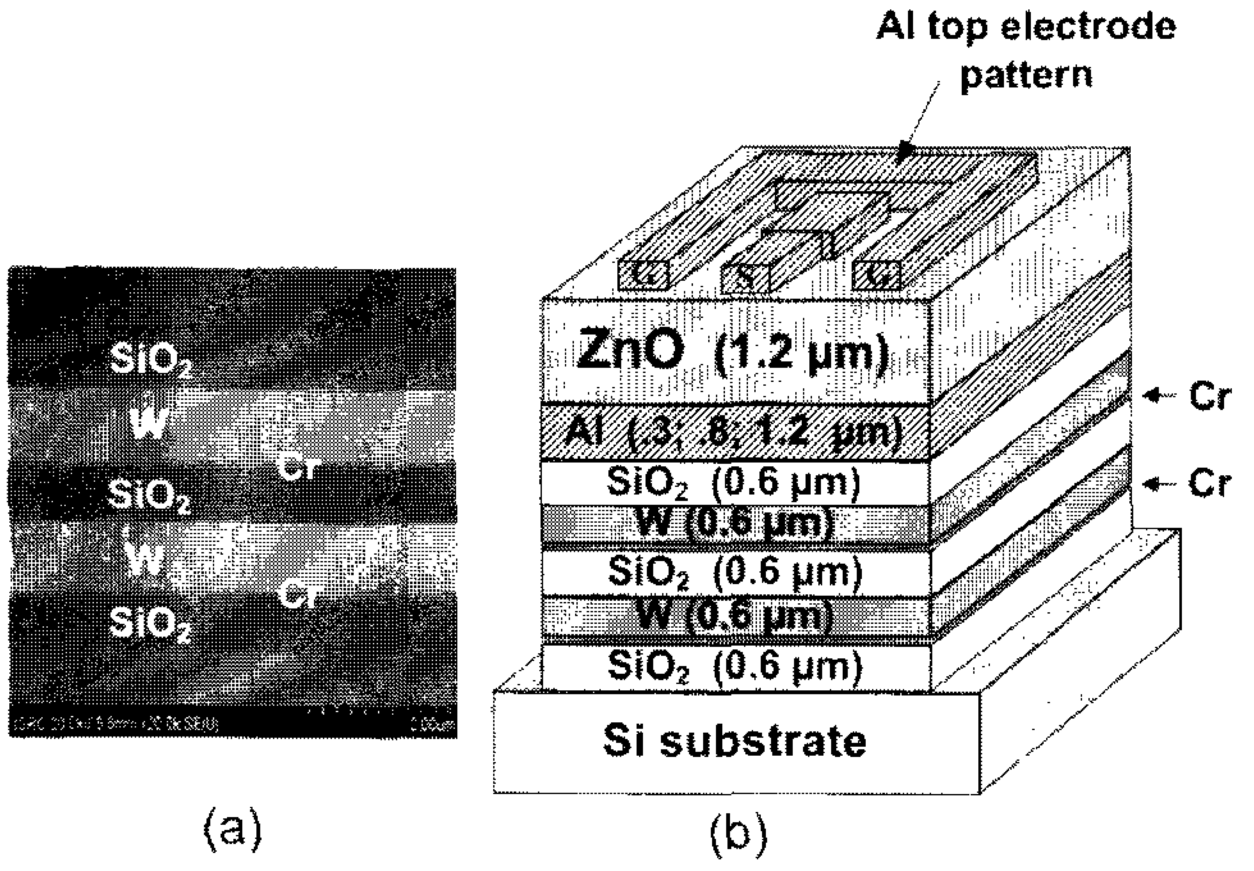

Fig. 1 FBAR device structure:
(a) Cross section view image of Bragg reflector
(b) Three-dimensional schematic of FBAR device

III. RESULTS AND DISCUSSION

Fig. 2 shows three resonator patterns and their return loss characteristics versus frequency for various bottom electrode thicknesses. Fig. 2a compares the return loss characteristics of the FBAR devices with the resonator pattern 1 with the bottom electrode Al 0.3μm-thick, 0.8 μm-thick, and 1.2μm-thick. Similarly, Fig. 2(b) and 2(c) show the return loss characteristics of the FBAR devices with the resonance patterns 2 and 3, respectively. The S_{11} values of the two resonator patterns fabricated on S2 and S3 samples show the same increasing trend in comparison with that of resonators on S1. Clearly, the resonators with the thickest bottom electrode of Al have the largest return loss characteristics. From Fig. 2(a), at the higher resonant point, the resonators on S1 sample have the smallest return loss value (S_{11} = -18.41 dB). Meanwhile, the return loss values of S2, S3 samples are -20.41 dB and -26.45 dB, respectively. All the extracted values S_{11} of the three resonator patterns are summarized in Table 1.

Also from Fig. 2, the resonators were fabricated at the operational resonance frequency at 2.7 – 3 GHz. The resonators fabricated on S1, S2, S3 have the high S_{11} values at resonance frequency of 2.9, 3.0, and 2.7 GHz, respectively.

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

Samples / Patterns	Return loss S_{11} [dB]		
	S1	S2	S3
Pattern 1	-18.41	-20.41	-26.45
Pattern 2	-19.64	-21.12	-26.63
Pattern 3	-16.48	-19.63	-24.97

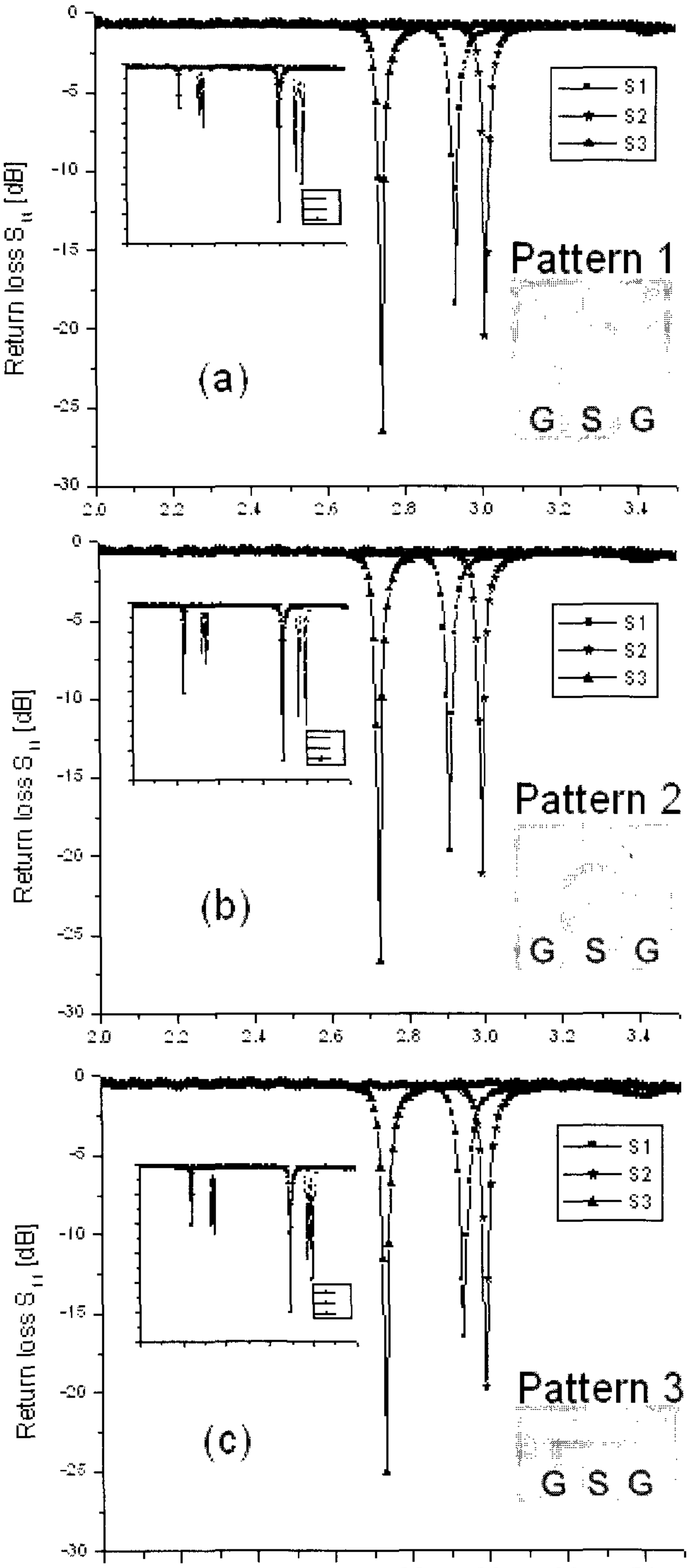

Fig. 2 Return loss characteristics versus frequency for various bottom electrode thicknesses
(a) Pattern 1, (b) Pattern 2, (c) Pattern 3

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 insertion of Cr adhesion layers is believed to effectively reduce any possibly existing incomplete adhesions in the multilayer reflectors, eventually improving the resonance characteristics.

On the other hand, owing to the Bragg reflector multilayer W/SiO_2 inserted ultra thin Cr layers, the variation of thickness of bottom electrode, and the technical fabrication processes of the devices, the FBARs could be resonated at higher frequency (~3 GHz) with considerable S_{11} values. From the measured S-parameters, these FBARs can be used in the high frequency of from 2.7 - 3 GHz broadband WiMAX.

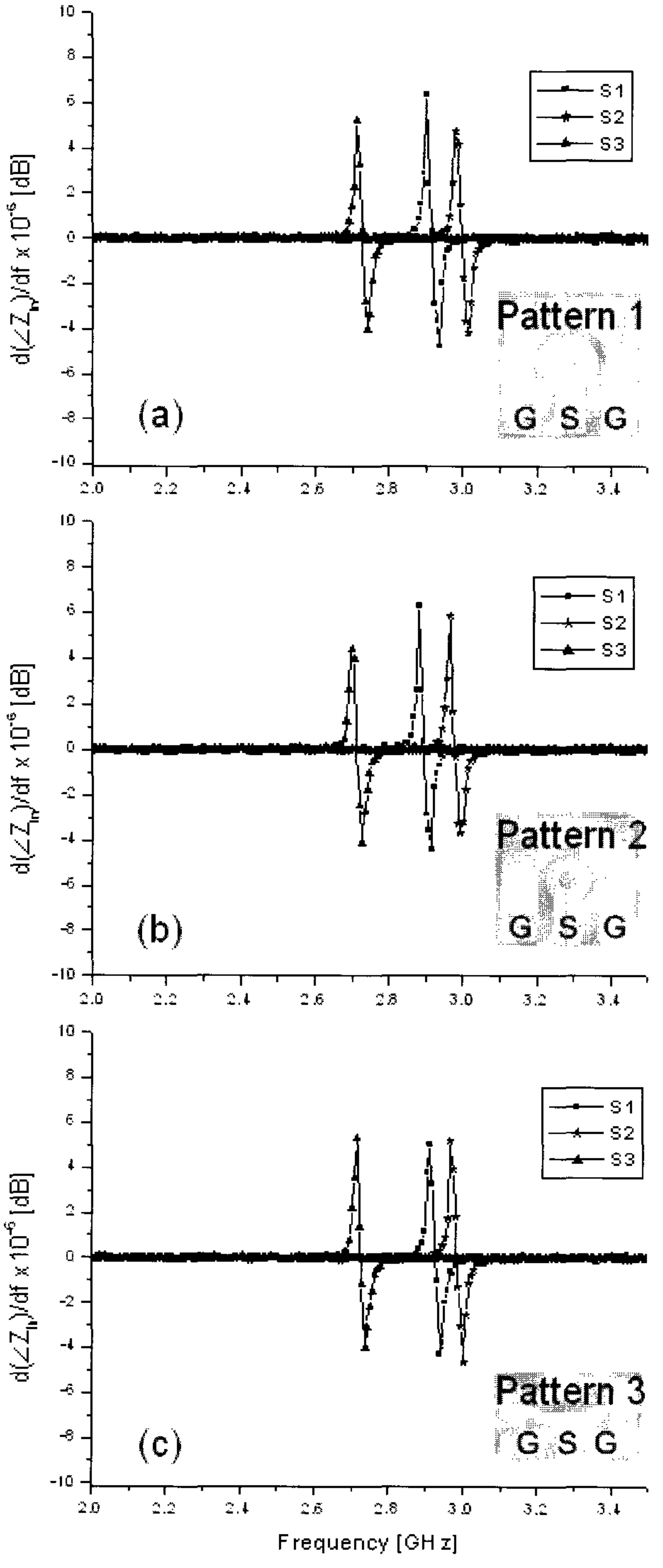

Fig. 3 Slope of input impedance phase (∠Zin) versus frequency
(a) Pattern 1, (b) Pattern 2, (c) Pattern 3

Although further investigations need to be carried out for more clear understanding, we strongly believe at this point that the use of SMR-type FBAR devices at high frequency is possible.

The performance of FBAR devices can be determined by the figure of merit in terms of Q-factor [8].

$$Q_{s/p} = \frac{f_{s/p}}{2}\left|\frac{d\angle Z_{in}}{df}\right|_{f=f_{s/p}} \qquad (1)$$

According to the empirical definition [9] that uses the local extrema in the slope of the input impedance phase ($\angle Z_{in}$) as a function of the frequency for the resonator pattern 1, 2, and 3. The series resonance frequency (f_s) and parallel frequency (f_p) and the slope of $\angle Z_{in}$ as a function of the frequency are obtained. Fig. 3 represents the slope of $\angle Z_{in}$ as a function of the frequency for the three resonator patterns.

The series/parallel resonance Q-factors ($Q_{s/p}$) were calculated and shown in Table 2.

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
S1	7210	5016	8056	5395	7311	6344
S2	8456	6827	8722	6434	7710	6923
S3	7859	6086	5988	5590	7227	5524

IV. CONCLUSION

The combined effects of the insertion of Cr adhesion layers into multilayer BR and variation of thickness of bottom electrodes were investigated. The fabricated FBAR devices are observed to resonate at a high frequency regime (2.7–3 GHz). The proposed FBAR fabrication technique appears to be very suitable for the mobile broadband WiMAX technology.

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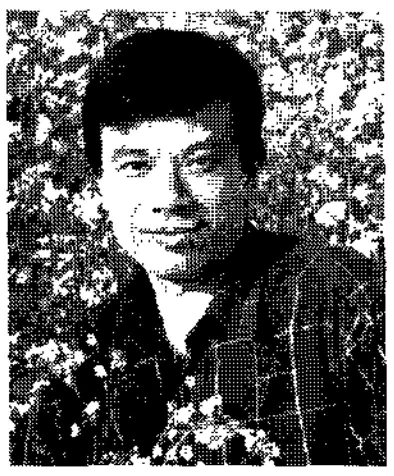

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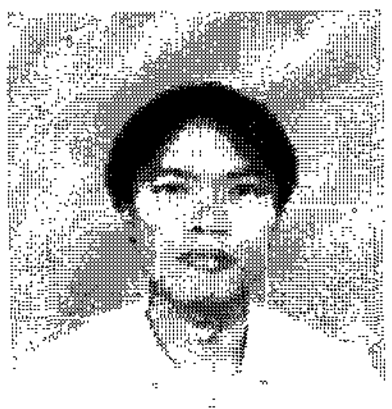

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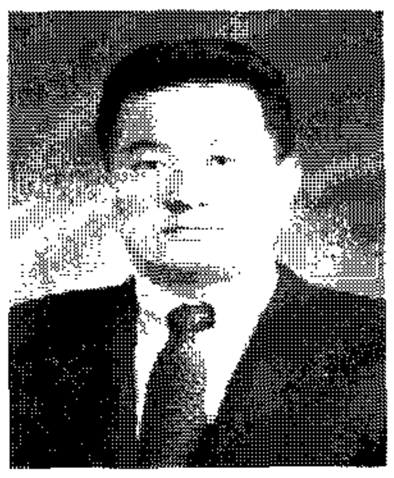

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