Thin Film Bulk Acoustic Resonators for RF Applications

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***Abstract*—**A new thin film deposition technique of piezoelectric ZnO film and its successful application for film bulk acoustic resonator (FBAR) devices are presented. The two-step deposition used seems to be able to deposit ZnO film with a highly preferred orientation. The FBAR devices with the ZnO films show an excellent return loss of 35~50 dB at 1.5 ~ 2 GHz.

***Index Terms*—**Resonator, Bragg reflector, Quality factor Q, return loss S11.

I. INTRODUCTION

Rapid development of wireless communications has led to an explosion of innovative RF/Microwave devices. Above all, high-performance RF filters have become increasingly important as the spectrum crowding increases [1]. Recently, ZnO-based FBAR devices have become one of the most promising components, due to their small size, high device performance and strong potential for the realization of MMIC [2, 3]. Considerable effort has been made to fabricate high-quality ZnO films with a strongly preferred orientation [3-6]. However, each approach has shown its own limitations such as the complexity of the fabrication methods [3-5]. From the manufacturing perspective, it is highly desirable to develop processes that do not deviate significantly from conventional techniques. In this paper, a two-step sputtering deposition technique for piezoelectric ZnO film formation and its successful application for FBAR are presented.

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II. FBAR FABRICATIONS

To investigate the process dependence of the ZnO films, 1200Å gold (Au) films were evaporated on Si (100) wafers with a precleaning, followed by ZnO deposition under various sputtering process conditions. Crystal structure and surface roughness of the films were measured. FBAR devices (Fig. 1) were also fabricated and characterized.

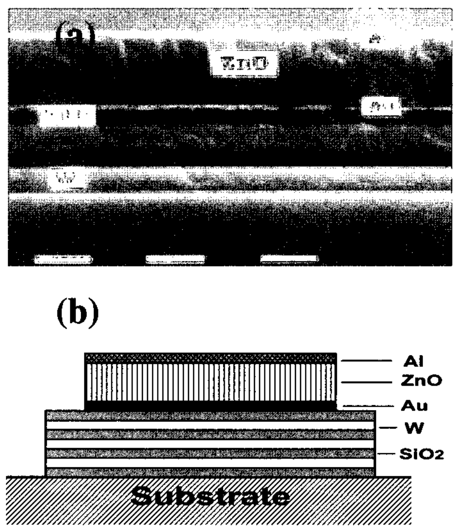

Fig. 1 Cross-sectional views :
(a) SEM image of FBAR with four layers reflector
(b) Schematic of FBAR with seven layers reflector

III. RESULTS AND DISCUSSION

Surface morphologies of the deposited ZnO films were investigated. Increasing the deposition pressure resulted in larger grains. Low pressure of 5mTorr has resulted in 30~40nm grains while 120~150nm grains were grown at 20mTorr. This is because the increase in deposition pressure also increases the number of atoms [6]. Surface roughness of ZnO films deposited at 10mTorr showed a good surface roughness of 10Å (Fig. 2). However, at 20mTorr, the surface roughness increased to 70Å. Increasing the RF power resulted in more enhanced growth towards the c-axis. Also, RF power was found to have no significant effect on surface roughness. The effects of O2/Ar ratio on the ZnO films were investigated. The surface roughness decreased with increasing O2. Without use of O2, the surface roughness was ~60Å, whereas with 75% O2 gas, the surface roughness was reduced to 10Å. More O2 gas in the sputter chamber appears to reduce the sputter yield and hence reduce the deposition rate, mainly because of the increased collision rate between Ar and O atoms.

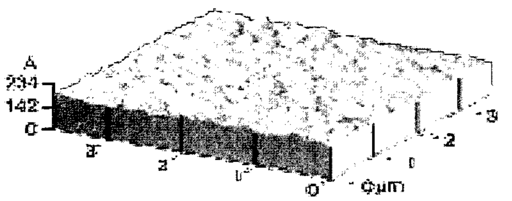

Fig. 2 AFM images of ZnO films deposited at 10 mTorr.

By controlling the deposition pressure or RF power, increasing the deposition rate resulted in a ZnO film with more strongly preferred orientation toward the c-axis and it increased the surface roughness. However, by controlling the O2 concentration, decreasing the deposition rate reduced the surface roughness. In this work, a two-step (step1+step2) deposition technique was implemented to achieve high-quality ZnO films as shown in Table 1.

Table 1 Summary of two-step deposition process condition.

Step	RF power	Gas pressure	O_2 conc.
Step 1	90 W	5 mTorr	75%
Step 2	120 W	10 mTorr	50%

As a result, the initial 0.1μm film with fine grains was deposited on the amorphous Au electrode with a low deposition rate. Then, strongly preferred columnar grains were grown with a high growth rate, eventually resulting in fine columnar grains. The ZnO films deposited by the two-step deposition technique were compared with those

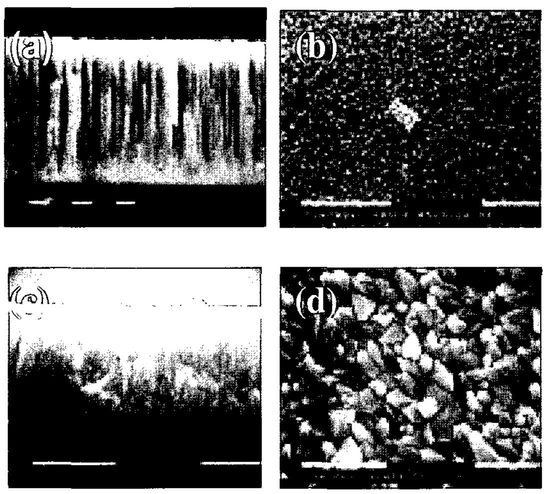

Fig. 3 SEM images of ZnO films by two-step deposition: (a) cross-sectional view and (b) top view, and SEM of ZnO films deposited by conventional deposition: (c) cross-sectional view and (d) top view

deposited by the conventional deposition technique (Fig. 3). Conventional deposition resulted in random crystal grain structures and large grains (500nm), whereas two-step deposition resulted in ZnO films with more strongly preferred orientation towards the c-axis and relatively fine grains (50nm).

The resonance characteristic of the FBAR device exhibits its characteristic impedance as a loop mostly located in the capacitive part on the Smith chart (Fig. 4). As shown in the Smith chart, the FBAR with a large return loss seems well-matched to the 50Ω impedance without any additional outer matching circuits. The corresponding area matched to the 50Ω impedance was found to be 150μm x 150μm. The resonance frequency is accepted to be f = v/2d (v = wave velocity, d = ZnO film thickness). However, the bottom electrode reduces the resonance frequency by its presence as part of the acoustic path of the resonator [7]. The so-called mass loading effect is significantly more pronounced with the Au electrode because of its low acoustic velocity. Quarter wavelength thick film can acoustically isolate the piezoelectric layer from the substrate [8]. This implies that the FBAR device could be easily matched by simply adjusting its resonance area.

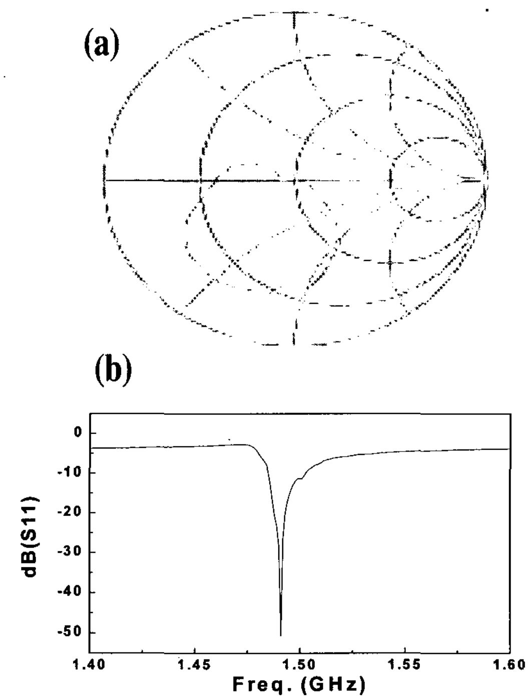

Fig. 4 (a) Smith chart and (b) return loss (S11).

The performance of the resulting FBAR was evaluated using the following two figures of merit [9]. K^2_{eff} (effective electromechanical coupling coefficient) is a measure of the relative frequency spacing between the series resonance frequency (fs) and the parallel resonance frequency (fp) and also determines the maximum bandwidth that can be achieved with a filter [10]. Qs/p (quality factor) is a measure of the resonator loss of a device at fs or fp.

$$K_{eff}^2 = \frac{(\frac{\pi}{2})(\frac{f_s}{f_p})}{\tan((\frac{\pi}{2})(\frac{f_s}{f_p}))} \quad (1)$$

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

It is noted that the product of K^2_{eff} and Qs/p (i.e., K2eff Qs/p) of the devices is inversely proportional to the insertion loss of a filter. Based on the empirical definition, we extracted the fs and fp from the slope of ∠Zin plotted as a function of frequency. The fs and fp were 1.48 GHz and 1.487 GHz, respectively. From these findings, both K2eff of 1.16% and Qs of 7235 (K2eff Qs = 84) could be obtained using eqs. (1) and (2).

IV. CONCLUSION

A piezoelectric ZnO film deposition technique and its successful application to FBAR devices are presented. Measurement shows an excellent resonance characteristic, mainly due to the strongly preferred orientation of the deposited ZnO films. It is believed that the proposed two-step deposition technique can be a promising method for the fabrication of high-quality ZnO films for FBAR device application.

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REFERENCES

[1] K. M. Lakin, G. R. Kline and K. T. McCarron, "Development of miniature filters for wireless applications", IEEE Trans. Microwave Theory & Techniques, vol. 43, no. 12, 1995, pp. 2933-2939.

[2] S. V. Krishnaswamy, J. F. Rosenbaum, S. Howitz and R. A. Moore, "Film bulk acoustic wave resonator technology", IEEE Ultrasonics Symp, 1990, pp. 529-536.

[3] J. C. Zesch, B. Hadimioglu, B. T. Khuri-Yakub, M. Lim, R. Lujan, J. Ho, S. Akamine, D. Steinmetz, C. F. Quate and E. G. Rawson, "Deposition of highly oriented low-stress ZnO films", IEEE Ultrasonics Symp, 1991, pp. 445-448.

[4] M. Kadota, T. Kasanami and M. Minakata, "Deposition and piezoelectric characteristics of ZnO films by using an ECR sputtering system", IEEE Trans. on Ultrasonics, Ferroelectrics and Frequency Control, vol. 41, no. 4, 1994, pp. 479-483.

[5] N. W. Emanetoglu, S. Liang, C. Gorla and Y. Lu, "Epitaxial growth & characterization of high quality ZnO films for surface acoustic wave applications", IEEE Ultrasonics Symp. 1997, pp. 195-199.

[6] F. C. M. Van De Pol, F. R. Blom and T. J. Popma, "R.F. planar magnetron sputtered ZnO films", Thin Solid Films, vol. 204, 1991, pp. 349-364.

[7] J. F. Rosenbaum, "Bulk acoustic wave theory and devices", Artech House, 1988, pp. 411.

[8] W. E. Newell, "Face-mounted piezoelectric resonators", Proc. IEEE, vol. 53, 1965, pp. 575-581.

[9] K. M. Lakin, G. R. Kline and K. T. McCarron, "High-Q microwave acoustic resonators and filters", IEEE Trans. Microwave Theory & Techniques, vol. 41, no. 12, 1993, pp. 2139-2146.

[10] K.M. Lakin, G.R. Kline and K.T. McCarron, "Thin film bulk acoustic wave filters for GPS", IEEE Ultrasonics Symp, 1992, pp. 471-476.

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