RF 필터응용을 위한 FBAR 소자제작과 증착온도가 ZnO 박막의 결정성장에 미치는 영향

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FBAR Devices Fabrication and Effects of Deposition Temperature on ZnO Crystal Growth for RF Filter Applications

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요 약

본 논문에서는 Al 하부전극 상에서 RF magnetron sputtering 기술을 이용한 ZnO 박막 증착 및 공정온도가 ZnO 결정성장에 미치는 영향을 고려하여 제작한 FBAR 소자에 대한 연구를 발표한다. 결과적으로, 200℃의 공정온도에서 주상형 결정립(columnar grain)을 가지고 c축 우선 배향된 ZnO 박막을 얻을 수 있었다. 이렇게 얻은 ZnO 박막을 FBAR 소자에 적용하여 제작한 결과, 2.05GHz의 공진 주파수에서 ~19.5dB의 반사손실을 보였다.

ABSTRACT

In this paper, the characteristics of the ZnO films deposited on Al bottom electrode and the temperature effects on the ZnO film growth are presented along with the fabrication and their evaluation of the film bulk acoustic wave resonator (FBAR) devices. All the films used in this work were deposited using a radio-frequency (RF) magnetron sputtering technique. Growth characteristics of the ZnO films are shown to have a strong dependence on the deposition temperatures ranged from room temperature to 350°C regardless of the RF power applied for sputtering the ZnO target. In addition, according to the growth characteristics of the distinguishably different micro-crystal structures and the degree of the c-axis preferred orientation, the deposition temperatures can be divided into 3 temperature regions and 2 critical temperatures in-between. Overall, the ZnO films deposited at/below 200°C are seen to have columnar grains with a highly preferred c-axis orientation where the full width at half maximum (FWHM) of X-ray diffraction rocking curve is 14°. Based on the experimental findings, several FBAR devices were fabricated and measured. As a result, the FBAR devices show return loss of ~19.5dB at resonant frequency of ~2.05GHz.

키워드

FBAR, ZnO Film, Temperature region, Critical temperature, C-axis preferred growth, Resonance characteristic

I. Introduction

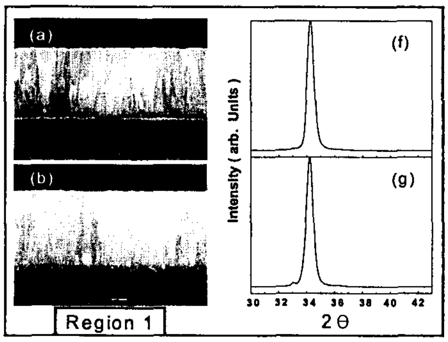
This film bulk acoustic wave resonator (FBAR) or its technology seems very promising to fabricate the next generation radio-frequency (RF) filters from the manufacturing point of view. This is because the FBAR technology can be integrated with the current silicon process technology, eventually enabling the current off-chip type of RF filters to be realized in the type of the microwave monolithic integrated circuits (MMICs)[1, 2]. The FBAR device operation is based on the fact that an acoustic wave propagates through the piezoelectric film sandwiched between top and bottom metal electrodes and generates the resonance between the two electrodes due to piezoelectric film[3]. Accordingly, the piezoelectric property may play a critical role in determining the resonance characteristic of the FBAR device and also the piezoelectric property is determined by the degree of the c-axis preferred orientation of the piezoelectric film. In this paper, we present the characteristics of the ZnO films deposited on Al bottom electrode and the temperature effects on the ZnO film growth along with the fabrication and their evaluation of the FBAR devices. The growth characteristics of the deposited ZnO films are shown to have a strong dependence on the deposition temperature. From the grain characteristics standpoint, the temperature regions can be divided into three sub-regions by two critical temperatures. Also, the ZnO film deposited at ≤200℃ showed a highly preferred orientation towards c-axis where the full width at half maximum (FWHM) value of the X-ray diffraction rocking curve was found to be 14.0~14.4°. Based on the experimental findings, several FBAR devices were fabricated and measured.

II. Experiment

In this work, the ZnO piezoelectric films were deposited using a RF magnetron sputtering technique. Prior to ZnO film deposition, the base pressure ($< 2.0\times10^{-6}$ torr) using turbomolecular pump has been kept to remove impurities in chamber as much as possible. Then, the reaction gas of high purity was injected into the chamber and ZnO film was deposited on Al/Si substrates at room temperature with the substrate rotating at 6 RPM while the distance between the substrate and target set to be 6.5cm. The preferred growth characteristics of the ZnO films were analyzed with a Rigaku D/max-RC X-ray diffractometer (XRD) with CuK_α radiation at 30kV and 60mA. The microstructures and preferred crystal planes paralleled to substrates were evaluated by the θ-2θ scan method with rotating x-ray detector by 2θ and sample by θ. But this method cannot determine the degree of the preferred orientation growth towards c-axis. Instead, the rocking curve technique was used to calculate the full-width at half maximum (FWHM) value of the Gaussian distribution obtained by performing θ scan (17.21°) of the sample with the x-ray detector fixed at position of 2θ value (34.42°) of the (002) ZnO plane observed at θ-2θ scan. The smaller FWHM value indicates the higher degree of c-axis preferred orientation growth. Next experiment is to realize a FBAR using the ZnO film with a highly preferred c-axis orientation. The patterning for top Al electrodes formation was defined on the ZnO films by the conventional photolithography technique using AZ1512 photoresist (PR) and pattern masks. Then, the Al films were deposited on the patterned PR layer, followed by the lift-off processing to strip off the remaining PR layers. The top Al electrodes patterning completed the fabrication of the FBAR devices.

III. Results and discussion

Firstly, the effects of the deposition temperature on the growth characteristics of these ZnO films were performed using SEM and XRD methods. Fig. 1 shows the resulting SEM and XRD measurements of the ZnO films deposited under various deposition temperatures. From the standpoint of growth characteristics of ZnO films, the deposition temperatures could be divided approximately into three regions (regions 1, 2, 3).



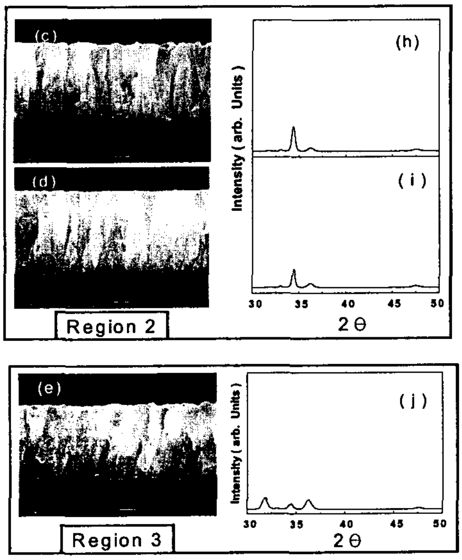


Fig. 1 SEM images of the ZnO films deposited at (a) 23, (b) 200, (c) 250, (d) 300 and (e) 350℃, and XRD θ-2θ scan results of ZnO films deposited at (f) 23, (g) 200, (h) 250, (i) 300 and (j) 350℃.

It is clearly certified that the different growth orientation behaviors of the ZnO films are shown for three different temperature regions, as shown in both SEM images (Fig. 1 (a)~(e)) and XRD measurements (Fig. 1 (f)~(j)). In the temperature range for the region 1 (23~200°C), the (002) peak alone is observed in displayed 2θ scope and have a very large intensity as shown in Fig. 1 (f) and (g). The existence of the large intensity of the (002) peak indicates that the ZnO film deposited at this temperature range strongly orients towards the c-axis perpendicular to the surface of the substrate. Furthermore, the SEM images of the ZnO films (Fig. 1 (a) and (b)) also show a highly preferred orientation towards c-axis with columnar grain structures. For the region 2 (250~300°C), the intensity of the (002) peak seems remarkably diminished, and a small peaks at (101) and (102) of the ZnO films are additionally observed, as shown in Fig. 1 (h) and (i). This means that the ZnO film begins to deviate from the preferred c-axis orientation growth, thus leading to have a mixed-axis orientation. The SEM images of the ZnO films are also shown to have much less preferred orientation towards c-axis. For the region 3 (> 350°C), the (100), (002), (101) and (102) peaks of ZnO films were detected in displayed 2θ scope as shown in Fig. 1(j). And, the SEM image also shows a randomly grown grain microstructure at this relatively high temperature. The positions of 2θ values of (100), (002), (101) and (102) planes observed at θ-2θ scan are 31.77, 34.42, 36.25 and 47.54°, respectively. Overall, as the deposition temperature increases, the growth characteristics of ZnO films change from the highly preferred orientation growth into a completely mixed-axis orientation growth mainly because the more random crystal growth along (100), (002), (101) and (102) planes proceeds together at relatively high temperature. For more clarity, the XRD rocking curves of the ZnO films deposited under various deposition temperatures from room temperature to 350°C are extracted and compared, as shown in Fig. 2. The characteristics of the growth orientation are clearly classified by three temperature regions divided roughly by two critical temperatures. The FWHM values of the XRD rocking curves at region 1 and region 2 are 14.0~14.4 and 16.8~19.1°, respectively. Particularly, at region 3, it was not feasible to calculate the FWHM value because the rocking curve does not follow Gaussian distribution, as shown in Fig. 2(e). Consequently, below 200°C, the ZnO film deposition results in columnar grains with a *highly preferred c-axis orientation.*

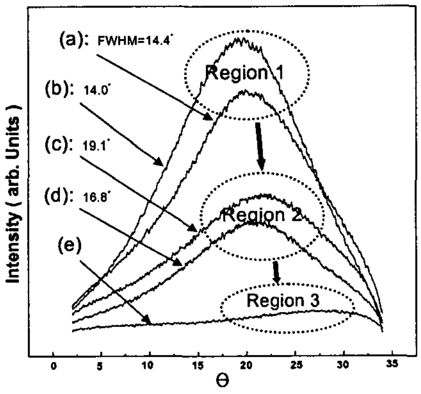
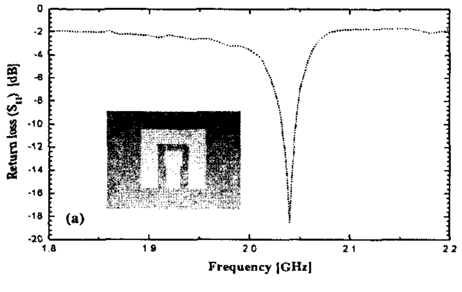


Fig. 2 XRD rocking curves of the ZnO films deposited at (a) 23, (b) 200, (c) 250, (d) 300 and (e) 350℃.

Based on the experimental findings, several FBAR devices were fabricated. After device fabrications, each resonator was measured to extract the S_{11} scattering parameters using an HP 8722ES network analyzer and a G-S-G probe tip. It is noted that the bottom Al electrode serves as a floating ground. Fig. 3 shows the top-view patterns and return losses of the one-port FBAR devices where the resonance areas are 21,200㎛^{2} (Fig. 3(a)) and 23,500㎛^{2} (Fig. 3(b)). As a result, the FBAR devices show ~19.5dB at resonant frequency of ~2.05GHz as shown in Fig. 3. The resonator performance could be evaluated using the following two figures of merit (FOM)[4].

$$K^2_{eff} = \left(\frac{\pi}{2}\right)^2 \frac{f_p - f_s}{f_p}, \qquad Q_{s/p} = \frac{f}{2}\left|\frac{d\angle Z_{in}}{df}\right|_{f_{s/p}}$$

where K^2_{eff} and $Q_{s/p}$ determine the maximum attainable bandwidth of filter and resonator loss, respectively[5]. The K^2_{eff} of 3.24%, Q_s of 6,363 and Q_p of 6,749 were calculated using above equations at the series resonance frequency (f_s) of 2.032GHz and the parallel resonance frequency (f_p) of 2.059GHz for FBAR device with resonance areas of 21200㎛^{2}. Also, The K^2_{eff} of 2.05%, Q_s of 8,114 and Q_p of 10,045 were calculated at the f_s of 2.042GHz and the f_p of 2.059GHz for FBAR device with resonance areas of 23,500㎛^{2}.



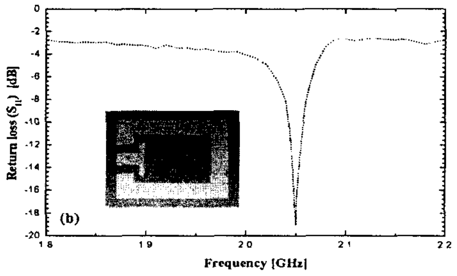


Fig. 3 The top-view patterns and return losses of the one-port FBAR devices with the resonance areas of (a) 21,200㎛^{2} and (b) 23,500 ㎛^{2}.

Ⅳ. Conclusion

In this paper, the characteristics of the ZnO films deposited on Al bottom electrode and the temperature effects on the ZnO film growth are presented along with the fabrication and their evaluation of FBAR devices. The growth characteristics of the deposited ZnO films are shown to have a strong dependence on the deposition temperature and clearly classified into three temperature regions, divided roughly by two critical temperatures. Overall, the ZnO films deposited at/below 200°C are seen to have columnar grains with a highly preferred c-axis orientation. Based on the experimental findings, the FBAR devices show ~19.5dB at resonant frequency of ~2.05GHz.

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