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A Piezoelectric ZnO Film Prepared by RF Magnetron Sputtering

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Abstract—Crystalline structures, stress and surface roughness of ZnO films deposited on sapphire were investigated by X-ray diffraction and atomic force microscopy. The fabricated rf power and oxygen-argon gas ratio greatly affects the crystalline and surface roughness. Furthermore, a stress free and flat surface roughness at a post-annealing treatment of 400 ^{o}C under oxygen ambient was achieved. This ZnO film with stress free and smooth surface is promising for layered SAW device applications.

1. Introduction

In recent years, the surface acoustic wave (SAW) devices have been an increasing interest used in mobile cellular phones and broadcasting satellites. A layered SAW device with AlN or ZnO thin film is most favorable to achieve high electromechanical coupling coefficient [1-2]. The excellent piezoelectric and optical properties of ZnO films provide high coupling coefficient and an interaction in the frequency with UV light illuminations [3-4]. Since the most energy of the acoustic signal is focused at a depth of one wavelength (λ_o) from the surface, a signal crystalline and flat surface is the key issue to achieve high performance layered SAW devices. The rf magnetron sputtering technology has been widely utilized to fabricate well-oriented ZnO films at room temperature. The crystalline and surface roughness of ZnO films are found to correlate with the rf power, inlet gas ratio and post-annealing treatments [5-7].

In this paper, ZnO films were deposited on sapphire by rf magnetron sputtering system. Film stress and surface roughness at various rf powers, inlet mixed gas ratios and post-annealing treatments were systematic investigated by X-ray diffraction (XRD) and atomic force microscopy (AFM) measurements to prepare a layered SAW device with high coupling coefficiency and fast acoustic velocity.

2. Experimental procedure

ZnO thin films were deposited on sapphire (0001) substrate by rf magnetron sputtering system using a ZnO target. The rf power supplied to the ZnO target was ranged from 100 to 300 W and the inlet mixed O_2-Ar gas during deposition was varied from 0 to 50% to study the influences of rf power and oxygen on the quality of the ZnO films. Furthermore, these films were thermally annealed at various temperatures under oxygen atmosphere to study the structure and surface evolution influenced by heat treatments. The crystallinity and surface morphologies were examined by XRD and AFM, respectively.

3. Experimental results

Figure 1 shows the XRD patterns of ZnO films as functions of rf power ranged from 100 to 300 W. The as-deposited ZnO films were poly-crystal structure with three markedly peaks of ZnO (100), (002) and (101). The c-axis (002) phase of ZnO films was more obvious than

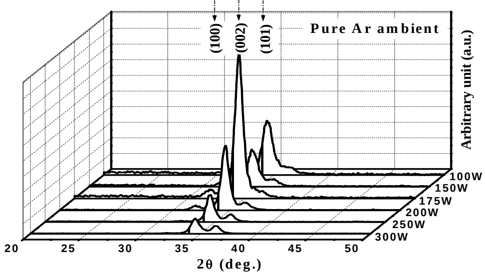

Fig.1 XRD pattern of ZnO films as functions of rf powers

others indicated the preferred orientation deposited on the sapphire (0001) substrates. Since the strengthened (002) phase as well as small FWHM was demanded for a superior layered SAW device, the relative intensity of ZnO (002) phase (I (002) / I (101)) and grain size evaluated from Sherrer equation are shown in Fig. 2. A maximum relative intensity was found as rf power at 175 W which indicated the ZnO (002) phase was dominated. The grain size was

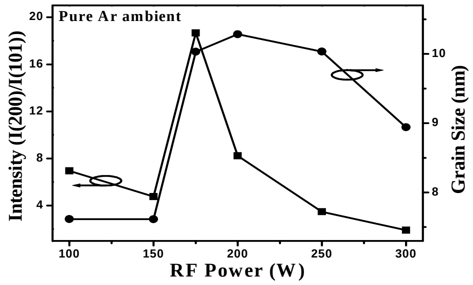

Fig.2 Relative intensity and grain size of ZnO (002) phase as functions of rf powers

higher than 10 nm at rf power ranging from 175 to 250 W. In addition, a low stress and uniform surface were also important to achieve a propagation of the surface acoustic wave without dissipation. The stress and surface roughness of ZnO films deposited at various rf power is shown in Fig.3. The stress of ZnO films were calculated as following [8-9] :

$$\sigma = [2C_{13} - (C_{11} + C_{12})C_{33} / C_{13}]e_{ZZ} \quad (1)$$

From Fig. 3, a low stress with compress component parallel to c-axis was obtained at rf power of 175 W while a large grain size and highest relative intensity also acquired. However, the surface was still too rough to employ to fabricate layered SAW devices. In order to flat the surface roughness, a mixed O_2-Ar gas ranged from 0 to 50% was introduced to compensate the appearance of oxygen vacancies during deposition. The XRD measurement at various oxygen ratios is shown in Fig. 4. Signal crystal ZnO films were obtained under O_2-Ar mixed gas. A highest ZnO

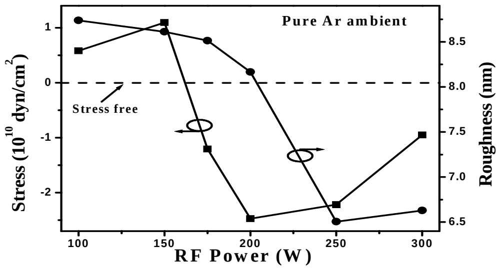

Fig.3 Stress and surface roughness of ZnO films as functions of rf powers

(002) intensity was obtained at O_2-Ar inlet gas ratio of 30%. The surface roughness was also markedly flattened out (~ 3 nm) while ZnO films were deposited under O_2-Ar mixture gas (as shown in Fig. 5). However, a incremental stress with tensile component parallel to c-axis was appeared due to the excess oxygen atoms filled in the interstitial site. Therefore, an adequate post-annealing treatment was needed to remove the intrinsic stress and suppress the thermal stress. The post-annealing treatment was carried out under oxygen atmosphere. Figure 6 shows XRD patterns of annealed

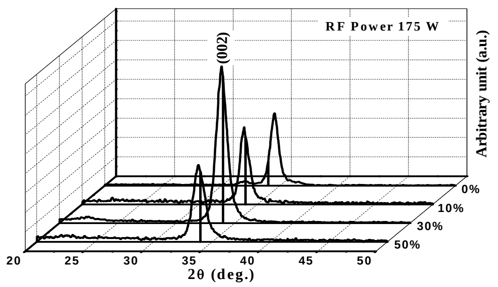

Fig.4 XRD pattern of ZnO films as functions of mixed O_2-Ar gas

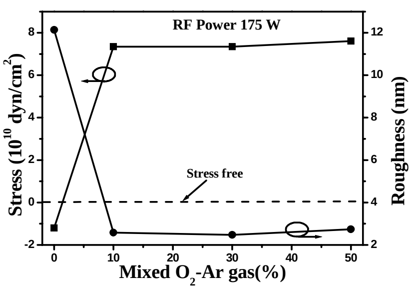

Fig.5 Stress and surface roughness of ZnO films as functions of mixed O_2-Ar gas

under oxygen atmosphere at various temperatures. The FWHM of each annealed ZnO film was much narrower than un-annealed one which implied that grain size grew at high annealing temperatures. An intense and narrowest FWHM was observed at annealing temperature of 400 ^oC. As annealed at 500 ^oC, both the intensity and FWHM were degraded due to the crystal overgrowth. The stress approached to stress free (~0.325 × 10^{10} dyn/cm^2) at annealing temperature reached 400 ^oC (as shown in Fig. 7). This revealed that the intrinsic stress induced from interstitial oxygen atoms was almost completely removed. Moreover, the surface roughness was also slightly improved after annealing.

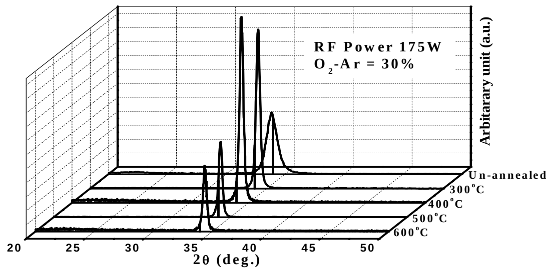

Fig.6 XRD pattern of ZnO films as functions of post-annealing treatments

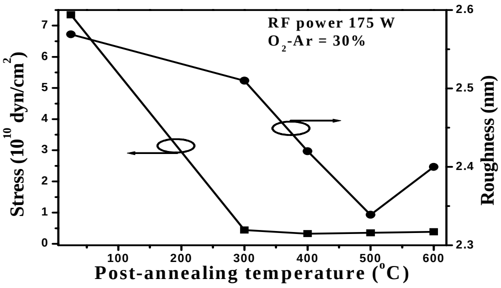

Fig.7 Stress and surface roughness of ZnO films as functions of post-annealing treatments

4. Conclusions

A preferred (002) oriented ZnO film with low stress and large grain size was obtained at an rf power of 175 W. Moreover, a best single crystallinity and superior surface roughness of ZnO film was achieved at the mixed O_2-Ar gas of 30 %. However, the stress was markedly increase attributed to the excess oxygen atoms. Therefore, a post-annealing treatment was employed to reduce the intrinsic stress. An excellent single crystalline ZnO film with almost stress free (~0.325 × 10^{10} dyn/cm^2) and lower surface roughness (~ 2.42 nm) was achieved as the ZnO films prepared at an rf power of 175 W under mixed O_2-Ar gas of 30% at room temperature and the associated post-annealing treatment at 400 ^oC under oxygen atmosphere. This ZnO film is promising to fabricate a layered SAW device with superior coupling coefficient.

Acknowledgments

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