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Structural studies of room-temperature RF magnetron sputtered ZnO films under different RF powered conditions

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Abstract

We have deposited the ZnO thin films on Si(0 0 1) substrate at room temperature by the RF magnetron sputtering method. We demonstrated that the radio frequency (RF) plasma power can dramatically affect the structural properties of ZnO thin films. Under the optimized condition of RF power of 150 W, a *c*-axis-oriented wurtzite structured ZnO thin film with the X-ray diffraction (XRD) full-width at half-maximum (FWHM) of 0.21° and the atomic force microscopy (AFM) root mean square (RMS) values of <20 nm was prepared.

Keywords: RF power; ZnO; Room temperature; Thin film

1. Introduction

ZnO thin films have been extensively studied for surface acoustic wave (SAW) devices, optical-wave guides, and transparent conducting coatings [1]. In addition, since the ZnO has a wide band gap of 3.37 eV, low power threshold for optical pumping at room temperature, and UV emission resulted from a large exciton binding energy of 60 meV, they can be used as light emitting diodes (LED), photodetectors, electroluminescence devices and the next generation UV laser.

ZnO films have been grown by various deposition methods, such as sputtering [2], sol–gel process [3], spray pyrolysis [4,5], pulsed laser deposition [6,7], ion beam deposition [8], plasma enhanced chemical vapor deposition (PECVD) [9], atomic layer deposition (ALD) [10], filtered cathodic vacuum arc technique [11], evaporation [12], metal–organic chemical vapor deposition (MOCVD) [13,14], and molecular beam epitaxy (MBE) [15].

High quality ZnO films grown on Si substrate pave the way for integration of devices with the mature Si integrated circuits technology and amorphous substrates such as SiO_2 and glass substrate have obvious technological advantages and potential applications [16]. Also, the magnetron sputtering is a preferred technique due to its potential for low temperature processing [17]. Although some researchers have grown ZnO films at very low temperatures such as room temperature, the effects of radio frequency (RF) power on the structural characteristics of ZnO thin films have not been sufficiently investigated. In this study, we deposit the ZnO thin film on Si(0 0 1) substrates at room temperature using the RF magnetron sputterer and investigated the effect of RF power on the structural quality of ZnO thin films. The properties of the ZnO thin films were studied employing X-ray diffraction (XRD), atomic force microscopy (AFM), and scanning electron microscopy (SEM).

2. Experimental

A schematic diagram of the RF sputtering system used in our experiments is described in Fig. 1. The sputtering was carried out in an Ar (99.99% purity) gas atmosphere by supplying 150–300 W RF power at a frequency of 13.56 MHz. The flow rate of the Ar gas was set to 30 sccm. The distance between target and substrate was about 80 mm.

Before loading into the reactor, the Si(0 0 1) substrate was cleaned in acetone for 10 min, HF (20:1) for 1 min and then rinsed by deionized water for 1 min. In this experiment, we have used a ZnO (99.99% purity) target with a diameter and

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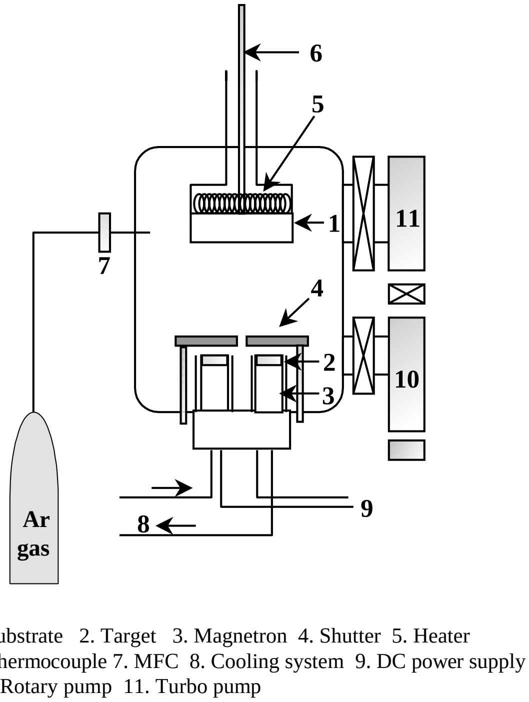

Fig. 1. Schematic diagram of RF magnetron sputtering system.

a thickness of 75 and 6 mm, respectively. The ZnO film was grown at room temperature at a pressure of 5.0×10^{-2} Torr and deposition was carried out for 2 h. The structural characteristics of the films were analyzed by XRD using Cu Kα1 radiation ($\lambda = 0.154056$ nm) and by SEM (Hitachi S-4200). The surface roughness was measured using AFM (Digital Instruments Nanoscope III).

3. Results and discussion

In order to investigate the surface roughness of the ZnO films grown on Si(0 0 1) substrate, we have presented the AFM data. The root mean square (RMS) roughness values of the surface of ZnO layers are summarized in Fig. 2. They become larger with increasing the RF power. Fig. 3 shows the AFM topographies of ZnO film surface, indicating that the grain size on top of the ZnO film increases with increasing the RF power.

Fig. 4 shows the plain-view SEM images of ZnO thin film deposited at room temperature, with varying the RF power ranging from 150 to 300 W. The images indicate that the grain size on top of the ZnO film increases with increasing the RF power in the range of 150–300 W. The SEM images agree with AFM measurement, because larger grain size may induce the rougher surface. It is worthy noting that the shape of the grain changes from the round type at 200 W to the plate type at 250 W.

Fig. 5 shows the cross-sectional SEM images of ZnO films deposited at room temperature with the RF power of (W): (a) 150, (b) 200, (c) 250, and (d) 300. The image of the ZnO film deposited with the RF power of 150–200 W shows that most film structure consist of columnar-structured grains, possibly representing *c*-axis oriented grains. However, close examination of the image reveals that there are some small-grained structures especially at the bottom part of the film, corresponding to the initial growth. We surmise that the ZnO films deposited with the RF power of 150–200 W have smaller grains at the beginning and as the growth proceeds, the small-grained structures are changing into the larger-grained columnar structures. The image of

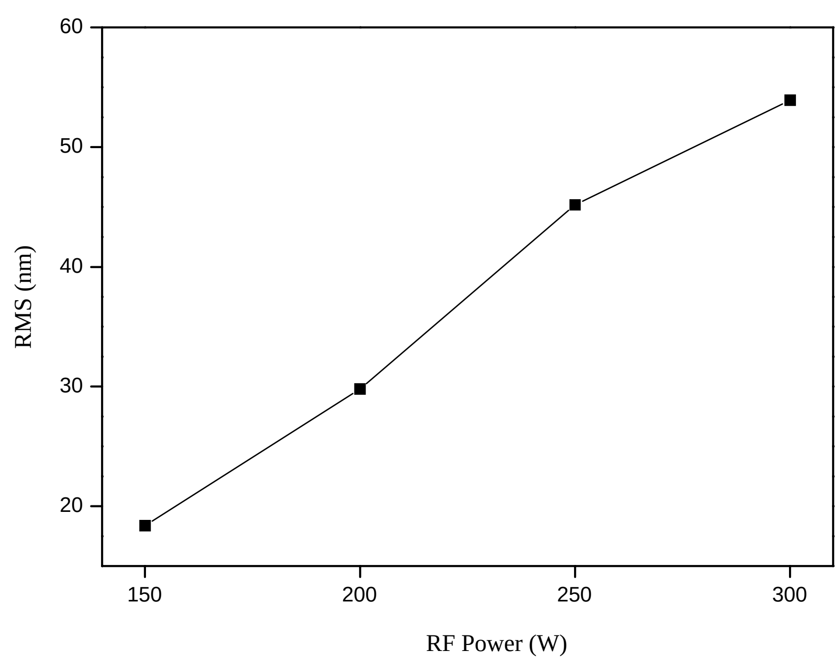

Fig. 2. AFM RMS roughness values of ZnO thin film on Si(0 0 1) substrate deposited at room temperature with the RF power ranging from 150 to 300 W.

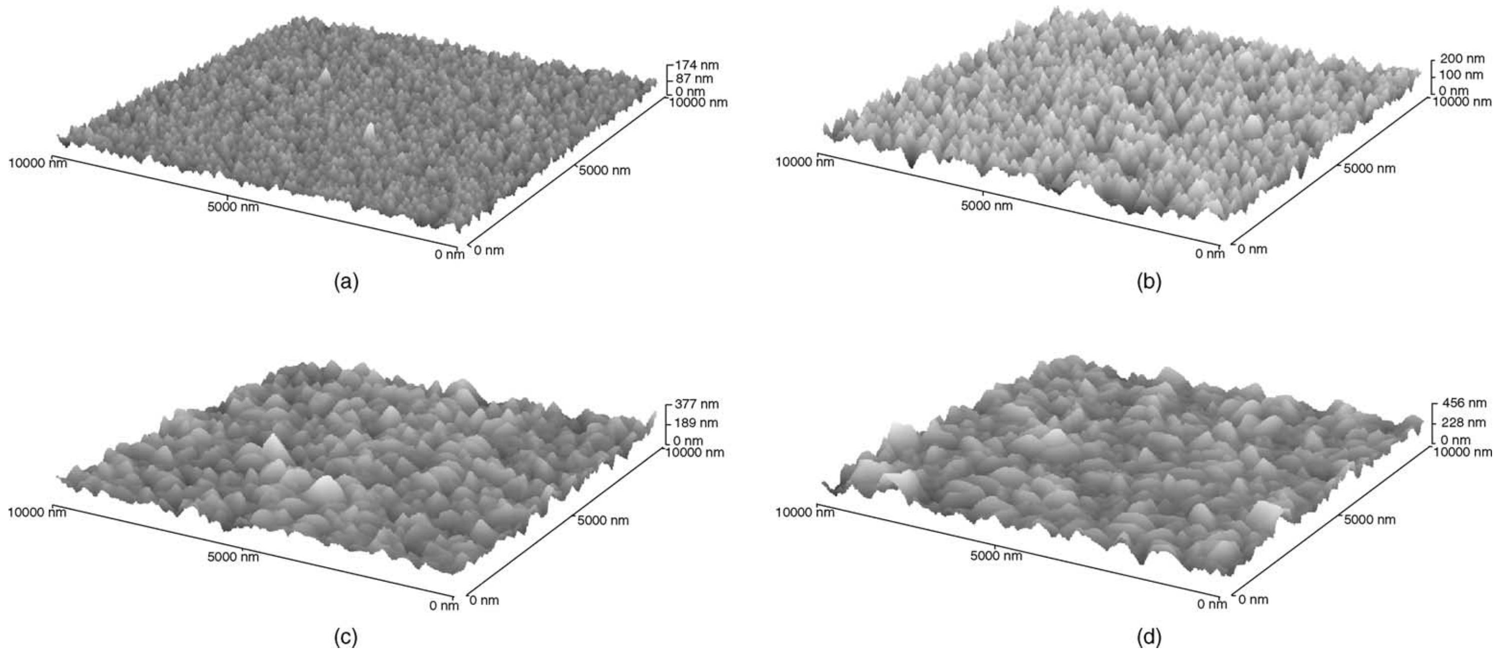

Fig. 3. Images of the ZnO thin film deposited with the RF power of (W): (a) 150, (b) 200, (c) 250, and (d) 300.

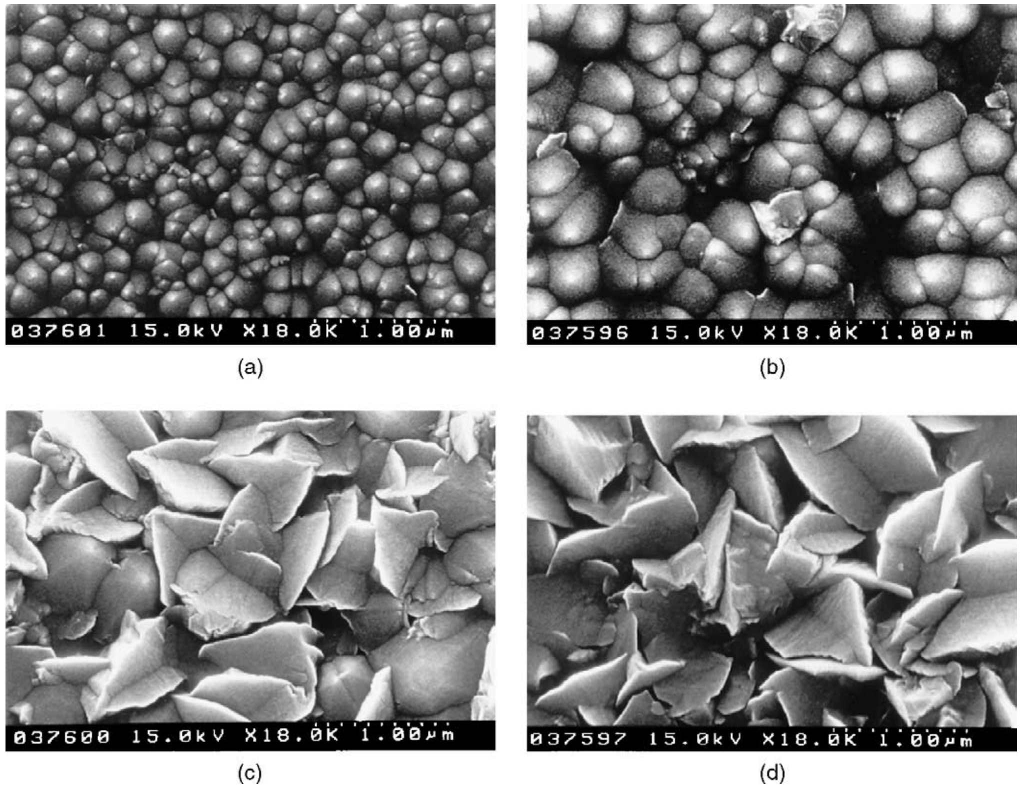

Fig. 4. Plain-view SEM images of the ZnO thin deposited with the RF power of (W): (a) 150, (b) 200, (c) 250, and (d) 300.

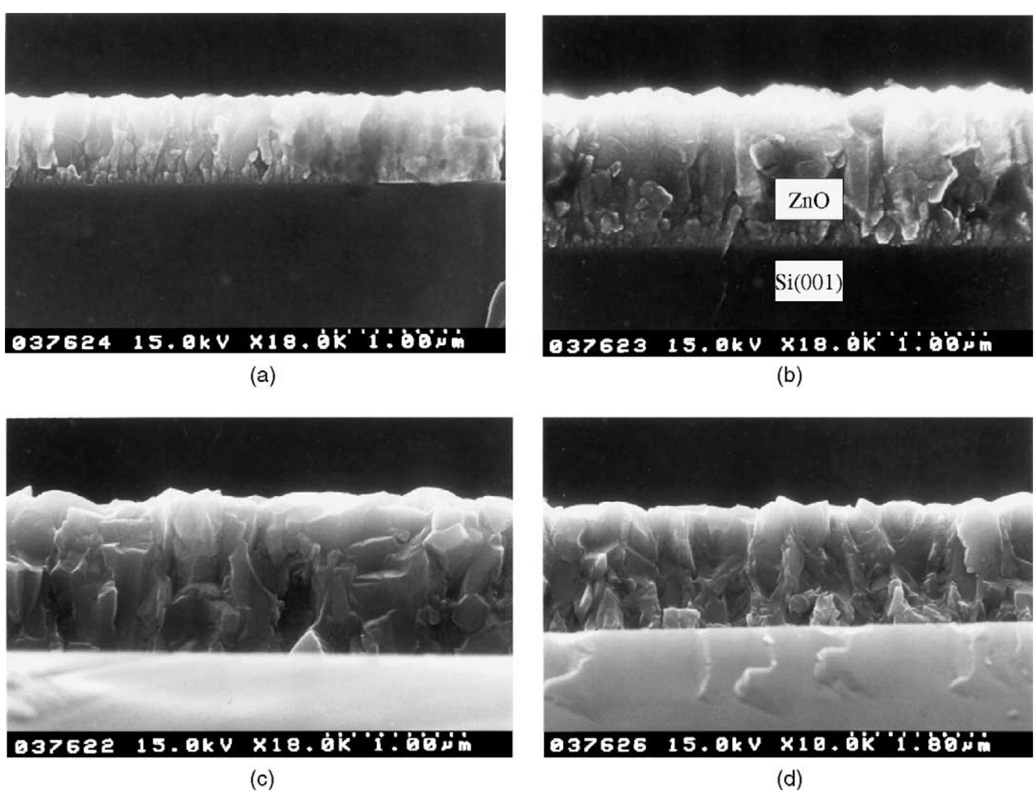

Fig. 5. Cross-sectional SEM images of the ZnO thin film deposited with the RF power of (W): (a) 150, (b) 200, (c) 250, and (d) 300.

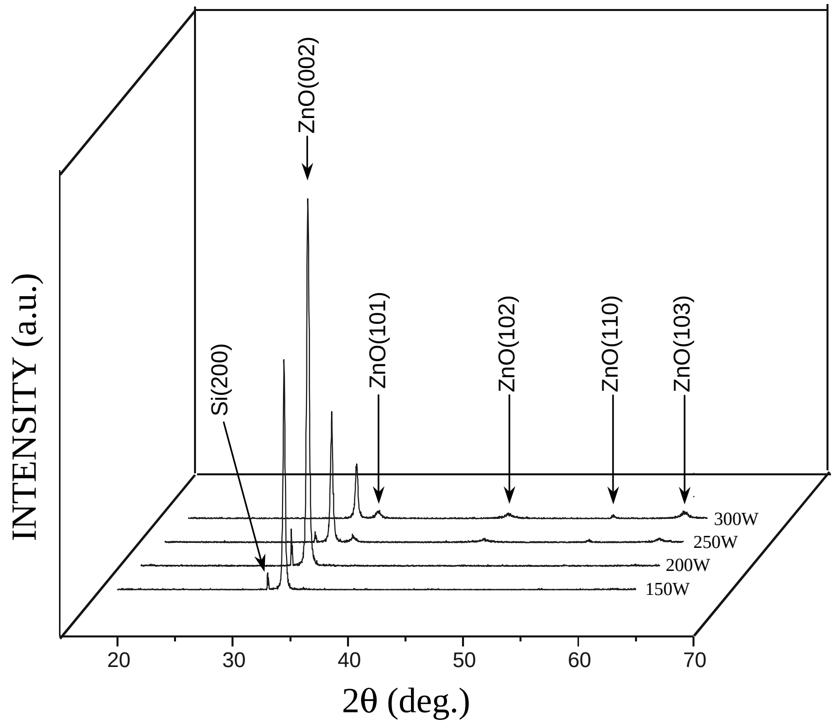

Fig. 6. XRD patterns of the ZnO thin film deposited with varying RF power ranging from 150 to 300 W.

the ZnO film deposited with the RF power of 250–300 W (Fig. 5(c) and (d)) shows that most film structure consists of plate-like grains, very much different from the film with the RF power of 150–200 W (Fig. 5(a) and (b)). Although we cannot explain the growth mechanism at this moment, further study is necessary to understand this observation.

Fig. 6 shows the θ–2θ XRD patterns of the ZnO thin film deposited at room temperature with varying RF power ranging from 150–300 W. The θ–2θ scan data of ZnO films exhibit a strong 2θ peaks at 34.53°, corresponding to the (0 0 2) peaks of ZnO. Since the relative intensity of the ZnO(0 0 2) diffraction peak is significantly strong compared to the neighboring ZnO(1 0 1) peak, we surmise that the *c*-axis oriented ZnO films is obtained.

Close examination of the XRD patterns indicates that the relative intensity of the ZnO(0 0 2) diffraction peak compared to the neighboring peaks, such as (1 0 1) and (1 0 2) peaks in case of 250–300 W, is lower than in case of 150–200 W, indicating that the *c*-axis orientation of ZnO films decreases by introducing the excessive RF power. The FWHM of (0 0 2) diffraction peaks at RF powers of 150, 200, 250, and 300 W, respectively, are 0.21, 0.24, 0.24, and 0.28°.

We surmise that excessive RF power induces the faster reaction rate and the severe surface damage, resulting in the poor crystalline quality. Accordingly, the RF power needs to be sufficiently low for efficient nucleation and growth and thus for obtaining the *c*-axis oriented and smooth-surface films. Further study is necessary to reveal the detailed mechanism. Also, although the deposition rate is supposed to be very low at the lower RF-powered conditions (<150 W), more systematic study is underway to reveal the structural characteristics of the ZnO thin films in those cases.

4. Conclusion

ZnO thin films have been grown on Si(0 0 1) substrates at room temperature. It has been shown that the RF power affects the structural quality of the ZnO thin films. The *c*-axis orientation, as well as the morphology of the surface of ZnO thin films, are dependent on the RF power. At the optimal RF power of 150 W, a *c*-axis oriented ZnO thin film with a smooth surface is obtained and the FWHM of the ZnO(0 0 2) diffraction peak is about 0.21°.

Acknowledgements

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