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Effect of substrate position on Structural, Morphological, and Optical properties of reactively sputtered ZnO thin films

J. Vinoth Kumar, Y. Matsumoto, A. Maldonado, and M. de la L. Olvera

Departamento de Ingeniería Eléctrica, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, CINVESTAV-IPN, SEES, Apartado Postal 14740, México, D.F., 07000, México.
Email: vinoth.jc@gmail.com

Abstract— **In this work, we have investigated the structural, morphological, and optical properties of ZnO thin films by placing the substrate at different locations of the substrate holder. ZnO thin films were grown on glass substrates by reactive radio frequency (RF) sputtering at 100W. Structural results obtained from XRD revealed that ZnO thin films were grown along (002) plane. Morphological studies showed that films were formed from nanograins of ZnO. Optical measurements in the UV-vis region presented an average transmittance >90%.**

Keywords—ZnO; thin films; substrate position; rf sputtering; structural; optical; morphological properties.

I. Introduction

Zinc oxide (ZnO) is a wide bandgap semiconductor (3.3eV) of II-VI group in periodic table [1]. ZnO has excellent properties such as optical transparency in the visible region, good electrical conductivity by doping, piezoelectricity and photocatalytic properties [2-5]. Richness in several properties enables ZnO to be used in applications like solar cells [6], thin film transistors [7], waveguides [8], and gas sensors [9], among others.

ZnO in thin film form can be achieved by different deposition techniques like molecular beam epitaxy [10], sputtering [11], chemical vapor deposition [12], pulsed laser deposition [13], atomic layer deposition [14], thermal evaporation [15], e-beam evaporation [16], chemical bath deposition [17], electrophoretic deposition [18], sol-gel [19], and ultrasonic spray pyrolysis [20]. Among these several vacuum and non-vacuum techniques, we have chosen sputtering. The various parameters involved in sputtering are power [21], pressure [22], substrate temperature [23], distance between target and substrate [24], and substrate rotation speed [25].

In the literature, there are reports available based on the sputtering parameters mentioned above. However, to the best of our knowledge, there are no much studies reported about the substrate position effect. In this work, we have placed substrates at different locations on the rotating substrate holder and carried out the sputter deposition of ZnO. In addition, we have examined the structural, morphological and optical properties of grown ZnO thin films.

II. Experimental

A. Thin films deposition

Undoped ZnO thin films were deposited by RF sputtering on glass substrates by using a zinc metallic target (99.993-99.995% pure, from Kurt J. Lesker). Two substrates were placed on a substrate holder as shown in the schematic (Fig. 1). Then vacuum was created in the chamber using mechanical pump and turbo molecular pump. Once the base pressure of ~5.5×10^{-5} Torr was achieved, by passing the working gases, argon (10 sccm) and oxygen (7.5 sccm), working pressure of 13 mTorr was maintained in the chamber. Later, by supplying 100W of RF power to the magnetron source, ZnO thin films were grown on the glass substrates. The rotation speed of the substrate holder was kept at 5 rpm and the deposition time was of 2h. Based on the substrate positions, the thin films were labelled as P1, and P2.

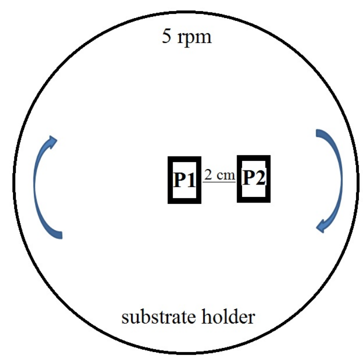

Fig. 1. Placement of the substrates: One substrate is placed in the center of the substrate holder (P1), and another is placed 2 cm away from the center (P2).

B. ZnO thin films characterization

We have measured the thicknesses of the ZnO films using a KLA Tencor profilometer (P1=302 nm, and P2=334 nm). The structural properties were analyzed using the X-ray diffraction patterns obtained from PANalytical instrument. The morphological characteristics were viewed with a Zeiss-Auriga scanning electron microscope (SEM). The optical transmittance of the ZnO films was measured from a Shimadzu spectrophotometer in the UV-vis region, 300-1000 nm.

III. RESULTS AND DISCUSSION

A. *Structural properties*

X-ray diffraction patterns of sputtered ZnO thin films are given in Fig. 2. Both films presented a strong intense peak along (002) plane which confirms ZnO films are grown along c-direction of hexagonal wurtzite structure. A very weak peak is found for (103) plane. The peak positions (2θ) of (002) planes of P1 and P2 are 33.85 and 34.09°, respectively. However these values are little shifted from the standard value 34.42° (JCPDS File No: 01-089-0510) which reveals that strain exists in the films [26]. The intensity of the peak (002) is increased when the substrate is placed at P2. This result can be associated to the higher thickness of P2, nevertheless the thickness hardly changes by 32 nm.

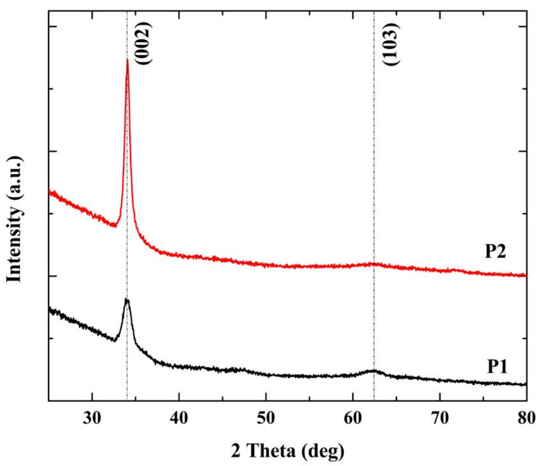

Fig. 2. XRD patterns of ZnO thin films deposited at different positions.

The crystallite sizes (L) are determined by employing Scherrer's formula, $L = 0.9\lambda/\beta\cos\theta$ [26], where
$\lambda = 1.54$Å
β = Full-width at half-maximum (FWHM)
θ = diffraction angle in radians.
The estimated L values of P1 and P2 samples are 7.4 and 9.3 nm, respectively. Identical low level values are found in the previous report of Yoshitake's group [27].

B. *Morphological characteristics*

ZnO thin film morphologies are shown in Fig. 3a-b. Both samples presented nanograined ZnO. P1 thin film has nanograins of size variations between ~30 to 70 nm. P2 thin films also presented the same nanograined ZnO structures. The sizes of the nanograins oscillate between ~20 to 60nm. Though the grain size didn't make much difference, there are some differences based on the agglomeration sites. The P1 sample surface appears to be agglomerated more than the sample P2. Identical nanograins of ZnO films have been reported by different authors [28,29]. Thus from the morphological images we can understand that the placement of the substrate is an important factor in preventing agglomeration.

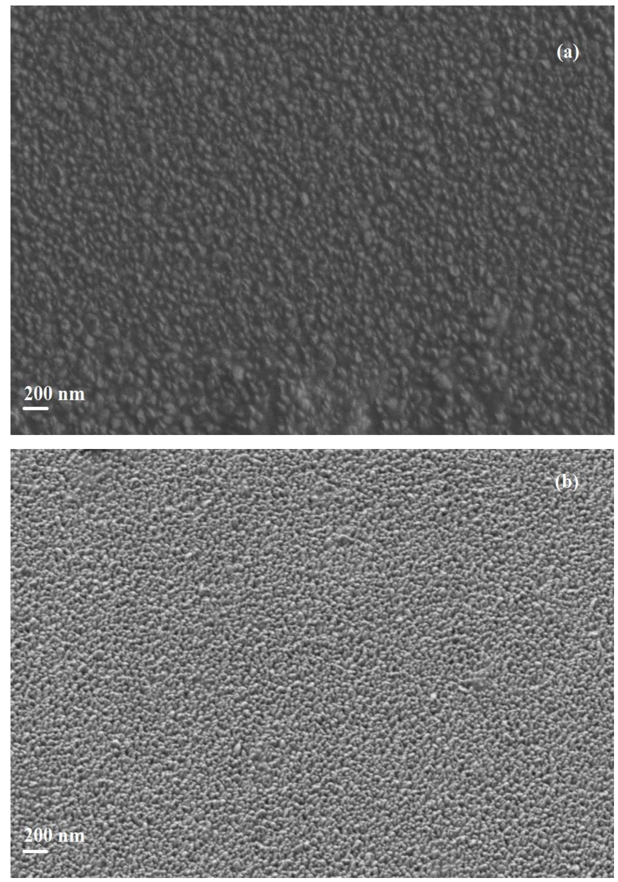

Fig. 3. Sputtered ZnO thin film morphologies; (a) P1, and (b) P2.

C. *Optical characteristics*

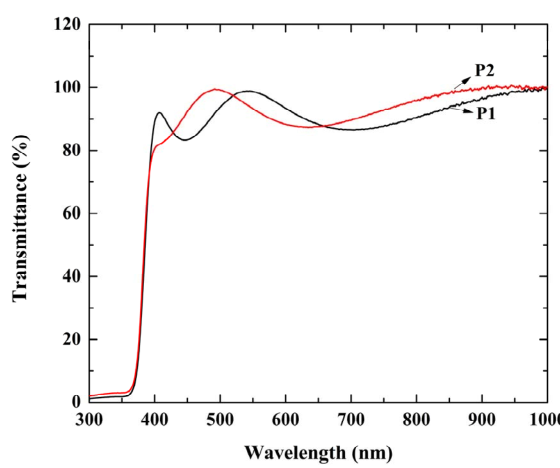

Fig. 4. Transmittance spectra of ZnO thin films deposited at P1 and P2 positions.

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The transmittance spectra of undoped ZnO thin films in 300-1000 nm region are shown above in Fig. 4. Both samples presented high transmittance values. The transmittance at 550 nm of P1, and P2, are 93.4 and 98.4%, respectively. However, there is a slight difference in the transmittance values which appeared due to the difference in the thickness magnitude of the ZnO films. Similarly, many studies have reported that thickness affects the transmittance values [30]. Additionally, the presence of interference fringes in the transmittance assures that films are grown with high quality. In this respect, Ilican et al. also correlated the interference fringes with the quality of indium doped ZnO films [31]. The bandgap of the films was calculated using the plot hγ versus $(\alpha h\gamma)^2$, and then extrapolating the linear part to the αhγ=0 value. The extrapolated (E_g=band gap) values of P1 and P2 are 3.25 and 3.26 eV, respectively.

IV. Conclusions

The undoped ZnO film fabrication was carried by placing glass substrates at different locations of substrate holder. The growth of ZnO was well controlled by maintaining a working pressure of 13 mTorr in an RF sputtering chamber. Structural, morphological, and optical characteristics of ZnO thin films were investigated. The structural results confirmed that films were grown along (002) plane with good crystallinity. From scanning electron microscope images, the estimated grain size of ZnO was found to be <100 nm in both samples. Optical transmittance of ZnO films were >90%. According to the characterization results it can be concluded that, sample position in the substrate holder in the sputtering system influences the physical properties of the deposited ZnO thin films. Our prospective work is to analyze the properties of doped ZnO thin films with respect to the placement of substrates.

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