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Dependence of the electrical and optical properties on the bias voltage for ZnO:Al films deposited by r.f. magnetron sputtering

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Abstract

Aluminum-doped zinc oxide (ZnO:Al) thin films were deposited on glass, polycarbonate (PC), and polyethylene terephthalate (PET) substrates by r.f. magnetron sputtering. The substrate dc bias voltage varied from 0 V to 50 V. Structural, electrical and optical properties of the films were investigated. The deposition rate of ZnO:Al films on glass substrate initially increased with the bias voltage, and then decreased with further increasing bias voltage. It was found that the best films on glass substrate with a low as 6.2×10^{-4} Ω cm and an average transmittance over 80% at the wavelength range of 500–900 nm can be obtained by applying the bias voltage of 30 V. The properties of the films deposited on polymer substrate, such as PC and PET, have a similar tendency, with slightly inferior values to those on glass substrate.

Keywords: Al-doped ZnO (ZnO:Al); R.f. magnetron sputtering; Bias voltage; Polymer substrate

1. Introduction

Transparent conducting oxide (TCO) films based on zinc oxide are taking a great impact because they have a number of advantages, such as non-toxicity, low cost, material abundance, relatively low deposition temperature, and high stability against hydrogen plasma compared to ITO and SnO_2 films [1]. TCO films deposited on polymer substrates have many merits due to their light weight, small volume. Devices made from these films can be folded and easily carried. They can be used in plastic liquid crystal display devices, transparent electromagnetic shielding materials, flexible electro-optical devices, and unbreakable heat-reflecting mirrors [2]. In order to realize sputter deposition of the ZnO films on plastic substrate, low temperature and damage-less deposition is necessary to obtain the film with low resistivity. Many researchers have tried to produce highly conductive ZnO films at low substrate temperature [3–5]. However, it became difficult to obtain a film with low resistivity without substrate heating. Recently, the introduction of H_2 gas during film growth or *in-situ* H_2 post-treatment on the undoped ZnO films were performed in order to achieve highly conductive films [3,6]. In addition, Raniero et al. [7] and Tohsophon et al. [8] reported the electro-optical behavior and the structure of gallium-doped zinc oxide (GZO) after hydrogen plasma treatment and the damp heat stability behavior of aluminum doped zinc oxide (AZO or ZnO:Al) films to investigate the chemical stability and the long-term stability.

For sputtering technique, it is well known that the energetic particles such as electrons [9] and negative ion [10] have some impact on the deposited film. Also it was reported that composition of a ceramic film was much dependent on substrate bias [11] and proper ion impact on the deposited film caused improvement of film properties [12]. In this study, ZnO:Al films were deposited on glass, PC, and PET at room temperature by r.f. magnetron sputtering. The effects of bias voltage on the electrical and optical properties of the films were evaluated.

2. Experimental

The ZnO:Al films were prepared by r.f. magnetron sputtering system. The polymeric substrate used in this work was PC and PET with a standard thickness of 100 μm. A commercially available, sintered ceramic ZnO:Al (2 wt.% Al_2O_3) target with

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99.99% purity (Superconductive Materials Co.) of 3 inch in diameter was employed as source materials. The target-to-substrates distance was 7 cm. Before depositing the ZnO:Al thin films, the substrates were ultrasonically cleaned in a detergent bath, followed by methanol alcohol and dried in nitrogen. The substrates were placed inside the chamber and then evacuated to a base pressure of 6.6×10^{-4} Pa. The gas pressure was kept at 0.3 Pa and the sputtering power during deposition was 150 W. All the films were deposited at room temperature and the target was water-cooled. The substrate surface was monitored by thermocouple during sputter deposition. Although the substrates were not intentionally heated, the surface temperature reached about 40 °C. The substrate was negatively biased with d.c. source of −20 to −80 V.

The film thickness was measured by a conventional stylus surface profiler. The film thickness is 200 nm and all samples kept the same thickness in this work. Because the polymer substrate, such as PET, deforms during electron microscopic investigation, atomic force microscope (AFM) was used to investigate the microstructure of films. A compositional analysis was performed using X-ray photoemission spectroscope (XPS). The sheet resistance of the samples was measured with a four-point probe and the resistivity of the film was calculated. Carrier concentration and Hall mobility were obtained from Hall-effect measurement by the Van der Pauw technique. The optical transmittance measurements were performed with a Hitachi UV-3200 spectrophotometer.

3. Results and discussion

The prepared films at optimum conditions on PC or PET substrates were physically stable and had good adhesion to the substrates. No cracking or peel-off of the films was observed after deposition.

Fig. 1 shows the deposition rate of ZnO:Al films deposited on glass substrate at different bias voltages. The deposition rate initially increases with the bias voltage. This is due to the Ar^+ cation and clusters of the sputtered material in the plasma being

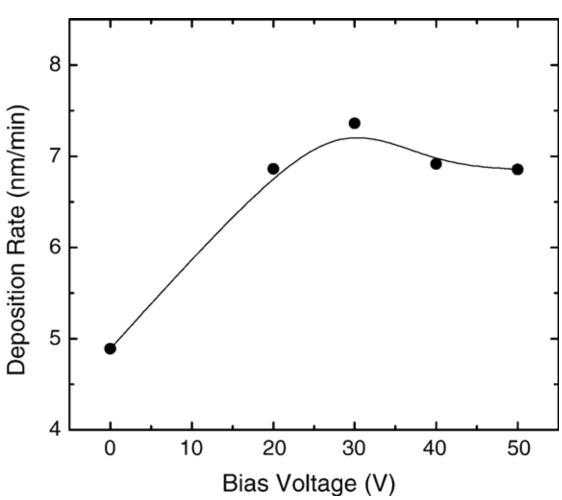

Fig. 1. The dependence of the deposition rate on bias voltage for ZnO:Al films.

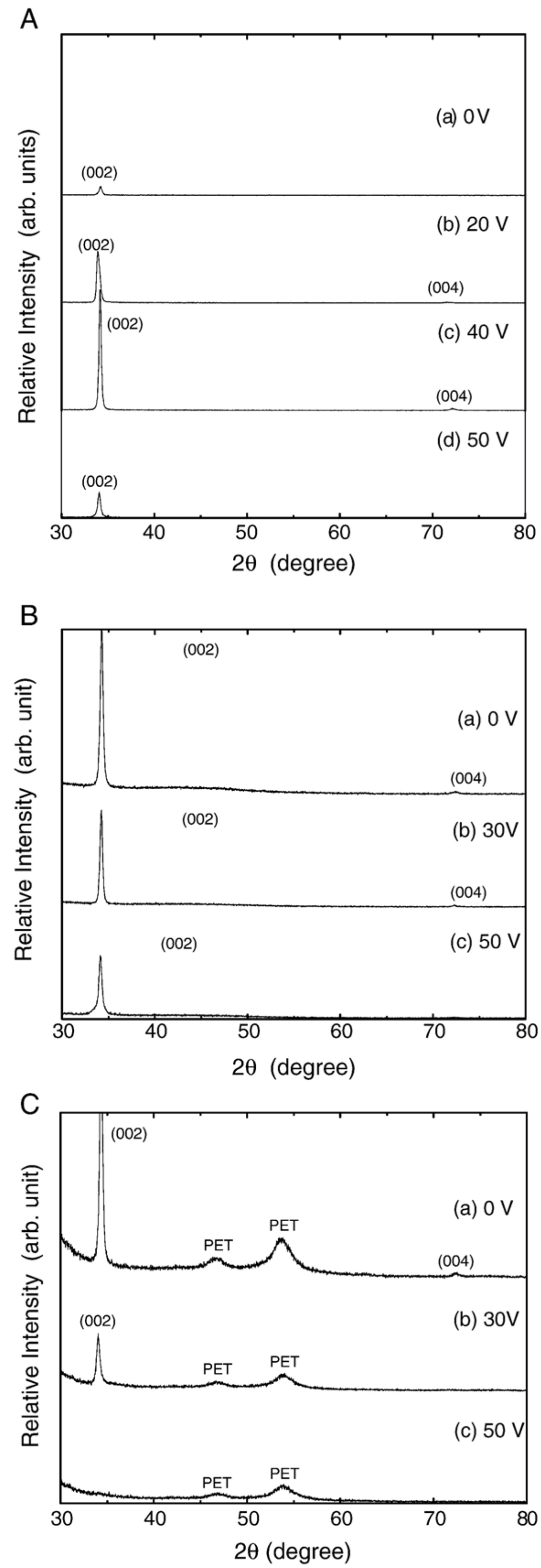

Fig. 2. X-ray diffraction patterns for films deposited at different bias voltages: (A) glass substrate; (B) PC substrate; (C) PET substrate.