Applied Surface Science 257 (2010) 1063–1067

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Structural, electrical and optical properties of Ga-doped ZnO films on PET substrate

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ARTICLE INFO

Article history:
Received 6 February 2010
Received in revised form 29 July 2010
Accepted 3 August 2010
Available online 8 August 2010

Keywords:
Transparent conducting oxide
ZnO
O_2 plasma
Polyethylene terephthalate (PET)

ABSTRACT

The effects of O_2 plasma pretreatment on the properties of Ga-doped ZnO films on PET substrate were studied. Ga-doped ZnO films were fabricated by RF magnetron sputtering process. To improve surface energy and adhesion of PET substrate, O_2 plasma pretreatment process was used prior to GZO sputtering. With increasing O_2 plasma treatment time, the contact angle decreases and the RMS surface roughness increases significantly. The transmittance of GZO films on PET substrate in a wavelength of 550 nm was 70–84%. With appropriate O_2 plasma treatment, the resistivity of GZO films on PET substrate was 3.4×10^{-3} Ω cm.

1. Introduction

Transparent conducting oxide (TCO) films have been widely used in various optoelectronic applications. One of the TCO films, In-doped SnO_2 (ITO) film has been mostly used in flat panel display (FPD) such as liquid crystal display (LCD), plasma displays (PDP) and organic light-emitting devices (OLEDs). However, ITO exhibits disadvantages including toxicity, instability to hydrogen plasma and increasing price due to the global indium shortage. Accordingly indium-free TCO materials have attracted considerable attention.

ZnO-based TCO materials have been studied extensively to replace ITO as they exhibit strong merits including low material cost, relatively low deposition temperature, non-toxicity and the stability in hydrogen plasma [1,2]. As the TCO films require low resistivity of less than 10^{-3} Ω cm, Group III donor elements (Ga, Al, and B) are typically added to improve the electrical properties of ZnO film [3–5]. Although Al-doped ZnO TCOs present favorable electrical properties, aluminum exhibits significantly high reactivity to oxygen leading to the oxidation during film growth, which may result in the degradation of electrical properties. As the gallium is less reactive to oxidation, Ga-doped ZnO (GZO) TCO materials has been reported to have better stability [6].

Among various deposition process, RF and DC magnetron sputtering methods are widely used to prepare GZO films because of high deposition rate, good adhesion, and easy controlling the electrical properties of films by adjusting processing parameters [7–9]. The resistivity of GZO films was reported as $<2.0 \times 10^{-4}$ on glass substrate and $4–9 \times 10^{-4}$ Ω cm on polymer substrates [7,10,11].

Recently the necessity of studying deposition process of TCO films on polymer substrates has increased as the polymer substrates are suitable for flexible displays and optoelectronics. As the polymer substrates are cheaper, lighter and flexible when compared to conventional glass substrate, they could be effectively used in the applications such as flexible display and flexible solar cells. However, polymer substrates exhibit several demerits such as poor thermal, optical and electrical properties. To improve surface energy and adhesion between TCO and polymer substrate, oxide buffer layers (e.g. SiO_2) are typically used [12].

In this work, the properties of GZO films grown on polyethylene terephthalate (PET) by RF sputtering processing were studied. Especially, O_2 plasma pretreatment process was used instead of conventional oxide buffer layers. The O_2 plasma treatment process have several merits compared to oxide buffer layer especially in mass production scale. In this process, there is no need of additional sputtering system for oxide composition and the plasma treatment process could be easily adopted as an in-line process. In this study, the effects of the O_2 plasma pretreatment of PET substrate on the electrical and optical properties of GZO films were examined and the properties were compared with those of GZO films on glass substrate.

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doi:10.1016/j.apsusc.2010.08.014

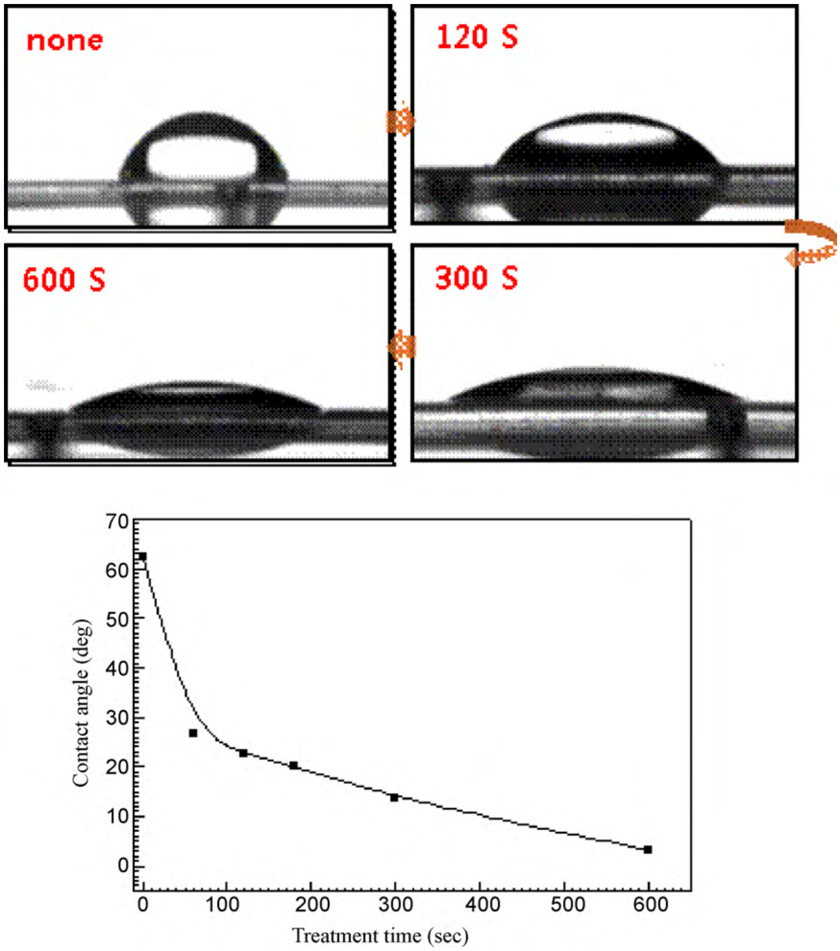

Fig. 1. The effect of O_2 plasma treatment time on the contact angle of PET substrate.

2. Experimental

In this work, RF (13.56 MHz) magnetron sputtering process was used. Sputtering target (4-inch diameter) was a mixture of ZnO powder and Ga_2O_3 (5.0 wt%) powder. The substrates were PET (Dupont 453) and glass (Corning 1737).

In case of the GZO films on the glass substrate, the RF power was controlled as 90–150 W and the substrate temperature as room temperature (RT) ∼ 400 °C. However, with PET substrate, the RF power was controlled as below 100 W and the substrate temperature was RT to avoid substrate damage. The thickness of GZO films was typically 150 nm. In case of PET substrate, the substrate was pretreated with high-density inductively coupled O_2 plasma prior to the GZO film growth to increase the surface energy of PET. Details of processing parameters are summarized in Table 1.

Table 1
The processing parameters of GZO films on PET and glass substrates.

Parameters	Glass substrate	PET substrate
Target	$ZnO:Ga_2O_3$ 5 wt%	$ZnO:Ga_2O_3$ 5 wt%
Surface plasma pretreatment	None	RF power: 100 W O_2 flow: 15 sccm Pressure: 20 mTorr Process time: 60–600 s
Substrate temperature	R.T. ∼ 400 °C	R.T.
RF power	90–150 W	90 W
Atmosphere	Ar 20 sccm	Ar 20 sccm
Processing pressure	5 mTorr	5 mTorr

The surface morphology was analyzed using a field emission scanning electron microscope (GELO, JSM-6700), atomic force microscope (PSIA, XE-100). The electrical resistivity, free carrier concentration and Hall mobility were estimated by a Hall effect measurement system (HMS-3000). The effects of the O_2 plasma pretreatment were measured by using contact angle measurement system (SEO, Phoenix 300). The optical transmittance of the films was measured by using a UV/VIS spectrophotometer (Agilent, HP 8453) in the wavelength range between 350 and 1000 nm.

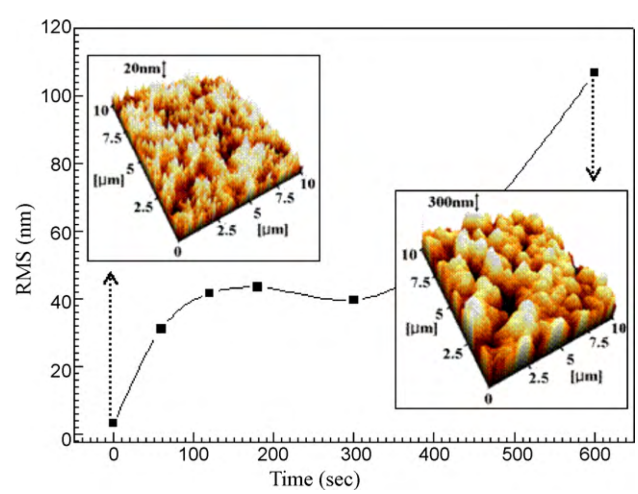

Fig. 2. The effect of O_2 plasma treatment time on the RMS surface roughness of PET substrate.