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Thin Solid Films 483 (2005) 296–300
www.elsevier.com/locate/tsf

Influence of annealing on the properties of ZnO:Ga films prepared by radio frequency magnetron sputtering

Xuhu Yu, Jin Ma*, Feng Ji, Yuheng Wang, Xijian Zhang, Honglei Ma

School of Physics and Microelectronics, Shandong University, Jinan 250100, China

Received 18 May 2004; accepted in revised form 11 January 2005
Available online 2 March 2005

Abstract

Transparent conducting gallium-doped Zinc Oxide (ZnO:Ga) thin films were prepared on glass substrates by r.f. magnetron sputtering technique at low substrates temperature. The effects of post-annealing treatment on structural, electrical and optical properties of ZnO:Ga films were investigated. The results show that the annealing treatment leads to substational changes in the structural, electrical and optical characteristics of ZnO:Ga thin films. The electrical resistivity and the average transmittance of ZnO:Ga films were improved by annealing in vacuum ambient. The average transmittance increases from 85% to more than 90% and the electrical resistivity decreases from 1.13×10^{-3} Ωcm to 5.4×10^{-4} Ωcm after annealing treatment.

PACS: 68.55Gi; 73.60.Cs; 78.30.Fs
Keywords: Sputtering; Zinc oxide; Electrical properties and measurement; Annealing

1. Introduction

ZnO transparent conducting films possess very interesting properties in the electrical and optical application fields. Due to their high conductivity and high transmittance in the visible part of the radiation spectra, ZnO based transparent conducting oxide thin films are widely used as amorphous silicon solar cell, liquid crystal display, gas sensors, and energy efficient windows [1–4]. Its n-type electrical conductivity is due to deviations from the stoichiometry resulting from oxygen vacancies and interstitial zinc, giving rise to a shallow donor level just below the conduction band. However, the electrical behavior of ZnO thin films could be improved by replacing Zn^{2+} atoms by elements with higher valence such as In^{3+}, Al^{3+} and Ga^{3+}. ZnO is commonly doped with Group III elements (B, In or Al) [5–7]. As for the ZnO films doped with Ga (ZnO:Ga),the common fabrication techniques are sputtering [8,9], chemical vapor deposition [10,11], sol–gel techniques [12], and pulsed laser deposition [13], et al. Independent of the deposition technique used the properties of the films, especially the

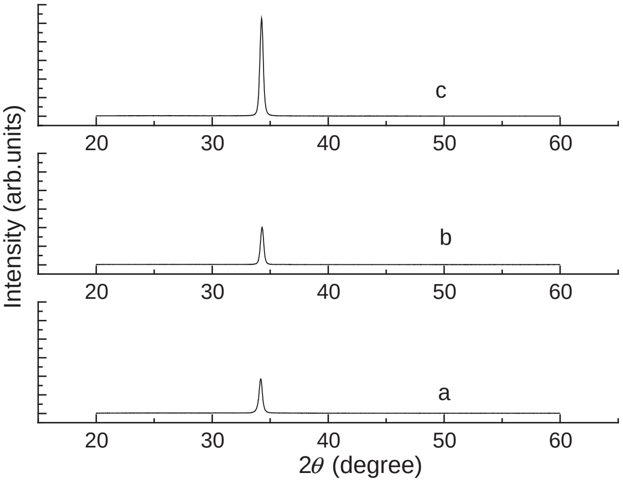

Fig. 1. X-ray diffraction spectra of ZnO:Ga films annealing at different temperatures: (a) as deposited, (b) 373 K and (c) 573 K.

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* Corresponding author. Tel.: +86 5 31 8361057; fax: +86 5 31 8564886.
E-mail address: yuxuhu111@mail.sdu.edu.cn (X. Yu).

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doi:10.1016/j.tsf.2005.01.013

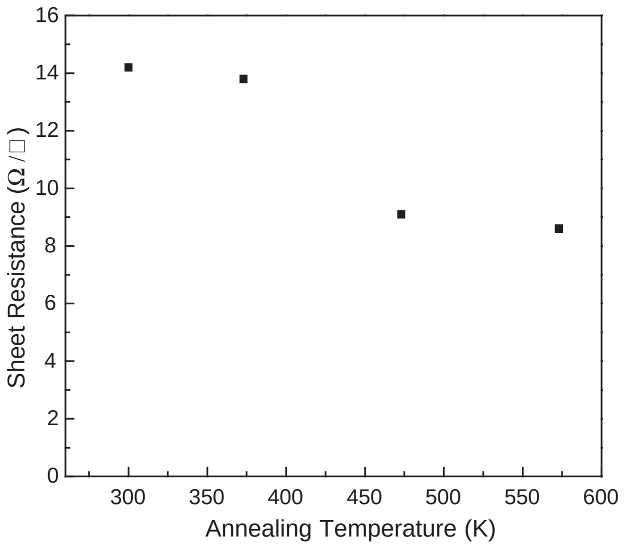

Fig. 2. Sheet resistance of ZnO:Ga films as a function of annealing temperature.

structural, electrical and optical ones, could be improved by post-annealing treatment under suitable conditions.

In this paper, transparent conducting ZnO:Ga films prepared on glass substrates by r.f. magnetron sputtering technique were reported and the effects of post-annealing treatment on structural, electrical and optical properties of ZnO:Ga thin films were investigated.

2. Experimental details

The films were prepared on glass substrate by sputtering an 8-cm diameter ZnO:Ga target in a conventional r.f. magnetron sputtering system with 8×10^{-4} Pa base pressure. A power supply operated at a crystal-controlled frequency of 13.56 MHz. The target with a mixture of ZnO (99.99% purity) and Ga_2O_3 (99.999 purity) was employed as source materials. The target was prepared using conventional sintering process. The amount of Ga_2O_3 added to the target was 3 wt.% [10,14]. The separation between target and substrates was 5 cm. The sputtering gas Ar with 99.999% purity was controlled via a crystal controlled high frequency power source. The r.f. sputtering power was 150 W and the argon gas pressure was 1 Pa. All the films with a 600–800 nm thickness were deposited at room temperature and the target was water-cooled. The films were annealed in vacuum at temperatures ranging from 200–400 °C in 50 °C intervals for 20 min.

The sheet resistances were measured with a four-probe instrument. The thickness of the films was measured using a Dektak II step-meter. The structural properties were determined with a Rigaku D/Max-γA X-ray diffractometer (XRD) which uses a Cu Kα radiation. The electrical resistivity and Hall mobility of the films were measured with Van der Pauw technique in the temperature range from 30 to 300 K. The optical transmittance measurements were performed with a Shimadzu TV-1900 spectrophotometer.

3. Results and discussion

Fig. 1 shows the X-ray diffraction spectra of an as-deposited sample and two samples annealing at different temperatures. All the sputtered ZnO:Ga films are highly textured , with the *c*-axis perpendicular to the substrates. Concerning the influence of the post-annealing, no other peak was detected with the increase of the temperature. Only (002) diffraction peak located at $2\theta=34.30^\circ$ is

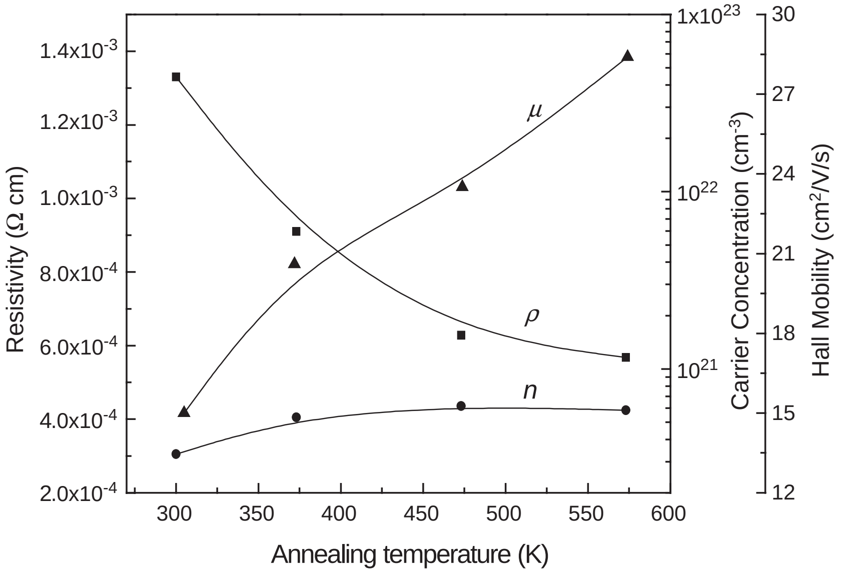

Fig. 3. The resistivity, Hall mobility and carrier concentrations as a function of annealing temperature.