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Preparation and characteristic of ZnO thin film with high and low resistivity for an application of solar cell

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Abstract

Al-doped zinc oxide (AZO) and undoped zinc oxide (UZO) films for the use as a transparent conductor and buffer layer of solar cell have been prepared using RF magnetron sputtering. Thin films with low resistivity can be achieved by using an Al-doped ZnO target, while films with high resistivity can be obtained by introducing an oxygen atmosphere during the deposition procedure. The AZO thin film shown with the lowest resistivity in this work was prepared with an RF power of 180 W, a sputtering pressure of 10 mTorr and a film thickness of 5000 Å that shows a resistivity of 1.4×10^{-4} Ω·cm and a transmittance of 95% in the visible range. On the other hand, the UZO film fabricated using reactive sputtering under a condition of more than 10% oxygen content exhibited the highest resistivity of 6×10^{14} Ω·cm. We have expected that the fabricated AZO and UZO thin films in this work are suitable for the application of a buffer layer and transparent electrode of CIS solar cell.

Keywords: ZnO; Solar cell; Sputtering; TCO

1. Introduction

Transparent conductive oxide (TCO) consists of a degenerated wide band-gap semiconductor with low electrical resistivity and high transparency in the visible and near-infrared wavelength range. Recently, zinc oxide thin films have been investigated due to their potential applications such as transparent electrodes [1,2] and windows in solar cells [3], in gas sensors [4], and as photocatalytic agents [5]. The ZnO is an n-type wide band-gap semiconductor and the electrical conductivity of the films is mainly due to intrinsic defects such as interstitial zinc atoms and oxygen vacancies. Its electrical conductivity can be increased by doping with group III elements such as aluminum, boron, gallium, and indium [6,7], or group VII elements such as fluorine [8,9], as well as by annealing treatments in controlled atmospheres [10]. In this direction, the AZO thin films have been obtained by several techniques such as sputtering [7,11], spray pyrolysis [12], pulsed-laser [13], and sol–gel [6,14]. The AZO films studied so far shows the resistivity ranging from 2 to 5×10^{-4} Ω cm, depending on the preparation technique, measurement conditions and, quite relevant, the atmosphere where the annealing treatment is done.

In this study, the high-quality ZnO films (doped and undoped) were fabricated on glass substrates using RF magnetron sputtering technique. Then, the films were characterized to examine the electrical, optical, and structural properties for the application of CIS solar cell. The detailed fabrication procedures and results of the AZO and UZO are described.

2. Experimental

The ZnO thin films were fabricated by unbalanced magnetron sputtering under a condition of a magnetic field of 3000 Gauss, and the target was prepared by sintering the mixture of ZnO powder with a purity of 99.9% and Al_2O_3 powder with a purity of 99.999%.

Sputtering was carried out at an rf power of 60–300 W and oxygen content of 0–100%. The films were deposited onto Corning 7059 glass, and the substrate was placed parallel to the target surface with a 5-cm distance. The shutter was placed between the target and the substrate in order to prevent undesirable sputtering.

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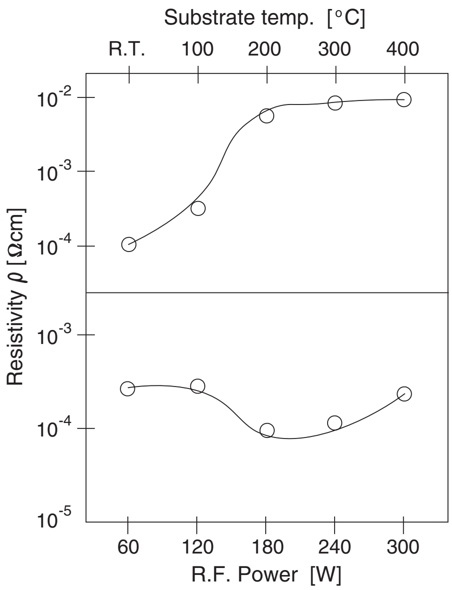

Fig. 1. Dependence of resistivity of AZO thin film on rf power.

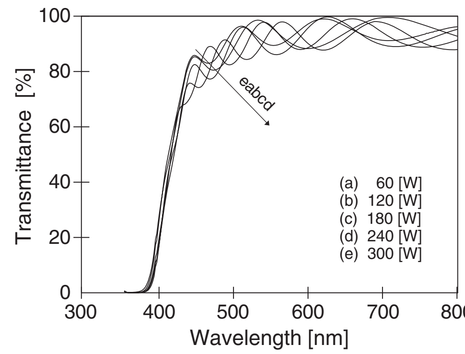

Fig. 3. Dependence of optical transmittance of AZO thin film on rf power.

The electrical characteristics of the fabricated thin films made with conditions of an rf power of 60–300 W and an oxygen content of 0–100% were investigated. The electrical resistivity (or resistance) was measured by a four-point probe system (SR1000, Chang Min Tech.) and electrometer (610C, Keithley). The optical transmission of the films was measured by spectrophotometer (U-3501, Hitachi). The film thickness was measured by surface profile measuring system (DEKTAK3, USA), respectively.

3. Results and discussion

Fig. 1 shows the electrical resistivity of the AZO films as functions of the RF power and the substrate temperature. All the films are deposited under conditions of 5000 Å thickness, 11 mTorr gas pressure, and room temperature. The resistivity of AZO without intentional heating exhibits the lowest value of about 1.4×10^{-4} Ω·cm at 180 W rf power [15]. As increasing RF power over ~180 W, the resistivity value of the samples was somewhat increased. In order to analyze this conduction mechanism, the Hall mobility and carrier concentration of the films were measured.

As shown in the Fig. 2, as the RF power increases, the resistivity values of the samples are decreased while showing higher Hall mobility and the carrier concentration at the RF power range of <180 W. The conduction mechanism of TCO investigated by many scholars is classified into two large groups: one was the occurrence of intrinsic carrier by oxygen vacancy, and the other was the introduction of extrinsic carrier by impurity doping. In this letter, the occurrence of the carrier caused by the development of resistivity was greatly affected by impurity doping than oxygen vacancy because the film deposited by the undoped target did not show a great increase like the case of Al-doped target. On the other hand, both Hall mobility and carrier concentration were decreased at the higher range of 180 W RF power. This characteristic can be understood from the fact that the

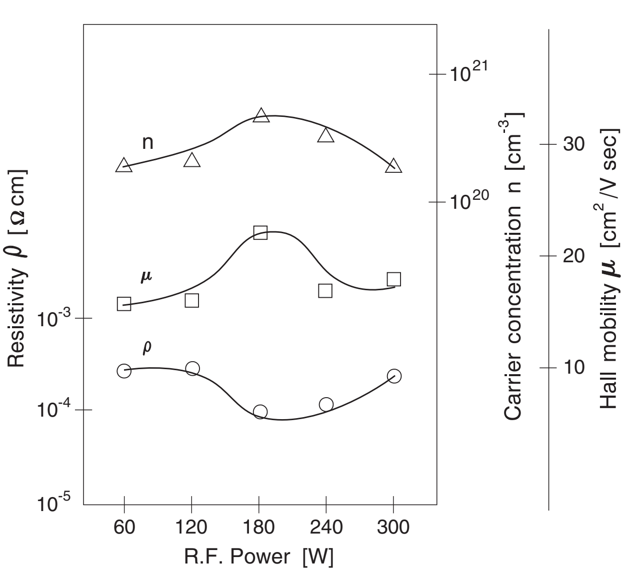

Fig. 2. Dependence of resistivity, carrier concentration and Hall mobility of AZO thin film on rf power.

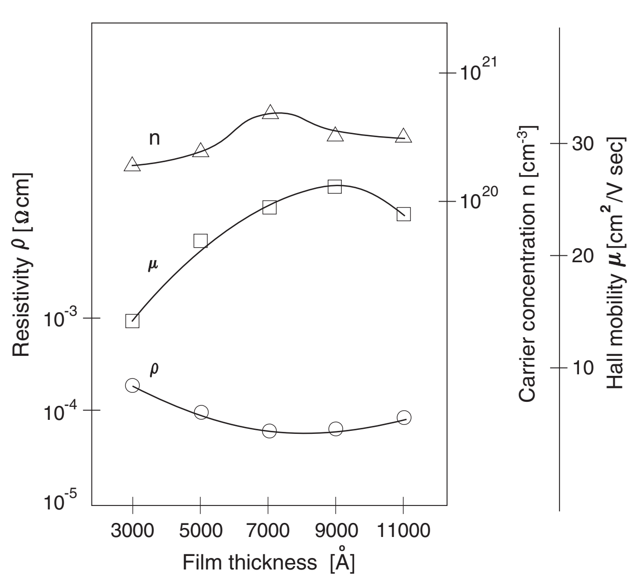

Fig. 4. Dependence of resistivity, carrier concentration and Hall mobility of AZO thin film on thickness.