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Effect of dopants and thermal treatment on properties of Ga-Al-ZnO thin films fabricated by hetero targets sputtering system

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ABSTRACT

In this study, we fabricated Ga and Al doped ZnO (Ga-Al-ZnO; GAZO) thin films by using the facing targets sputtering system under various conditions such as input current and thermal treatment temperature. The properties of the as-deposited GAZO thin films were examined by four-point, UV/Vis spectrometry, X-ray diffraction, atomic force microscopy and field-emission scanning electron microscopy.

The result showed that the lowest sheet resistance of the films was 59.3 ohm/sq and transmittance was about 85%. After thermal treatment, the properties of GAZO thin films were improved. The lowest sheet resistance (47.3 ohm/sq) of the GAZO thin films were obtained at thermal treatment temperature of 300 °C, considered to be the result of continuous substitutions by dopants and improved crystallinity by the thermal treatment.

1. Introduction

Transparent conducting oxide (TCO) materials are widely used for various devices such as organic light emitting devices, solar cells and transparent thin film transistors [1–3]. The most commonly used TCO material is indium tin oxide (ITO) because it has excellent conductivity and high transparency. On the other hand, ITO has some disadvantages such as high cost of indium and its instability in hydrogen plasma [4,5].

Among the various TCO materials, zinc oxide (ZnO) has been receiving much attention as the material to replace ITO. ZnO is an n-type semiconductor of hexagonal structure with a wide band gap of 3.4 eV and large exciton binding energy of 60 meV. It has many advantages including non-toxicity, good electrical, optical and piezoelectric properties, stability in hydrogen plasma atmosphere and low cost. However, ZnO has lower electrical properties than ITO, requiring the improvement of its electrical conductivity without affecting its high transparency. For this reason, Al or Ga-doped ZnO has recently gained much attention as an alternative material to ITO [6,7].

These impurity doped ZnO films have been fabricated by various deposition methods such as radio-frequency sputtering, direct-current sputtering, pulsed laser deposition, chemical vapor deposition, spray pyrolysis, ion plating and sol–gel method [8–14]. Among the various methods, the most representative one is sputtering, which produces films of low resistivity and high transparency with a dense structure. However, sputtering methods have a problem such as damage of film surface. In the case of the conventional sputtering method, the substrate is exposed to plasma because the structure of sputtering is designed to target the face of the substrate. So during the deposition process, the film surface is damaged by high energy particle bombardment, and as a result, the property of the as-fabricated film is degraded.

As shown in Fig. 1, the facing targets sputtering (FTS) system arrays two targets sheets to face each other. Because of this array formation, spiral shaped plasma is formed, and the *r*-electron is confined in the magnetic field. As a result, high density plasma is formed, and the gas ionization rate is increased. These conditions yield high quality films. And the substrate is located in a plasma-free area. Because of this structure, the FTS system can suppress high energy particle bombardment on the substrate. Therefore the FTS system is considered a low damage sputtering method for top emission organic light emitting devices which have high efficiency without defects. Also, the FTS system has another advantage. It is suitable for stable fabrication of multi-component thin films by installation of another kind of target in stable plasma atmosphere. Also, the component ratios of the thin films can be adjusted by through the additional power supply. Therefore, the FTS system is a suitable method for preparing various thin films [15–18].

It has also been applied with thermal treatment as an additional process to improve its properties. The electrical property of a thin film is decreased when a thin film has an unstable structure that cannot be crystallized. In this case, thermal treatment can be applied

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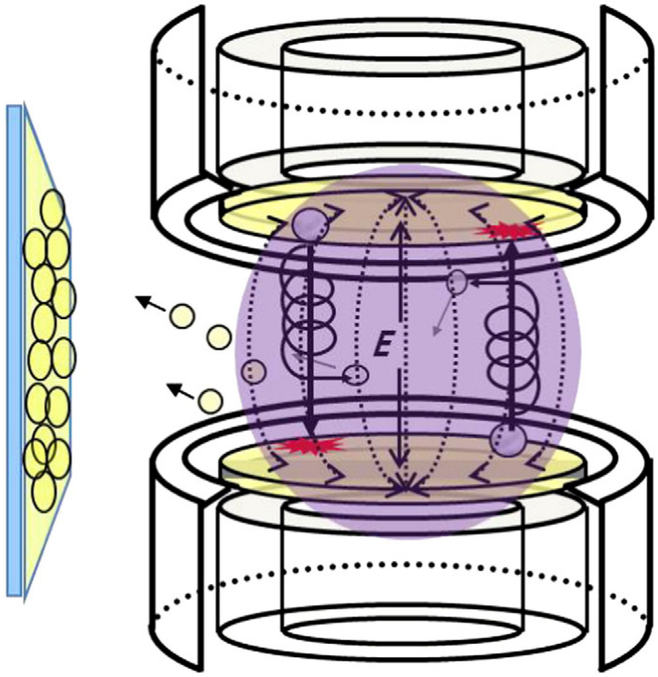

Fig. 1. Schematic of facing targets sputtering (FTS) system.

to remove the stress and defect in the thin film to fabricate a high quality thin film [19].

In this study, we fabricated Ga and Al doped ZnO (GAZO) thin films by the facing targets sputtering system. We expected to improve the properties of the as-fabricated films by continuous substitution of Ga and Al because ion radii are similar with that of the Zn ion. Additionally, we confirmed the influence of rapid thermal treatment and investigated the electrical, optical and structural properties of the fabricated thin film.

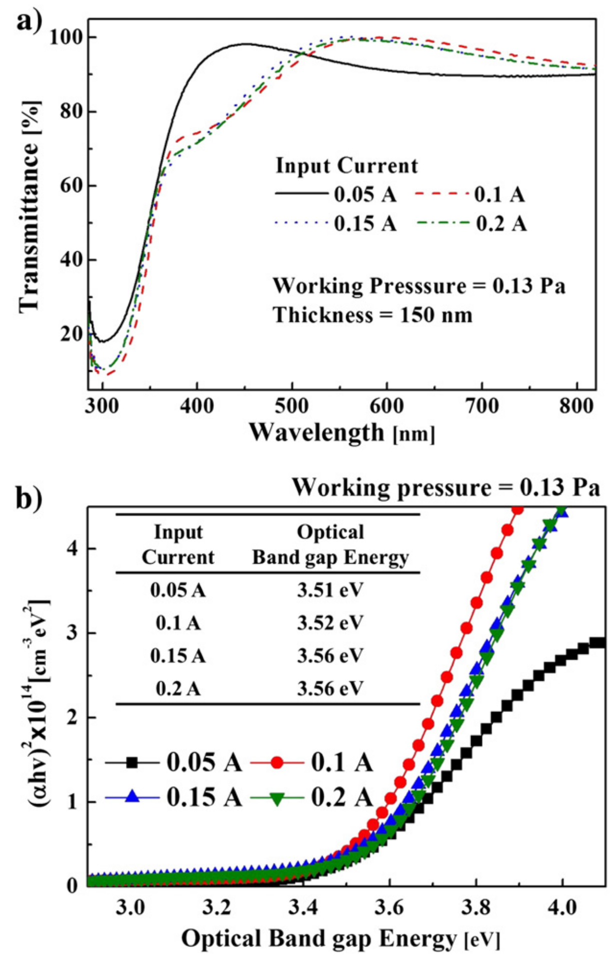

Fig. 2. Optical properties of GAZO thin films as function of input current;. a) Transmittance, b) Optical band gap energy.

2. Experimental details

2.1. Fabrication process

Before the deposition, the glass substrate (75 mm × 25 mm) was ultrasonically cleaned with de-ionized water for 15 min and then with isopropyl alcohol for 15 min. It was then dried with N_2 gas. The deposition chamber was then evacuated to a pressure of 6.4×10^{-4} Pa. We used a GZO (Ga_2O_3 3 wt%, ZnO 97 wt%) target and an AZO (Al_2O_3 2 wt%, ZnO 98 wt%) target. Ga and Al doped ZnO thin films were deposited in Ar gas atmosphere as function of input current at 0.13 Pa of working pressure. After deposition, the as-deposited films were thermal treated by using the rapid thermal process system in nitrogen ambient environment for 1 min. Details of the experimental conditions are given in Table 1.

Table 1
Sputtering condition.

Deposition Parameter	Sputtering Condition
Target	4 inch GZO and 4 inch AZO
Substrate	Slide glass (75 mm × 25 mm)
Base pressure	6.4×10^{-4} Pa
Working Pressure	0.13 Pa
Ar gas flow	10 sccm
Input current	0.05, 0.1, 0.15, 0.2 A
Thickness	150 nm
Thermal treatment Temp.	300 °C, 400 °C, 500 °C, 600 °C
Thermal treatment Time	1 min

2.2. Characterization

The as-deposited GAZO thin films were examined by various methods. Sheet resistance was evaluated by a four-point probe (CMT-SR1000N, AIT Co.,Ltd), optical property was confirmed by a UV/Vis spectrometer (8453, Hewlett-Packard). Crystallinity of as-fabricated films were examined by X-ray diffraction (XRD, D/MAX-2200, Rigaku) with Cu-Kα radiation ($\lambda = 1.5418$ Å) X-ray source at 40 kV and 20 mA in the scanning angle (2θ) from 20° to 80°. Surface properties were analyzed by atomic force microscopy

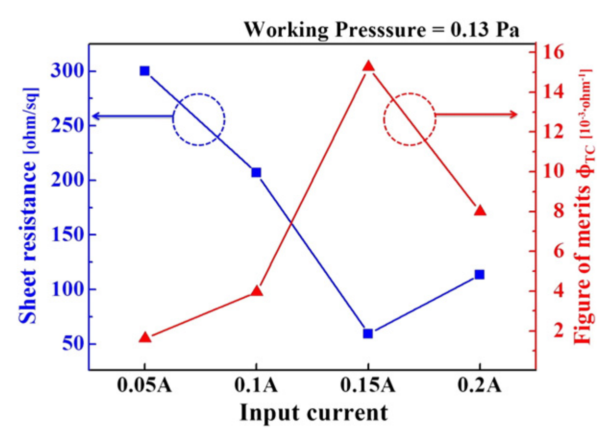

Fig. 3. Sheet resistance and figure of merit of GAZO thin films as function of input current.