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Thin Solid Films 475 (2005) 262–266

www.elsevier.com/locate/tsf

Electrical and optical characteristics of ITO films by pulsed laser deposition using a 10 wt.% SnO_2-doped In_2O_3 ceramic target

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Abstract

We have investigated the effect of the oxygen pressure and the deposition temperature on the electrical and optical properties of the Sn-doped indium oxide (ITO) films on quartz glass substrate by pulsed laser deposition (PLD) using a 10 wt.% SnO_2-doped In_2O_3 target. The resistivity and the carrier concentration of the films were decreased due to the decrease of the oxygen vacancy while increasing the oxygen pressure. With increasing deposition temperature, the resistivity of the films was decreased and the carrier concentration was increased due to the grain growth and the enhancement of the Sn diffusion. We have optimized the PLD process to deposit a highly conductive and transparent ITO film, which shows the optical transmittance of 88% and the resistivity of 2.49×10^{-4} Ω cm for the film thickness of 180 nm.

Keywords: Transparent conducting oxide; PLD; Resistivity; Optical transmittance

1. Introduction

Sn-doped In_2O_3 (ITO) is an *n*-type, highly degenerate, wide-bandgap semiconductor with an optical bandgap of more than 3.4 eV [1]. Due to its high transmittance to visible light and to its low resistivity [2,3], ITO thin films have been applied in optoelectronic devices such as transparent electrodes for light-emitting diodes, flat panel displays [4], and solar cells [5,6]. Electrical and optical properties of ITO thin films are strongly dependent on the deposition method and have been extensively studied by different physical measuring techniques [7–12]. Among the several fabrication techniques, pulsed laser deposition (PLD) has attracted much attention because the fabrication process is quite suitable for optoelectronic devices using the ITO transparent electrode. The composition of films grown by PLD is quite close to that of the target, even for a multicomponent target. PLD films may crystallize at lower deposition temperatures relative to other physical vapor deposition techniques due to the high kinetic energies of the ionized and ejected species in the laser plumes. However, it is difficult to make the transparent layer on the optoelectronic devices because the electrical and optical properties of ITO films vary drastically depending on PLD conditions. In this study, we have focused on the optimization of the electrical and optical properties of ITO film by varying the oxygen pressure and deposition temperature.

2. Experimental details

ITO thin film was prepared using excimer laser ablation in an oxygen gas atmosphere. Namely, the excimer laser ablation of In_2O_3–SnO_2 (ITO) target was performed in oxygen ambient gas at various oxygen pressures and deposition temperatures. A Krypton–Fluoride (KrF) excimer laser (λ=248 nm, energy density=2 J/cm^2, pulse duration=12 ns, repetition rate=10 Hz) was focused onto 1×5 mm^2 rectangular spot at the surface of the ITO target. In this condition, ablation rate of the ITO target was about 0.82 nm/pulse. The target was rotated at 10 rpm. During the laser ablation of ITO, the oxygen ambient gas was introduced into a vacuum chamber and was maintained at various pressures using a differential evacuation system, after the chamber was evacuated to the base pressure of 1.0×10^{-6}

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doi:10.1016/j.tsf.2004.08.032

Torr. A substrate was kept in 0.05~25 mTorr of oxygen ambient gas. The composition of the hot-pressed target, which was 1/4-in. thick and 1 in. in diameter, was In_2O_3 doped with 10 wt.% SnO_2. The deposition was performed at room temperature ~300 °C.

The electrical properties of the films were determined at room temperature by Hall system using van der Pauw measurement equipment (HP5500C, Accent). Optical transmission measurements were performed using a HP8415 Diode Array Spectrophotometer. The structure and morphology of the films were measured by X-ray diffractometer (XRD; Dmax series, Rigaku) with CuK_α radiation and atomic force microscopy (XE10, PSAI), respectively.

3. Results and discussion

The electrical properties of ITO films depend on the film composition and deposition parameters such as oxygen pressure and deposition temperature. Fig. 1 shows the variation of the resistivity, carrier concentration, and carrier mobility as a function of the oxygen pressure for the ITO films deposited at 150 °C. The resistivity of the films was varied in the range of 9.4×10^{-1}~4.5×10^{-4} Ω cm for oxygen pressure from 0.05 to 20 mTorr. The resistivity of the films decreased with increasing the oxygen pressure from 0.05 to 10 mTorr and slightly increased with increasing the oxygen pressure from 5 to 20 mTorr. The resistivity of the films deposited at the oxygen pressure above 20 mTorr was too high to measure in our instrument. The carrier concentration and the carrier mobility of the films were measured in the range of 1.7~5.2×10^{20} cm^{-3} and 0.03~42.3 cm^2/V sec, respectively.

The oxygen pressure dependence of the resistivity of the films can be explained by the number of the oxygen vacancies in the film. Oxygen vacancies donate free carriers. An increase in the number of oxygen vancancies leads to an increase in conductivity. Hence, the resistivity of the ITO films decreases with decreasing oxygen pressure from 20 to 10 mTorr due to an increase in the number of oxygen vacancies. However, the resistivity of the ITO films increases with a further decrease in the oxygen pressure (<10 mTorr). The resistivity values of the ITO films grown in a pressure of 5×10^{-6} Torr (without oxygen addition) at 150 °C were 9.4×10^{-1} Ω cm. A severe oxygen deficiency may cause lattice structural disorder and reduce the mobility of carriers, which was already reported by Kim et al. [13].

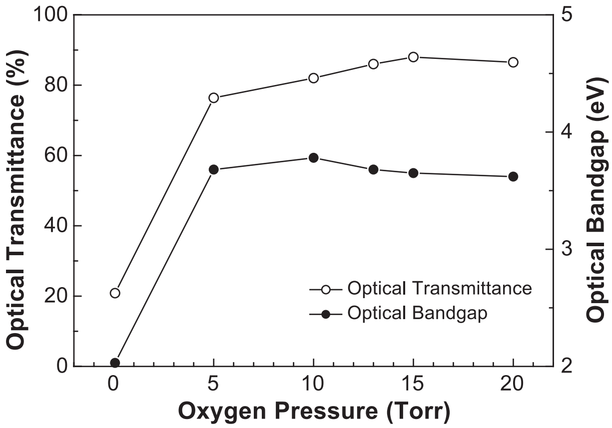

Fig. 2. Variation of the optical transmittance (○) and the optical bandgap (●) as a function of the oxygen pressure for the ITO films deposited at the deposition temperature of 150 °C.

Optical transmittance and optical bandgap of the ITO films are shown in Fig. 2. The optical properties of the ITO films were also affected by the oxygen pressure. We found that the optical transmittance at 550-nm wavelength slightly increased from 75% to 86% as the oxygen pressure was increased from 5 to 20 mTorr. However, the film grown in

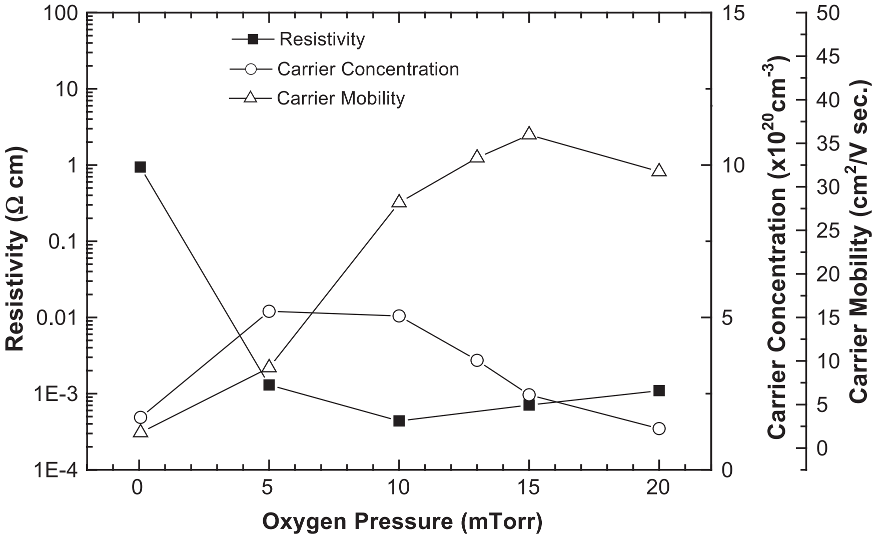

Fig. 1. Variation of the resistivity (■), the carrier concentration (○), and the carrier mobility (△) as a function of the oxygen pressure for the ITO films deposited at the deposition temperature of 150 °C.