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Smooth indium zinc oxide film prepared by sputtering a In_2O_3:ZnO = 95:5 target

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Abstract

Indium zinc oxide (IZO) films with surface roughness Ra < 0.3 nm have been prepared by radio frequency sputtering. The IZO film is the possible candidate for replacing the indium tin oxide (ITO) film in pattern precision or low processing temperature concern. Instead of commonly used In_2O_3:ZnO = 90:10 in weight percentage (wt%) target, a target doped with 5 wt% impurities was used in this study. It was found that the electrical resistivity of the IZO film increases rapidly if oxygen gas was introduced during the sputtering process. This increase tendency in electrical resistivity is much more significant than the IZO film prepared with a 10 wt% doped ZnO target. The electrical resistivity increased rapidly as soon as the IZO film became crystallized in heat treatment. Optical properties of the IZO film do not change significantly with varying process parameters. The appropriate processing condition for the prepared IZO film is no oxygen feeding and no heat treatment.

Keywords: Indium zinc oxide; Sputtering

1. Introduction

Transparent conductive oxide (TCO) has been widely used as electrode material in flat panel display industry. Indium tin oxide (ITO) is the most popular one in TCO. It has high visible light transmission and good electrical conductivity [1]. However, for obtaining good electrical conductivity, ITO usually needs crystallization. The crystallization temperature for ITO is 150–200 °C [2]. After heat treatment, the ITO film usually becomes polycrystallized. For the follow-up process flow-etching work, the etching rate of the poly crystal ITO film is very slow and the surface roughness usually increases [3,4]. This lowers pattern precision raising issues on display resolution. Besides, organic material stability in organic light-emitting devices (OLED) is sensitive to temperature. This limits ITO following heat treatment if ITO was used in OLED application. IZO is presently one of the potential replacement materials for ITO. As compared to ITO, the IZO film can be manufactured at lower process temperature with reasonable electrical and optical properties. This is most beneficial for both film production and the follow-up pattern etching process. The crystallization temperature for IZO is around 300 °C [5]. It implies that the finished IZO film can be amorphous if the processing temperature is lower than 300 °C. Amorphous film could possess low residual stress and small surface roughness. It is suitable to provide the required uniformity in display application. In the IZO film sputtering process, most of the used targets are 90 wt% indium oxide doped with 10 wt% zinc oxide. In this study, a target made of 95 wt% indium oxide and 5 wt% zinc oxide doping was used to produce IZO films by the radio frequency sputtering method. The influence of sputtering and film processing parameters (such as the processing gas composition, sputtering power, film thickness, and heat treatment) on the electrical and optical property of finished IZO films was studied and compared with the results of films produced with 10 wt% zinc oxide doping.

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2. Experimental

A radio frequency sputtering tool together with a target, made of 95 wt% indium oxide doped with 5 wt% zinc oxide, was used to produce IZO films on glass plate (Corning 1737). The chosen sputtering parameters were: base pressure 1×10^{-4} Pa, process pressure 5×10^{-1} Pa, substrate kept at room temperature, 15 sccm argon gas flow, and substrate rotating at an angular 20 rpm speed. Properties of all the produced films were measured in turn by the following means: electrical resistivity by a four-point probe analyzer (Keithley 237, Keithley), optical transmittance by a UV/Vis/NIR spectrometer (Lambda 900, Perkin-Elmer), crystallinity by a X-ray diffract meter (D5000, Siemens), and surface roughness Ra by an atomic force microscope (Dimension 3100, Veeco). The average transmission rates were calculated from measured transmission spectra by averaging the transmission rate in the visible wavelength 400–700 nm region. The process flow and test measurements were done under the following conditions.

Step 1: The ratio for oxygen to argon gas flow was varied between 0% and 10%. The sputtering power was kept at 150 W, and the film thickness was fixed at 200 nm.

Step 2: The sputtering power was varied between 100 and 180 W. Film thickness was fixed at 200 nm. The ratio of oxygen to argon gas flow was kept at the value yielding the highest electrical conductivity obtained in step 1.

Step 3: Film thickness was varied between 100 and 400 nm. The ratio of oxygen to argon gas flow and sputtering power were kept at the values yielding the highest electrical conductivity obtained in steps 1 and 2, respectively.

Step 4: Produced IZO films were heat treated in air. The heating temperature was regulated from 200 to 400 °C. The heat treatment time was kept at 90 min. Film thickness was fixed at 200 nm. The ratio of oxygen to argon gas flow in producing the film, sputtering power, and film thickness were again kept at the values which yield the highest electrical conductivity obtained in steps 1 and 2, respectively.

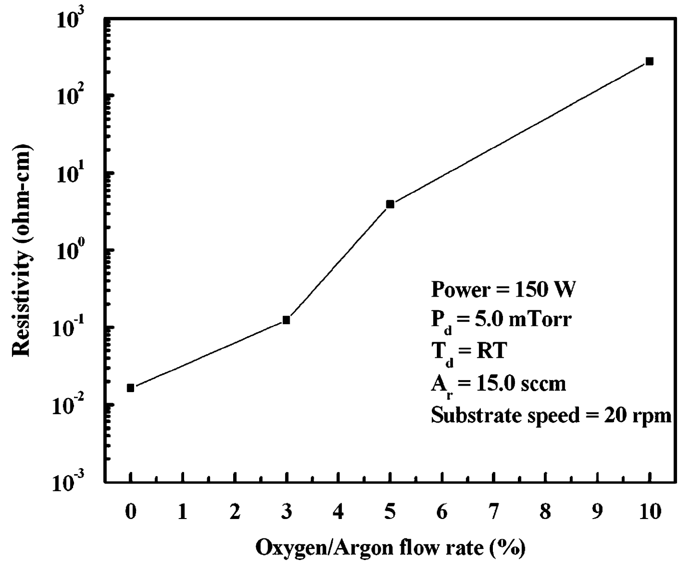

Fig. 1. Electrical resistivity of the IZO films produced at different oxygen to argon ratios.

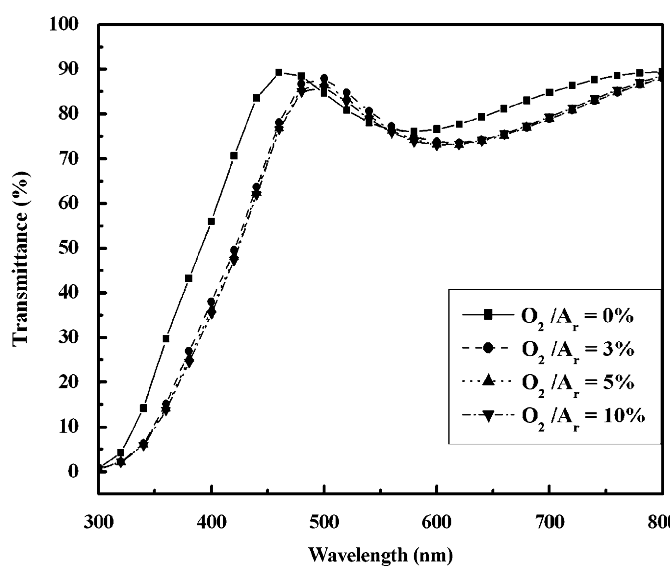

Fig. 2. Optical transmittance spectra of the IZO films produced at different oxygen to argon ratios.

3. Results

3.1. Ratio of O_2/Ar gas flow

Fig. 1 shows the electrical resistivity of IZO films for different ratios of O_2/Ar gas flow in processing. It indicates that the IZO film produced in pure argon exhibits the highest electrical conductivity. The electrical resistivity increases rapidly with increasing oxygen percentage. The transmittance spectra of IZO films in visible wavelength range are shown in Fig. 2 for different mixture of O_2/Ar gas flow used in processing. The optical absorption edge shifts toward the short wavelength region as the oxygen percentage decreases seen in Fig. 2. The average transmission rate decreases with increasing oxygen percentage. The surface roughness Ra increases slowly from 0.151 to 0.212 nm with increasing oxygen percentage.

3.2. Sputtering power

Fig. 3 shows the electrical resistivity of IZO films processed with different sputtering powers. It indicates that the electrical resistivity decreases with increasing sputtering power. Transmittance spectra in the visible wavelength range for IZO films processed with different sputtering powers are shown in Fig. 4. It can be seen that the transmittance spectra do not show any significant