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Effects of the O_2/Ar gas flow ratio on the electrical and transmittance properties of ZnO:Al films deposited by RF magnetron sputtering

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Abstract ZnO:Al thin films for transparent conductors were deposited on sapphire (0001) substrates by using an RF magnetron sputtering technique. Effects of the O_2/Ar flow ratio in the sputtering process on the crystallinity, carrier concentration, carrier mobility, and transmittance of the films were investigated. The FWHM of the (002) XRD intensity peak is minimal at the O_2/Ar flow ratio of 0.5. According to the Hall measurement results the carrier concentration and mobility of the film decrease and thus the resistivity increases as the O_2/Ar flow ratio increases. The transmittance of the ZnO:Al film deposited on the glass substrate is characteristic of standing wave. The transmittance increases as the O_2/Ar flow ratio in-RF magnetron sputtering increases up to 0.5. Considering the effects of the the O_2/Ar flow ratio on the electrical resistivity and transmittance of the ZnO:Al film the optimum O_2/Ar flow ratio is 0.5 in the RF magnetron sputter deposition of the ZnO:Al film.

Keywords ZnO:Al · RF-magnetron sputtering · Al doping · O_2/Ar gas flow ratio · Transparent conductor

1 Introduction

Indium tin oxide (ITO) has been most widely used as a transparent conducting oxide (TCO) electrode in liquid crystal displays (LCDs), organic light emitting diodes (OLEDs) and solar cells since it has high visible transmittance (~90% at 550 nm), low electrical resistivity ($\sim 2 \times 10^4 \Omega$ cm), and relatively high work function (~4.8 eV) [1]. Nevertheless, ITO is an expensive TCO since indium and tin in ITO are rare and expensive elements. Therefore, zinc oxide (ZnO) has been actively investigated as an alternative to ITO. ZnO is cheaper, and easier to etch than ITO. ZnO is nontoxic and much more resistant to hydrogen-plasma reduction and can be grown at lower temperatures. Therefore, ZnO is more favorable than ITO particularly for amorphous-silicon solar cells fabricated on transparent conducting (TC) substrates, since the TC substrates are exposed to hydrogen plasma [2, 3].

Undoped ZnO is an *n*-type semiconductor, but Al-doped ZnO (AZO) is more appropriate for TCO because of lower electrical resistivity (2–5 $\times 10^{-4}$ Ωcm) [4, 5]. However, further increase in transmittance is desirable for AZO to be used as a TCO in flat panel displays since Al doping does not improve the transmittance of ZnO. According to our experience an oxygen atmosphere is helpful in improving the transmittance of ZnO deposited by sputtering. However, effects of the atmosphere on the electrical and optical properties of sputtered ZnO films have not been nearly reported yet. In this paper, we report effects of the O_2/Ar flow ratio on the electrical and transmittance properties of AZO films deposited by RF magnetron reactive sputtering.

2 Experimental

ZnO:Al films were deposited on sapphire (0001) substrates by an RF magnetron reactive sputtering method using a ZnO:Al target with a 3 inch diameter. The distance between the target and the substrate was 8 cm. Prior to deposition of ZnO:Al films the substrates were cleaned with acetone and methanol for ten min each, rinsed with D. I. water and then

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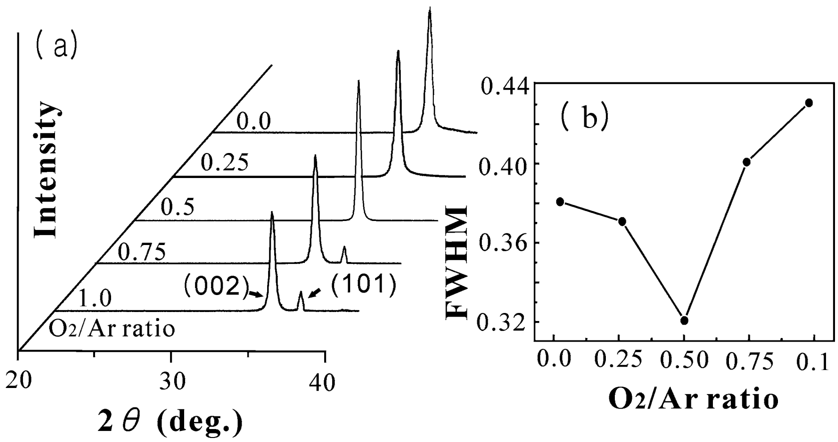

Fig. 1 The FWHM of the (002) XRD peak of ZnO:Al thin films as a function of the O_2/Ar gas flow ratio in RF magnetron sputtering

dried with nitrogen. Base vacuum was 10^{-6} Torr. The Ar gas flow rate was fixed at 20 sccm and the oxygen flow rates of 0, 5, 10, 15, and 20 sccm were used. The chamber pressure and the substrate temperature were fixed to be 0.05 Torr and 200°C, respectively. The RF power was maintained at 150 W. X-ray diffraction (XRD), UV/VIS spectroscopic analysis and Hall measurement were performed to investigate the crystallographic orientation, transmittance and electrical properties of ZnO:Al thin films.

3 Results and discussion

Figure 1(a) shows the XRD spectra of ZnO:Al thin films for different the O_2/Ar gas flow ratios. Most of the ZnO:Al films deposited by RF magnetron sputtering seem to be polycrystalline with a preferred orientation along the C-axis perpendicular to the substrate surface. The (002) peak intensity increases as the O_2/Ar gas flow ratio increases up to 0.5 and reaches maximum at 0.5. The crystallinity tends to decrease and the (101) peak appears as the O_2/Ar gas flow ratio increases further than 0.5. The full width at half maximum (FWHM) of the XRD (002) peak is shown in Fig. 1(b) as a function of the O_2/Ar gas flow ratio. The FWHM is minimal at the O_2/Ar gas flow ratio of 0.5, which implies that a certain amount of oxygen is necessary to grow a highly *C*-axis-oriented ZnO:Al thin film.

Figures 2(a) and (b) show the electron concentration, electron mobility and electrical resistivity of the ZnO:Al thin film as functions of the O_2/Ar gas flow ratio. Both the electron concentration and mobility decreases and thus the resistivity increases parabolically as the O_2/Ar gas flow ratio increases. The increase of the O_2/Ar flow ratio enhances oxygen doping and thus decreases the electron concentration by compensation since oxygen is an acceptor for ZnO. Also it is evident that the carrier mobility decreases owing to the enhancement of impurity scattering as the oxygen impurity concentration increases.

Figure 3 shows the transmittance spectra of the ZnO:Al films deposited on the glass substrate by RF magnetron sputtering with different O_2/Ar gas flow ratios. The thicknesses of the ZnO:Al films used in this experiment are 500 nm, more or less. The film thickness was fixed by controlling the deposition process parameters since the transmittance is significantly influenced by the film thickness. The shape of the transmittance curves indicate that the transmitted light form a standing wave. This standing wave must be caused by the interference between incident light and the light reflected from the interface between the ZnO:Al film and the glass substrate, since both ZnO:Al and glass are transparent. The transmittance increases as the O_2/Ar flow ratio increases in

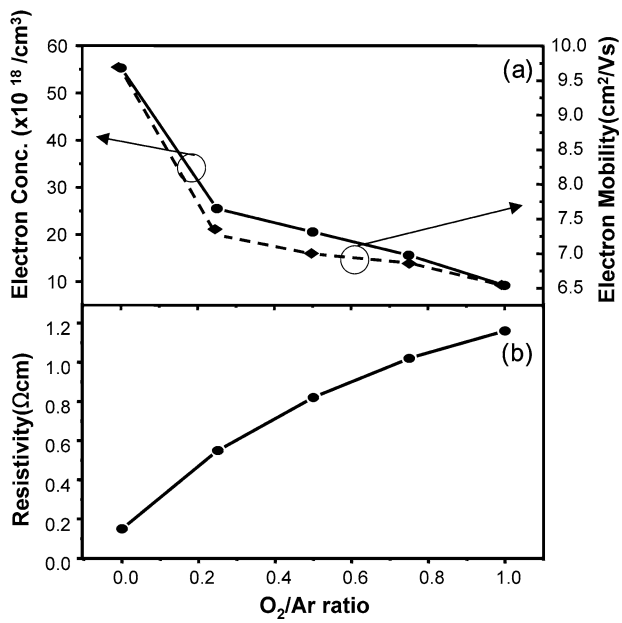

Fig. 2 The electron concentrations, electron mobility, and electrical resistivity of the ZnO:Al thin film as functions of the O_2/Ar gas flow ratios

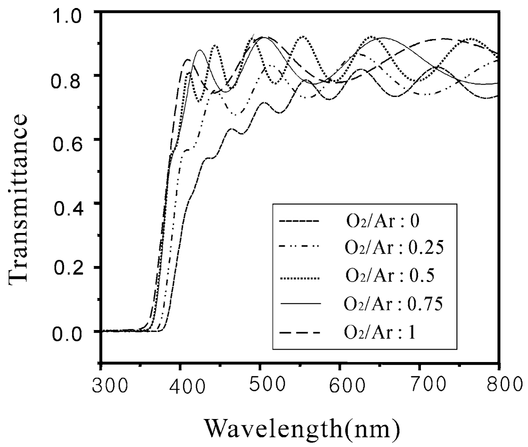

Fig. 3 The transmittance spectra of ZnO:Al thin films deposited by RF magnetron sputtering with different O_2/Ar gas flow ratios.

the O_2/Ar flow ratio range below 0.5, but there is no increase in the O_2/Ar flow ratio range above 0.5. The wavelength values for both the maxima and minima of the transmittance change with the O_2/Ar flow ratio in the O_2/Ar ratio range above 0.5.

4 Conslusion

Considering effects of the O_2/Ar flow ratio on the crystallinity, electrical resistivity and transmittance properties of the ZnO:Al film the optimum O_2/Ar flow ratio is 0.5 in RF magnetron sputter-deposition of the ZnO:Al film. Particularly, the precise optimal O_2/Ar flow ratio should be determined depending upon the wavelength appropriate for applications.

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