Electrical and Optical Properties of AZO/Ag/AZO Multilayer Thin Films Prepared by DC Magnetron Sputtering

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ABSTRACT

Silver nanoparticles were deposited on aluminium doped zinc oxide (AZO) thin films and coated with AZO to fabricate AZO/Ag/AZO multilayer thin films by DC magnetron sputtering. The electrical and optical properties of the multilayer thin films were studies by using Hall measurement and UV-visible spectroscopy and compared with AZO thin films. It was found that the sheet resistance and transmittance decreases with increasing of silver layer sputtering time. The figure of merit, which is used to determine a quality of thin films for transparent conducting oxide (TCO) applications, is found to be order of 10^{-4} Ω^{-1} for AZO/Ag(10 sec)/AZO compared to order of 10^{-7} Ω^{-1} for AZO. These multilayer thin films could be explored for TCO applications.

Key words: Ag nanoparticle, Sputtering, Thin film, Al-doped ZnO, Zinc oxide

INTRODUCTION

Transparent conducting oxide (TCO) thin films such as conducting tin oxide (CTO), indium tin oxide (ITO) and fluorine-doped tin oxide (FTO) have found extensive applications in optoelectronic devices such as flat panel displays (Betz et al., 2006), dye-sensitized solar cell (DSSC) (Katusic et al., 2006). For applications, the TCO thin film properties should exhibit low resistivity and high transparency. The most widely TCO thin films are indium tin oxide (ITO) thin film because of its good electrical and optical properties (Xu et al., 2007; Kim et al., 2006). However, the ITO thin films are high cost, toxicity and indium oxide is a scarcity material. Al-doped ZnO thin films (AZO) have attracted attention as TCO thin films because ZnO is a well-known wide band gap semiconductor material, ease in doping, low resistivity, a high transparency, abundance in nature, non toxicity and low cost (Pearton et al., 2005; Banerjee et al., 2006; Jeong et al., 2006).

Many techniques such as pulsed laser deposition (Shukla et al., 2006), sol-gel route (Kuo et al., 2006), spray pyrolysis (Romero et al., 2006), filter cathodic vacuum arc (Lee et al., 2004) and magnetron sputtering (Kim et al., 2005;

Ko et al., 2005) were used to prepare AZO thin films. For example, the AZO thin films were prepared by DC magnetron sputtering with heating of glass substrates of 320°C having sheet resistance of 3.3 Ω/Sq and transmittance of 90% (Fang et al., 2003). Moreover, the sheet resistance and transmittance could be reduced as very low as 3 Ω/Sq of 90% at 580 nm (Sahu et al., 2006), respectively by using conductive metals coated on AZO thin films.

In this work, we have prepared AZO and AZO/Ag/AZO multilayer thin films with Ag nanoparticles layer by DC magnetron sputtering without heating of glass substrates. The electrical and optical properties of both thin films were studied and compared.

MATERIALS AND METHODS

The AZO ceramic target was fabricated from the mixtures of ZnO powder and Al_2O_3 powder with the Al content of 1 at%. The mixed powder was grinded for 5 h and sintered at 1000°C for 12 h, respectively. The mixed powder was pressed at 30 ton for 10 min and sintered 1200°C for 24 h to form it an AZO ceramic target. Coating of both AZO and Ag thin films was performed in a DC magnetron sputtering system onto glass substrates without heating of glass substrates. The glass substrates were cleaned by ultrasonic cleaner for 30 min in acetone, ethanol and distilled water, respectively (Kim et al., 2006). The sputtering chamber was pumped below 5.0×10^{-5} torr and the sputtering processes were performed at a pressure of 5.0×10^{-3} torr by flowing pure argon gas into sputtering chamber. The sputtering power and the target-substrate distance were kept at 50 W and 10 cm for all sputtering processes. The AZO thin films were sputtered for 30 min on glass substrates, respectively. For AZO/Ag/AZO multilayer thin films, each AZO layer and Ag nanoparticles layer were sputtered for 15 min and 5 - 20 sec, respectively.

The electrical properties were measured by a Hall measurement set up in van der Pauw configuration at room temperature. The optical properties were measured by using a UV-Vis Jasco V-530 spectrophotometer. The surface morphologies and thickness were investigated by using a JOEL JSM-6335F field emission scanning electron microscope (FE-SEM).

RESULTS AND DISCUSSION

Figure 1 (a) shows the sheet resistance of the multilayer thin films as a function of Ag layer sputtering time. The sheet resistance decreases as the Ag layer sputtering time is increased and begins to steady at sputtering time of 10 sec. The sheet resistance values of the multilayer thin films with Ag layer sputtering time of 0, 5, 10, 15 and 20 sec are 8×10^6, 3×10^6, 23, 22 and 5 Ω/Sq, respectively. The sheet resistance of the multilayer thin films with Ag layer sputtering time of more than 10 sec exhibited less sheet resistance than that of AZO thin films.

Figure 1 (b) shows the carrier concentration and Hall mobility of the multilayer thin films as a function of the Ag layer sputtering time. The carrier concentration depends on the Ag layer sputtering time and increases to order of 10^{20} cm^{-3} for Ag layer sputtering time of more than 10 sec. Moreover, The Hall mobility was increased up to 40 $cm^2/V \cdot s$ for Ag layer sputtering time of more than 10 sec. The negative sign of Hall voltage for all thin films indicating all films are n-type.

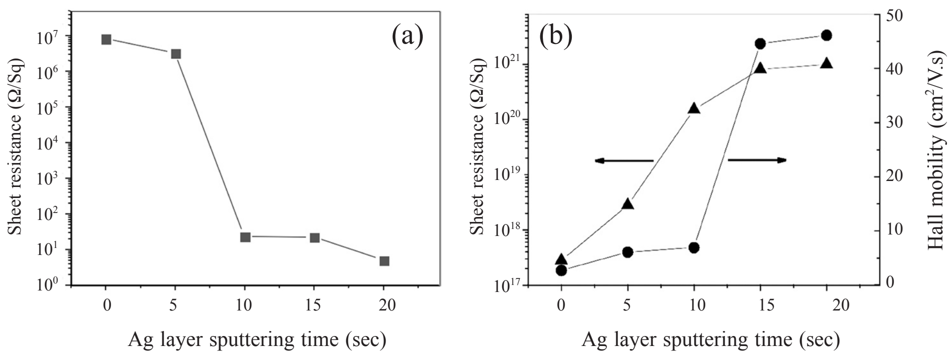

Figure 1. (a) The sheet resistance of AZO/Ag/AZO multilayer thin films. (b) Carrier concentration and Hall mobility of AZO/Ag/AZO multilayer thin films as a function of Ag layer sputtering time.

Optical transmittance spectra of AZO and AZO/Ag/AZO multilayer thin films were showed in Figure 2. The AZO/Ag/AZO multilayer thin films with Ag layer sputtering time of 0, 5, 10, 15 and 20 sec showed average transmittance values in visible region of 86%, 61%, 62%, 49% and 38%, respectively. The transmittance decreased with increasing of Ag layer sputtering time.

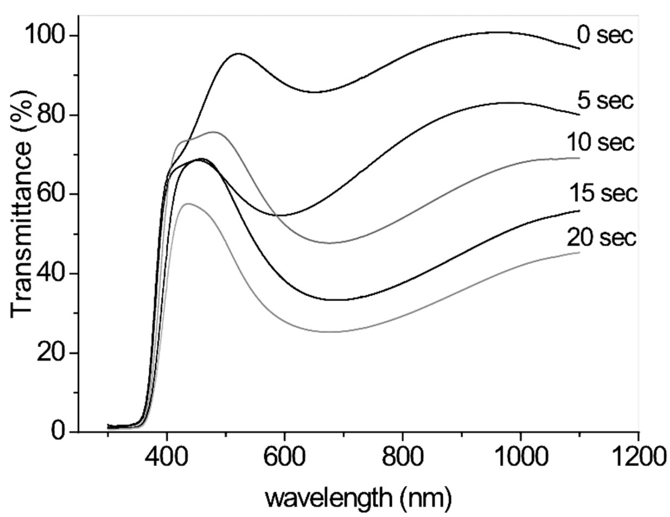

Figure 2. The optical transmittance spectra of AZO/Ag/AZO multilayer thin films at various Ag layer sputtering times.

The quality of TCO thin films was determined by figure of merit (FTC). The figure of merit is defined as $F_{TC} = T^{10}/RS$ (Haacke, 1976) where T is an average optical transmittance in visible region and R_S is a sheet resistance. Plot of F_{TC} as a function of Ag layer sputtering time was shown in Figure 3. FTC of the AZO/Ag/AZO multilayer thin films with Ag layer sputtering time of 10 sec has the highest value of 4.2×10^{-4} Ω^{-1} compared with 7.3×10^{-7} Ω^{-1} for AZO thin films. This indicated that the figure of merit of AZO thin films could be improved by inserting Ag layer between two AZO layers.

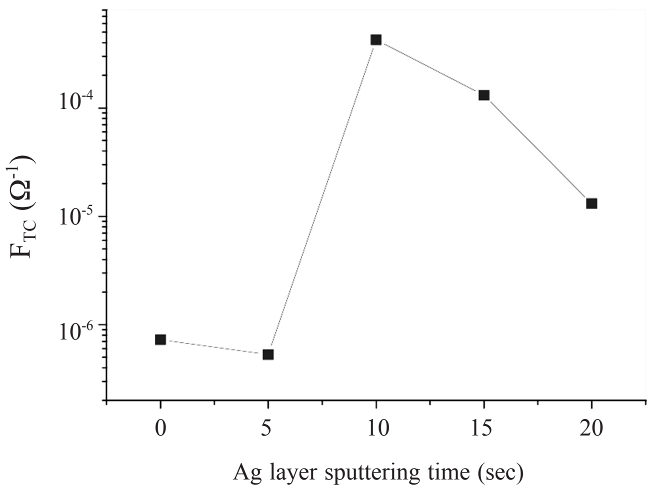

Figure 3. Plot of figure merit of AZO/Ag/AZO multilayer thin films as a function of Ag layer sputtering time.

Figure 4 shows the surface morphologies of (a) AZO thin films, (b) Ag thin films and (c)-(f) AZO/Ag/AZO multilayer thin films. The AZO thin films exhibited particles with average length of 155 nm and average width of 61 nm while the Ag thin films exhibited nanoparticles with average diameter of 130 nm. However, the AZO/Ag/AZO multilayer thin films at different Ag layer sputtering time exhibited similar surface morphologies with flake-like particles. The average diameter of flake-like particles is about 80 nm.

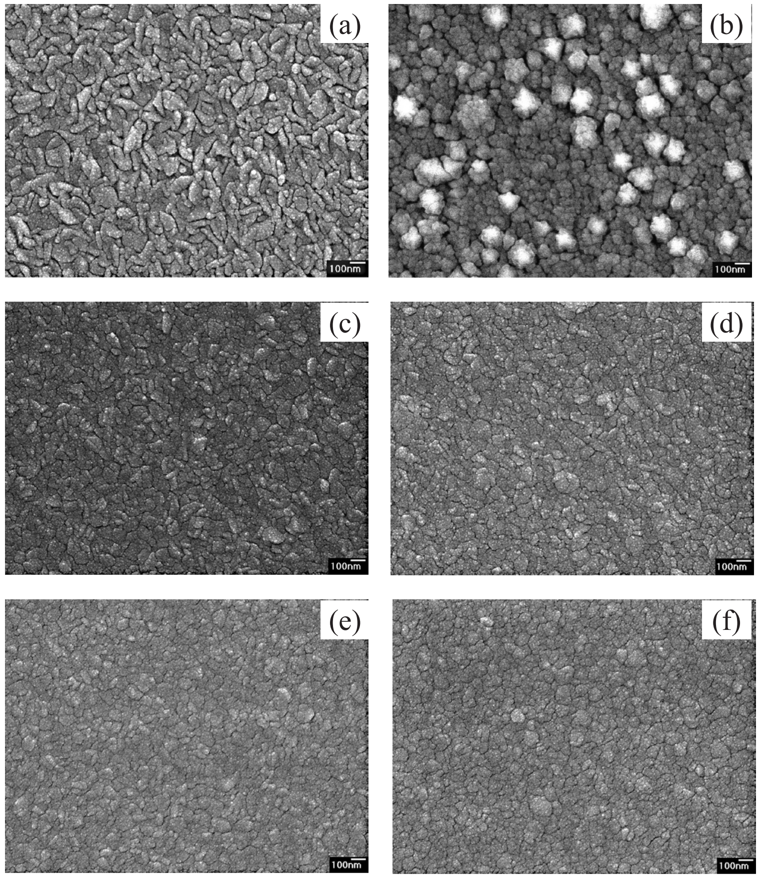

Figure 4. Surface morphologies of (a) AZO, (b) Ag, (c) AZO/Ag(5s)AZO, (d) AZO/Ag(10s) /AZO,(e) AZO/Ag(15s)/AZO and (f) AZO/Ag(20s)/AZO thin films.

CONCLUSION

Silver nanoparticle layers were inserted between two AZO layers to fabricate AZO/Ag/AZO multilayer thin films. The sheet resistance decreases as the Ag layer sputtering time is increased and begins to steady at sputtering time of 10 sec. The transmittance decreased with increasing of Ag layer sputtering time. The figure of merit of the AZO/Ag/AZO multilayer thin films with Ag layer sputtering time of 10 sec has the highest value of $4.2\times10^{-4}\ \Omega^{-1}$ compared with $7.3\times10^{-7}\ \Omega^{-1}$ for AZO thin films. This indicated that the figure of merit of AZO thin films could be improved by inserting Ag layer between two AZO layers.

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