TRANSACTIONS ON ELECTRICAL AND ELECTRONIC MATERIALS
Vol. 18, No. 1, pp. 13-15, February 25, 2017

Regular Paper

pISSN: 1229-7607 eISSN: 2092-7592
DOI: https://doi.org/10.4313/TEEM.2017.18.1.13
OAK Central: http://central.oak.go.kr

Low Emissivity Property of Amorphous Oxide Multilayer (SIZO/Ag/SIZO) Structure

Sang Yeol Lee†
Department of Semiconductor Engineering, Cheongju University, Cheongju 28503, Korea

Received August 19, 2016; Accepted November 1, 2016

Low emissivity glass for high transparency in the visible range and low emissivity in the IR (infrared) range was fabricated and investigated. The multilayers were have been fabricated, and consisted of two outer oxide layers and a middle layer of Ag as a metal layer. Oxide layers were formed by rf sputtering and metal layers were formed using by an evaporator at room temperature. SiInZnO (SIZO) film was used as an oxide layer. The OMO (oxide-metaloxide) structures of SIZO/Ag/SIZO were analyzed by using transmittance, AFM (atomic force microscopye), and XRD (X-ray diffraction). The OMO multilayer structure was designed to investigate the effect of Ag layer thickness on the optical property of the OMO structure.

Keywords: a-SiInZnO, Oxide-metal-oxide multilayer, Ag, Transparent film, Oxide based semiconductor

1. INTRODUCTION

Interest in to the energy saving technology of by adopting low emissive glass for conventional building has been rapidly increasing [1]. Low emissivity (Low-e) glass has been widely used to increase the energy efficiency of windows. Low-e glass has advantages, such as a high transmittance of about 80% or more in the visible range and a low emissivity in the infrared (IR) range [2].

Recently, OMO (oxide/metal/oxide) multilayer structures have emerged as an alternative to low emissive coatings because they provide good optical and electrical characteristics [1-3]. They are fabricated on glass substrates with a middle layer of Ag as a thin metal layer sandwiched between two outer oxides layers [3]. TCO (transparent conduction oxide) thin films have been extensively studied for use as electrodes in optoelectronic devices such as solar cells, organic light emitting diodes, and flat-panel display devices [4-6]. The essential conditions of TCO materials are high conductivity and transparency at a visible range (380 nm $< \lambda <$ 780 nm). Sn-doped indium oxide (ITO) thin films have been practically commercialized due to their low resistivity and high transparency in the visible range. However, Zn oxide based TCO has emerged as an alternative material to ITO, due to its low cost, wide bandgap, low absorption in the visible region, and good stability under an ambient atmosphere [7-9]. Amorphous silicon indium zinc oxide (SIZO) semiconductor has was high transparencyt and a smooth surface [10]. In this paper, we have investigated Low-e coatings with an OMO structure using amorphous SIZO/Ag/SIZO multilayers. Amorphous SIZO transparent semiconducting layers were fabricated and were then observed. The observation showed the possibility of improved optical property and the reduction of the use of Ag, showing the potential application of low emissivity coating with low cost.

† Author to whom all correspondence should be addressed:
E-mail: sylee@cju.ac.kr

2. EXPERIMENTS

SIZO/Ag/SIZO multilayer thin films on a glass substrate were used for this study. The amorphous SIZO layers were deposited by radio frequency sputtering method at room temperature. The middle layer of Ag film sandwiched between two outer oxide layers was grown using the thermal evaporation system. Both the top and bottom SIZO layers were approximately 25 nm thick, while the Ag thicknesses varied between 5 and 15 nm. The film thickness was measured using a surface profiler (Tencor, Alpha step 250). A UV-Vis spectrometer (Carry 5000, Agilent), was used to measure the optical transmittance of the multilayer in the wavelength range 300~1,400 nm as a function of Ag thickness. The structural properties of the multilayer were characterized by using atomic force microscopy (AFM, Probes).

3. RESULTS AND DISCUSSION

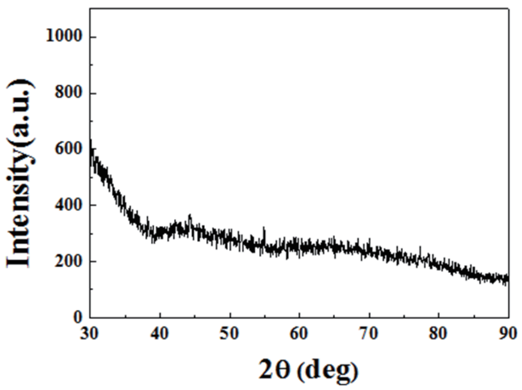

Fig. 1. X-ray diffraction patterns of SIZO single thin films.

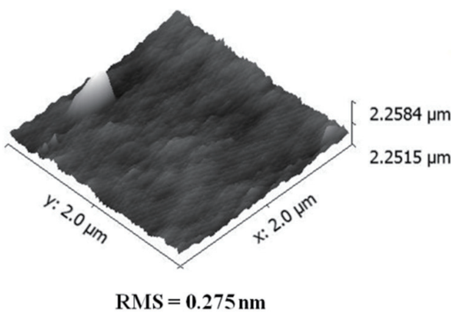

Fig. 2. AFM images of the surface of the SIZO single thin films.

Figure 1 shows the XRD (X-ray diffraction) patterns of the SIZO/Ag/SIZO multilayer films. Based on the results of XRD analysis, no peak that satisfies the Bragg's law was observed indicating the amorphous structure of SIZO. Figure 2 shows the surface topography of the SIZO single layer by AFM (atomic force microscopy). It is important to note that surface roughness was observed to have increased as the thickness of the Ag layer was increased. This can cause more scattering of the incident light, resulting in the reduction of transmission [11].

The roughness of the multilayer films increased with the increase of the Ag interlayer thickness before Ag formed a continuous film at about 9 nm. The roughness of the multilayer films decreased as increasing Ag thickness. The surface roughness of the SIZO/Ag/SIZO multilayer films was attributed to the formation of the Ag layer.

Figure 3 shows the optical transmittance spectra over a wavelength range of 300~1,400 nm for SIZO/Ag/SIZO multilayers with various the Ag interlayer thicknesses. In the short wavelength region, the transmittance was affected by the absorption of light by interband electronic transitions [12]. Therefore, the transmittance decreased with increasing Ag thickness because more electrons were available for inter-band transition, which resulted in greater light absorption. The decrease in transmittance in the near infrared region is observed with the increasing carrier density. This behavior is caused by the increasing plasma oscillation frequency with the increasing carrier density, which could be explained quantitatively by the Drude theory and is well known in degenerated TCO films

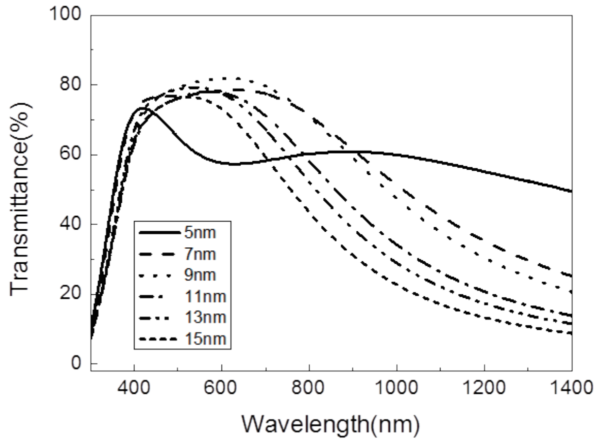

Fig. 3. Optical transmittance spectra of SIZO/Ag/SIZO films as a function of Ag interlayer thickness.

[13,14]. From the Drude-Lorentz free electron model, the plasmon frequency (ω_p) can be expressed as the following equation:

$$\omega_p = \sqrt{\frac{ne^2}{m\varepsilon_0}} \quad (1)$$

Here m is the effective mass of the electron, e is the electric charge, n is the carrier density of electrons, and ε_0 is the permittivity of free space [15,16]. ω_p is proportional to the square root of free electron density. According to Eq. (1), the eigenfrequency increased with the free carrier density. When the thickness of the Ag interlayer was less than 9 nm, a relatively low visible transmittance resulted, which is mainly due to the scattering of light from the isolated and discrete Ag islands. However, the insertion of the Ag interlayer of more than 9 nm thick resulted in improved optical transmittance due to the effects of the SPR (surface plasmon resonance) of the Ag interlayer. As shown in Fig. 3, the maximum optical transmittance of 83.5% was obtained for the SIZO/Ag/SIZO multilayer with a 9 nm thick Ag interlayer. When the films have low surface roughness, the use of Ag was reduced form continuous films and the scattering effect occurring at the boundary of Ag islands. Figure 4 shows the variation of optical band gap (Eg) for the SIZO/Ag/SIZO multilayer films with different Ag layer thicknesses. The optical band gap was extracted by linearly fitting the following equation

$$\alpha(h\nu) \propto (h\nu - E_g)^{1/2} \quad (2)$$

where hv is the incident photon energy of light and α is the absorption coefficient The optical band gap energies are determined to be 3.26,

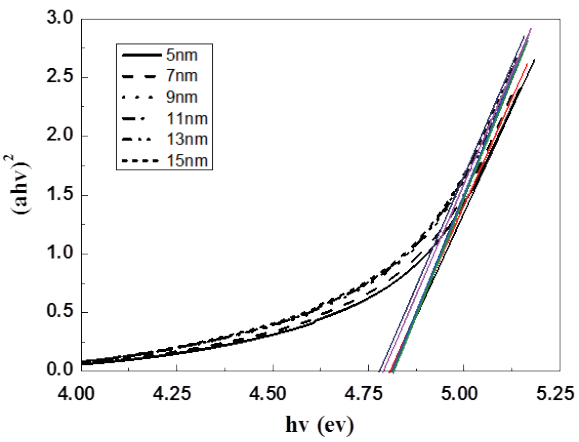

Fig. 4. The variation in Eg of SIZO/Ag/SIZO depending on Ag thickness.

3.29, 3.29, 3.28, 3.27, and 3.05 eV for the SIZO/Ag/SIZO multilayer films with the thicknesses of 5, 7, 9, 11, 13, and 15 nm, respectively. It was found that the optical band gap of the SIZO/Ag/SIZO multilayer films decreases with increasing Ag interlayer thickness.

The same trend was also observed by Alford et al., who explained that this type of behavior is due to the body effects that cause upward shifting of the valence band and downward shifting of the conduction band, resulting in the optical band gap shrinking [9].

4. CONCLUSIONS

In summary, through both experimental and the computational works, we reported on the characteristics of a SIZO/Ag/SIZO multilayer for low emissivity glass. It was found that the optical property of the multilayer was critically affected by the thickness of the inserted Ag layer. The multilayer with a 9 nm thick Ag layer showed the highest optical property of 83.5% in the visible region due to the surface plasmon resonance of the Ag layer. It was found that the surface plasmon resonance of the Ag layer could be rendered effective by finding the transition of the Ag morphology from disconnected islands to continuously connected films. These results show that the SIZO/Ag/SIZO multilayer deposited on a glass substrate could serve as a viable alternative for low emissivity glass.

ACKNOWLEDGMENT

This work was supported by the the research grant of Cheongju University in 2015.

REFERENCES

[1] P. H. Berning, *Applied Optics*, **22**, 4127 (1983). [DOI: https://doi.org/10.1364/AO.22.004127]

[2] C. Schaefer, G. Brauer, and J. Szczyrbowski, *Surf. and Coat. Tech.*, **93**, 37 (1997). [DOI: https://doi.org/10.1016/S0257-8972(97)00034-0]

[3] G. B. Smith, G. A. Niklasson, J.S.E.M. Svensson, and C. G. Granqvist, *J. Appl. Phys.*, **59**, 571 (1986). [DOI: https://doi.org/10.1063/1.336615]

[4] S. W. Chen and C. H. Koo, *Mater. Lett.*, **61**, 4097 (2007). [DOI: https://doi.org/10.1016/j.matlet.2007.01.064]

[5] K. H. Choi, J. Y. Kim, Y. S. Lee, and H. J. Kim, *Thin Solid Films*, **341**, 152 (1999). [DOI: https://doi.org/10.1016/S0040-6090(98)01556-9]

[6] C. G. Granqvist, Sol. *Energy Mater. Sol. Cells*, **91**, 1529 (2007). [DOI: https://doi.org/10.1016/j.solmat.2007.04.031]

[7] N. Mitoma, S. Aikawa, X. Gao, T. Kizu, and M. Shimizu, *Appl. Phys. Lett.*, **104**, 2103 (2014). [DOI: https://doi.org/10.1063/1.4868303]

[8] H. Kim, R.C.Y. Auyeung, and A. Pique, *Thin Solid Films*, **516**, 5052 (2008). [DOI: https://doi.org/10.1016/j.tsf.2007.11.079]

[9] H. Han, J. W. Mayer, and T. L. Alford, *J. Appl. Phys.*, **100**, 3715 (2006).

[10] H. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, and H. Hosono, Nature, 432, 488 (2004). [DOI: https://doi.org/10.1038/nature03090]

[11] G. Laukaitis, S. Lindroos, T. Tamulevieius, and M. Leskela, *Appl. Surf. Sci.*, **185**, 134 (2001). [DOI: https://doi.org/10.1016/S0169-4332(01)00775-9]

[12] K. C. Park, D. Y. Ma, and K. H. Kim, *Thin Solid Films*, **305**, 201 (1997). [DOI: https://doi.org/10.1016/S0040-6090(97)00215-0]

[13] H. Takeda, Y. Sato, Y. Iwabuchi, M. Yoshikawa, and Y. Shigesato, *Thin Solid Films*, **517**, 3048 (2009). [DOI: https://doi.org/10.1016/j.tsf.2008.11.114]

[14] Y. Shigesato, D. C. Paine, and T. E. Haynes, *J. Appl. Phys.*, **73**, 3805 (1993). [DOI: https://doi.org/10.1063/1.352887]

[15] P. Wang, D. Zhang, D. H. Kim, Z. Qiu, L. Gao, R. Murakami, and X. Song, *J. Appl. Phys.*, **106**, 103104 (2009). [DOI: https://doi.org/10.1063/1.3259426]

[16] R. Doremus, *Thin Solid Films*, **326**, 205 (1998). [DOI: https://doi.org/10.1016/S0040-6090(98)00554-9]