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Direct current magnetron sputtered ultrathin Ag/Ta/glass films

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ABSTRACT
In this study, ultrathin Ta, Ag and Ag/Ta thin films deposited onto glass substrates using direct current magnetron sputtering. The physical properties of as-deposited films were investigated by scanning electron microscopy, atomic force microscopy, UV-Vis-NIR spectrophotometry and four-point probe method. We found that Ta interlayer was effectively reduced the Ag agglomeration, both resistance and emissivity. In particular, Ag(10nm)/Ta(4nm)/glass films exhibited dense and smooth surface withhigh transmittance of 58% in the visible region.

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I. INTRODUCTION

Low emissivity (low-e) coatings play major role in energy efficient windows, due to its high transmittance of visible light in the solar spectrum and reflect most infrared light. Nobel metals are widely used in insulating glazing films due to their excellent electrical conductivity and low infrared emissivity. Among them, silver (Ag)based ultrathin films are widely used for low-e coatings due to their low electrical resistance compare to copper and aluminum, low absorption in the visible region and comparatively high reflectivity in the infrared region [1-5]. However, ultrathin Ag films shows poor adherent on the glass substrates and easily agglomerated, leading to a degradation of the optical and electrical properties. The main reason of Ag agglomeration on the glass substrate is high silver/glass interfacial energy [6]. By introducing a suitable interlayer between silver and glass can be changed the silver/glass interfacial energy, consequently the Ag agglomeration is reduced. In this work, tantalum (Ta) is used as an interlayer between silver and glass,because, Ta is good thermal stability and it can reduce the Ag/glass interfacial energy. The relation between surface morphology and the optical-electrical properties of Ag/Ta/glass films is studied.

II. EXPERIMENTAL

Ultrathin Ta, Ag, Ag/Ta/glass films were deposited by DC magnetron sputtering on glass substrates. The glass substrate was rinsed in acetone and acid solution (1/3 HCl: 2/3HNO_3) then were ultrasonically cleaned. Before deposition of the films the Ag and Ta targets were pre-sputtered in argon atmosphere for about 10 min in order to remove the surface oxide layer of the target. Prior to each deposition the deposition chamber was evacuated to reach base pressure to $5x10^{-6}$ mbar. The sputtering power of Ag and Ta targets was 40 W and 130 W respectively. The microstructure of the films was characterized by scanning electron microscopy (SEM). The surface morphology of the was examined with atomic force microscopy (AFM). UV-Vis-NIR spectrophotometer was used to measuring the optical properties of the films in the range was 300-2400 nm. The electrical resistance of the films was measured by standard four-probe method.

III. RESULTS AND DISCUSSION

3.1. Microstructure and Surface morphological studies

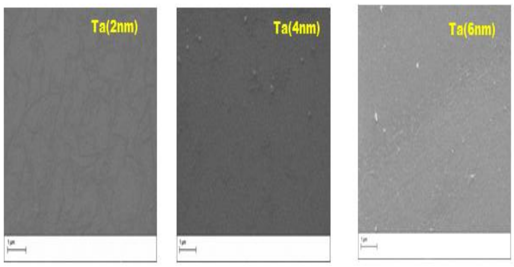

Fig. 1. SEM images of ultrathin Ta films at different thickness.

The SEM images of ultrathin Ta films at different thickness are shown in Fig. 1. The films deposited at 2nm thickness shows voids on surface of the films. As increasing the films thickness to 4nm the films exhibited dense and smooth background of the homogeneous surface without agglomeration. On further increasing the thickness to 6 nm, small grains are appeared and some patches like structures were observed.

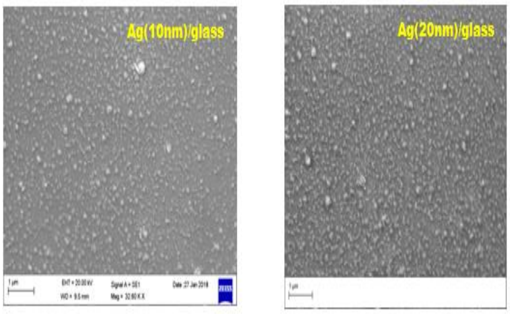

Fig. 2. SEM images of ultrathin Ag films at different thickness.

Fig.2. showsthe SEM images of ultrathin Ag/glass films at different Ag thickness. The Ag(10nm)/glass films show aggregates of crystals with significant amount of voids leading to the rough surface. The thickness of the Ag films increased to 20nm, the SEM image seen aggregates of crystals and voids with seemingly thick boundaries. As increasing the Ag thickness agglomeration of Ag was severe. Agglomeration is generally driven by the relatively high Ag/glass interfacial energy [6].

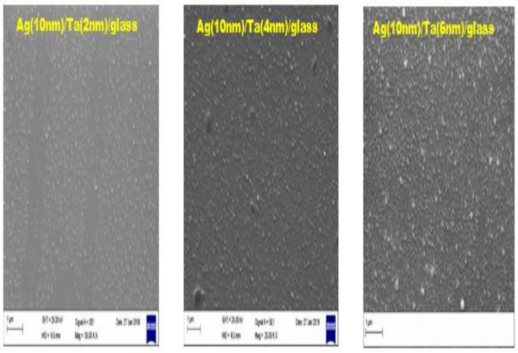

Fig. 3. SEM images of ultrathin Ag(10nm)/Ta/glass films at different Ta thickness.

Fig. 3. shows the SEM images of ultrathin Ag(10nm)/Ta/glass films with various Ta thickness. Ultrathin Ag(10nm) films deposited on Ta(2nm)/glass exhibited small grains with some patches on the surface. Whereas, the ultrathin Ag(10nm) films deposited on Ta(4nm)/glass exhibited small grains with dense surface. Beyond this Ta thickness the Ag(10nm) films shows bigger grain with irregular shape.Overall, it is evident that Ta interlayer induced the formation of a dense and smooth Ag film without agglomeration. This was due to modifying the Ag/glass interfacial energyand change in the film growth mode by introducing the Ta interlayer [7].

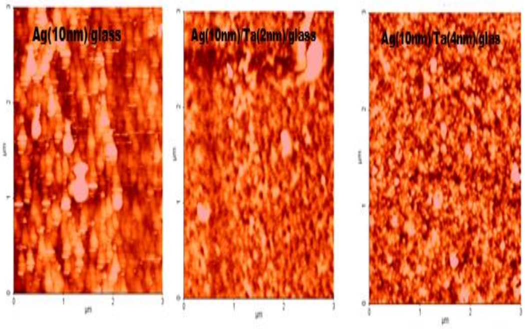

Fig. 4. AFM images of ultrathin Ag/glass and Ag/Ta/glass films.

The surface morphology of the ultrathin Ag/glass and Ag/Ta/glass films examined by atomic force microscopy and shown in Fig. 4. AFM images shows obvious difference in the surface morphology of films. The Ag(10nm)/glass exhibited a bigger size island structures with an average root mean square roughness(rms) of 1.3nm. Whereas, Ag(10nm) films deposited on Ta(2nm)/glass and Ta(4nm)/glass shows smooth surface with low rms roughness compere to Ag(10nm)/glass. The obtained rms roughness values of Ag(10nm)/Ta(2nm)/glass and Ag(10nm)/Ta(4nm)/glass are 0.95 and 0.57, respectively.

3.2. Optical andElectrical properties

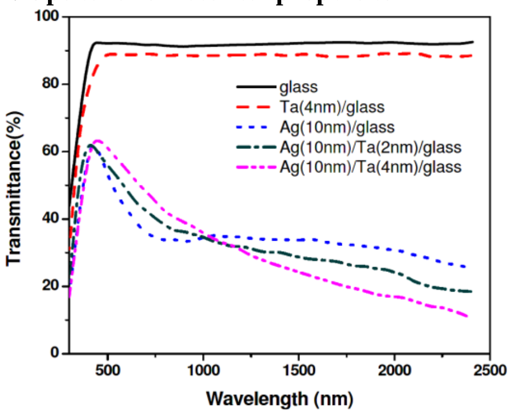

Fig. 5. Optical transmittance spectra of glass, Ta, Ag and Ag/Ta/glass films.

The optical transmittance of the films is strongly depending on their microstructure, density, surface roughness and the surface plasman effect. The optical transmittance ofultrathin Ta, Agand Ag/Ta/glass films was observed in the wavelength range of 300- 2400 nm and shown in Fig. 5. The optical transmittance of bare glass was more than 92% in the wavelength range of 550 nm. The optical transmittance of Ta(4nm) films in the visible range was more than 88%. The transmittance of Ag(10nm)/Ta(2nm)/glass was relatively high (51%) compared to Ag(10nm)/glass films (46%) at wavelength of 550nm. The thickness of the Ta interlayer increases to 4nm, the Ag(10nm)/Ta(4nm)/glass films optical transmittance was increased to 58%. The Ta interlayer play major role in the increase of optical transmittance. Which is induced the formation of a dense Ag thin film by 2-D growth, leading to high transmittance in the visible region and lower transmittance in the infrared region[7].

The sheet resistance of Ta films was above unmeasurable range. The ultrathin Ag(10nm) films on glass substrates shows the sheet resistance of 15.6Ω/□. After introducing the Ta interlayer between Ag(10nm) and glass, the sheet resistance values are reduced greatly. The sheet resistance values of Ag(10nm)/Ta(2nm)/glass and Ag(10nm)/Ta(4nm)/glass are 5.8 and 4.1Ω/□. The reduction of the resistance was attributed to the microstructural difference in the films. Emissivity (ε) depends on the sheet resistance (R□) and can be evaluated by using bellow equation [8],

$$\varepsilon = 0.0129.\ R_\square - 6.7X10^{-5}\ R^2_\square$$

The calculated emissivity values of Ag(10nm)/glass, Ag(10nm)/Ta(2nm)/glass and Ag(10nm)/Ta(4nm)/glass films are 0.18,0.073 and 0.052, respectively. The emissivity value of Ag/Ta/glass film was lower than Ag/glass films, which is originated from the reduction of the resistance.

IV. CONCLUSIONS

In summary, ultrathin Ta, Ag/glass, Ag/Ta/glass films were successfully deposited by dc magnetron sputtering. The effects of Ta interlayer on surface morphological, optical and electrical properties of ultrathin Ag based films were systematically studied. The results revealed that the Ta interlayer effectively reduce the Ag film agglomeration and surface roughness of Ag/Ta/glass films. Ag(10nm)/Ta(4nm)/glass films showed a lower sheet resistance of 4.1Ω/□, 58 % of transmittance in the visible region and leading to a lowest emissivity of 0.052.

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