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Effect of Thicknesses on the Optical and Electrical Properties of Ag Films on PET Substrates

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Abstract. A series of Ag films with different thicknesses were prepared on polyethylene terephthalate (PET) substrates under identical conditions by thermal evaporation. The effect of the thickness on the optical and electrical properties of the films was studied. The morphology of the samples was investigated by atomic force microscopy (AFM). The optical and electrical properties were measured by spectrophotometer and four-point probe method, respectively. The experimental results show that the reflectance increases, while transmittance and resistivity decrease with the increase of the thickness. There exists a critical thickness of the film and it is 75 nm in this experiment. The optical and electrical properties of Ag films on PET substrates with thickness larger than critical thickness, are close to those of the conventional bulk silver. The resistivity of the 150-nm film is 3.0±0.2 μΩ•cm, which is lower than that of the 250-nm Ag film grown on BK-7 glass substrates.

Introduction

Silver films have been of considerable interests for years due to their unique physical properties such as peculiar optical property and low resistivity[1-3]. Some investigations show that the effect of the thickness on properties of the silver films is crucial, e.g. the structure, morphology, electrical, optical properties, the thermal stability and so on rely on the thickness of silver films[4-7]. The effect of the thickness on optical and electrical properties may be correlated with the sizes and shapes of silver grains. Consisted of isolated islands, thinner silver films possess extraordinary optical properties, such as surface plasmon resonance, particle plasmon resonance and strong second harmonic radiation, which are used widely in colour filters[8], optical switching and optical limiting devices[9], etc. When the thickness increases beyond the critical value, their properties tend to be stable[10]. The thicker silver films, with high reflectivity and low resistivity, are used as electrode, reflectors, ohmic contacts in solar cells and light-emitting diodes[11-12], interconnect materials in ultra-large scale integration[13], etc.

Those reports above about the effect of the thickness on optical and electrical properties were done on glass substrates(Sub.). Recently, organic optoelectronic devices, such as organic solar cells[14], light emitting diodes[15] and sensors[16], attract lots of attention due to the outstanding properties of polymers, potentially low cost, light weigh and flexibility compared to glass Sub.. So it is necessary to investigate the relationship between the thickness and the optical and electrical properties of the silver films on polymer Sub..

In this work, we studied the effect of the thickness on the optical and electrical properties of the silver films on PET Sub.. It is found the reflectance spectrum of 75-nm-thick silver film is close to that of the conventional bulk silver, and resistivity is 4.7±0.9 μΩ • cm, which is a milestone of the optical and electrical properties of silver films grown on PET Sub.. And that the resistivity of 150- nm film decreases to 3.0±0.2 μΩ•cm, which is lower than that of the 250-nm Ag film grown on BK-7 glass Sub..

1. Experimental details.

A series of silver films with different thicknesses were deposited on PET Sub. by thermal evaporation under identical conditions using silver (99.99% purity) wires. Electric current for evaporation was 120 to 150 ampere and deposition pressure was 5.0×10^{-3} Pa. The deposition rate (about 1.5 nm/s) and thickness (15,30,75,120,150 nm) were measured with a quartz crystal micro balance. The surface morphology of the samples was examined by atomic force microscopy (AFM) (CSPM 4000). The average surface grain size (ASGS) and the root mean square (RMS) surface roughness of the films were calculated from AFM images. The reflectance and transmittance were measured in the $200<\lambda<800$ nm wavelength range by use of a double beam spectrophotometer (UV—2450). Electrical resistivity was measured by a four-point probe method.

2. Results and discussion.

2.1 The surface morphology.

The evolution of surface morphology of silver films with different thicknesses deposited on PET Sub. are presented in Fig.1. The SAGS and the RMS surface roughness of the films calculated from AFM images data are shown in Table 1.

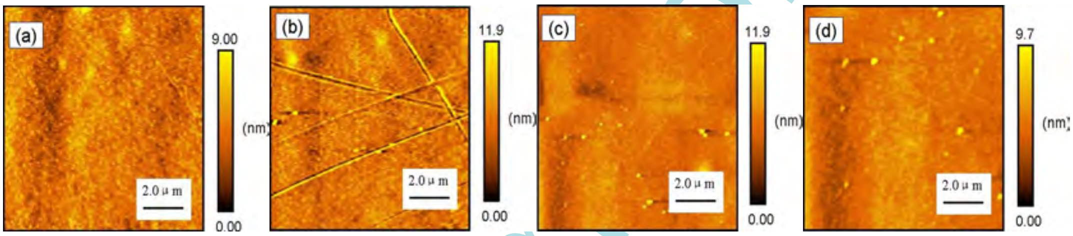

Fig.1. AFM images of Ag films with different thicknesses on PET Sub.: (a)15nm, (b)30nm, (c) 75nm and (d)120nm.

Table 1. SAGS and RMS roughness of Ag films with different thicknesses on PET Sub..

Thickness (nm)	15	30	75	120	150
RMS(nm)	2.55	2.35	2.05	1.95	1.79
SAGS (nm)	82.8	76.8	53.7	48.4	42.6

As can be seen in Fig.1, the substrate only has a visible influence on the surface morphology of silver films thinner than 30nm, in which the surface morphology of substrate can be seen(Fig.1(a)-(b)). And the 15-nm- thick film has the maximum ASGS(82.8nm) and RMS surface roughness(2.55nm) shown in Table 1. The grains are caky,and there are not clear lineaments between grains and grains, which are obviously different from the silver films grown on glass Sub.[17]. It is likely because silver is easily wet on PET Sub. compared to glass Sub. so that the grain is easily polarized to become caky[18] . The effect of the substrate decreases sharply with the increasing of the thickness. After the thickness increases to 75nm, the ASGS and RMS surface roughness decrease slightly(53.7, 48.4, 42.6nm and 2.05, 1.95,1.79nm). When the films become thicker, the evaporation time lengthens, the substrate temperature rises, which result in the high possibility of the migration and pervasion of surface particles. So, grain voids become smaller, RMS surface roughness decreases.

2.2 Electrical and optical properties.

Figure 2(a) and (b) present the reflectance and transmittance of Ag films with different thicknesses on PET Sub.. As indicated in Figs. 2(a), the reflectance of the films below 30nm drops from 800 to 320nm wavelength. And surface plasmon resonance is not very obvious, which is possibly caused by caky not globular nanoparticles grown on SiO_2-based substrate[1] or embedded in polymer matrices[2]. When the thickness increases to 75nm, the reflectance spectrum is similar to thick silver films grown on galss Sub.,with a plasmon resonance peak at 320nm[17]. With the increasing of the thickness, the reflectance is slightly enhanced because of the decrease of SAGS and RMS roughness(Table 1). For the transmittance spectra, as shown in Figs. 2(b), transmittance of all the sample increases with the decrease of the wavelength until 320nm,where the transmittance of PET Sub. is close to zero. And the transmittance drops sharply with the increase of thickness, then, when the thickness increases to 75nm and above, an acuti-peak is formed in 310～350nm wavelength, where the surface plasmon resonance appears.

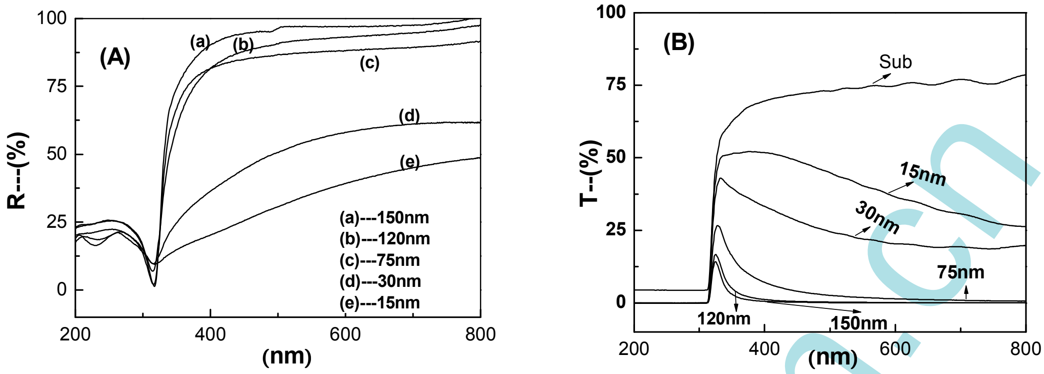

Fig.2. Spectra of Ag films with different thicknesses on PET Sub.: (A) reflectance and (B) transmittance.

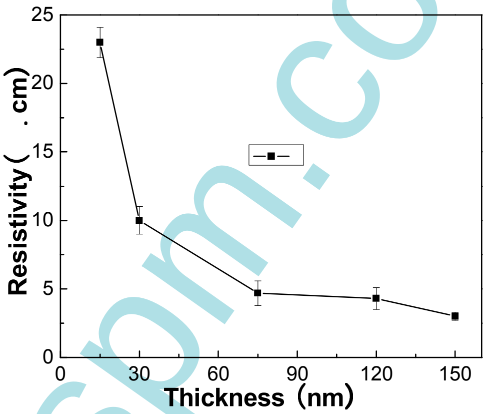

Fig.3. Resistivities Ag films on PET Sub. as a function of the thicknesses.

The variation of the resistivities of Ag films grown on PET Sub. was shown in Fig.3. As indicated in the figures, the resistivities drops with the increase of the thickness. The 15nm Ag film is electric, but the resistivity is big due to voids film as shown in Fig. 1(a). When the thickness increases to 30 and 75nm, the resistivity rapidly drops to (10.0±1.0) and (4.7±0.9)μΩ cm owing to the increase of thickness, decrease of voids and reduction of RMS roughness and ASGS, which decrease the surface electronic scattering, then avail electronic transfering. When the thickness continues increasing, the resistivity slightly drops because of the slight change of RMS roughness and ASGS. So 75-nm- thick is a turning point of the electrical property of silver films on PET Sub.. When the thickness increases to 150nm, the resistivity drops to (3.0±0.2)μΩ cm, which is obviously lower than that of the 250nm Ag films grown on BK-7 glass Sub.[17].

3.Conclusion

The effect of the thickness on the optical and electrical properties of the films grown on PET Sub. was investigated. A series of Ag films on PET Sub. with different thicknesses were prepared under identical conditions by thermal evaporation.The morphology of the samples was investigated by atomic force microscopy (AFM). The optical and electrical properties were measured by spectrophotometer and four-point probe method. It is found that the reflectance increases, while transmittance and resistivity decrease with the increasing of the thickness. The 75-nm film is a milestone of the optical and electrical properties of silver films on PET Sub., whose reflectance spectrum is close to that of the conventional bulk silver, and resistivity decreases to 4.7±0.9 μΩ • cm. The resistivity of 150-nm film decreases to 3.0±0.2 μΩ•cm, which is lower than that of the 250-nm Ag film grown on BK-7 glass Sub..

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