



# Effect of wettability on surface morphologies and optical properties of Ag thin films grown on glass and polymer substrates by thermal evaporation



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## ABSTRACT

A series of Ag films with different thicknesses were deposited on BK-7 glass, PET and PC substrates under identical conditions by thermal evaporation. The effect of the wettability on the morphology and optical properties of Ag/glass and Ag/polymer films was studied by atomic force microscopy and spectrophotometry. The experimental results show that the wettability of Ag grains with polymer is stronger than with glass, which results in the aggregation of bigger grains in initial layer. During deposition the interaction of interlayer plays an important role for the formation of the surface morphology. The strong wettability activates the nonlinear optical properties of Ag grains grown on polymer substrates, which result in the strong absorbance in short wavelength. The effect of the bare substrate on the transmittance of Ag films is more obvious than the reflectance. With the increasing of the thickness, the effect of the wettability on the morphology and optical properties of Ag films decline. In this experiment when the thickness is above 50 nm, the effect almost vanished.

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## 1. Introduction

Ag thin films have attracted much attention owing to their peculiar optical properties [1–3]. In previous investigations, it is found that the size and shape of silver nanoparticles, the surface roughness of the thin films will affect the optical properties of Ag films [4,5]. So, many efforts have been devoted to the preparation and stabilization of Ag nanoparticles in order to control their sizes, shapes and distribution [6–8]. In recent years, it is found that, excluding preparation technology, substrate material also affect the sizes, shapes and distribution of Ag nanoparticle. The dependence of Ag wettability between Ag and substrate material controls the aggregation of grain during deposition is a well known fact. But people fasten their attention upon how to improve adhesion of Ag films and substrate materials. Gadre and Alford found the annealing and plasma treatment are effective [9]. The effect of wettability on surface morphologies and optical properties of Ag thin films is few investigated. With the development of better organic semiconductor materials and fabrication procedures, organic solar cells, light

emitting diodes and so on have been of considerable interests. So that it is important to investigate comparatively the influences of inorganic and organic substrates on the properties of Ag thin films.

In this work, we studied the effect of the wettability on surface morphology and optical properties of the Ag/glass and Ag/polymer films. It is found that the wettability of Ag grains with polymer is stronger than with glass. The strong wettability activates the nonlinear optical properties of Ag grains grown on polymer substrates, which results in the strong absorbance in short wavelength. When the thickness is above 50 nm, the effect of the wettability nearly disappeared.

## 2. Experimental details

A series of Ag films with different thicknesses were deposited on BK-7 glass, polyethylene terephthalate (PET) and polycarbonate (PC) substrates under identical conditions using silver (99.99% purity) wires by thermal evaporation. Electric current for evaporation was about 110 A and deposition pressure was  $5.0 \times 10^{-3}$  Pa. The deposition rate (about 1.0 nm/s) and the thickness were measured with a quartz crystal micro balance.

The surface morphology of the samples was examined by atomic force microscopy (AFM) (CSPM 5500, Ben Yuan Ltd., China)

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**Table 1**  
RMS roughness and SAGS of Ag films grown on different substrates.

Thickness (nm)	Ag/BK-7		Ag/PET		Ag/PC	
	RMS/nm	ASGS/nm	RMS/nm	ASGS/nm	RMS/nm	ASGS/nm
20	3.33	40.2	4.02	62.8	5.52	70.3
30	3.01	35.3	3.35	51.3	5.01	60.2
50	2.42	25.8	2.63	30.5	4.38	40.5

equipped with a microscope and a CCD detection system. Scans were taken under a contact force of  $10^{-9}$  N and over areas of  $2.0 \times 2.0 \mu\text{m}^2$ . The average surface grain size (ASGS), the root mean square (RMS) surface roughness, surface grain sizes and height distribution were obtained by the corresponding software in CSPM 5500. The reflectance and transmittance were measured in the  $200 < \lambda < 800$  nm wavelength range by use of a double beam spectrophotometer (UV-2550).

### 3. Results and discussion

#### 3.1. The surface morphology

The RMS surface roughness and ASGS of the films calculated from AFM images data are listed in Table 1. The data revealed that in the same thickness, the RMS surface roughness and ASGS of the films grown on BK-7 glass were smaller than the other two. With the increasing of the thickness, the data decreased. When thickness was above 50 nm, the data changed slightly (not be listed about above 50 nm). Fig. 1 shows the surface morphology of the Ag 50 nm films. It was clear that the surface grains were spherical (Fig. 1(a1)), elliptical (Fig. 1(b1)) and flattened elliptical (Fig. 1(c1)) grown on BK-7 glass, PET and PC substrates.

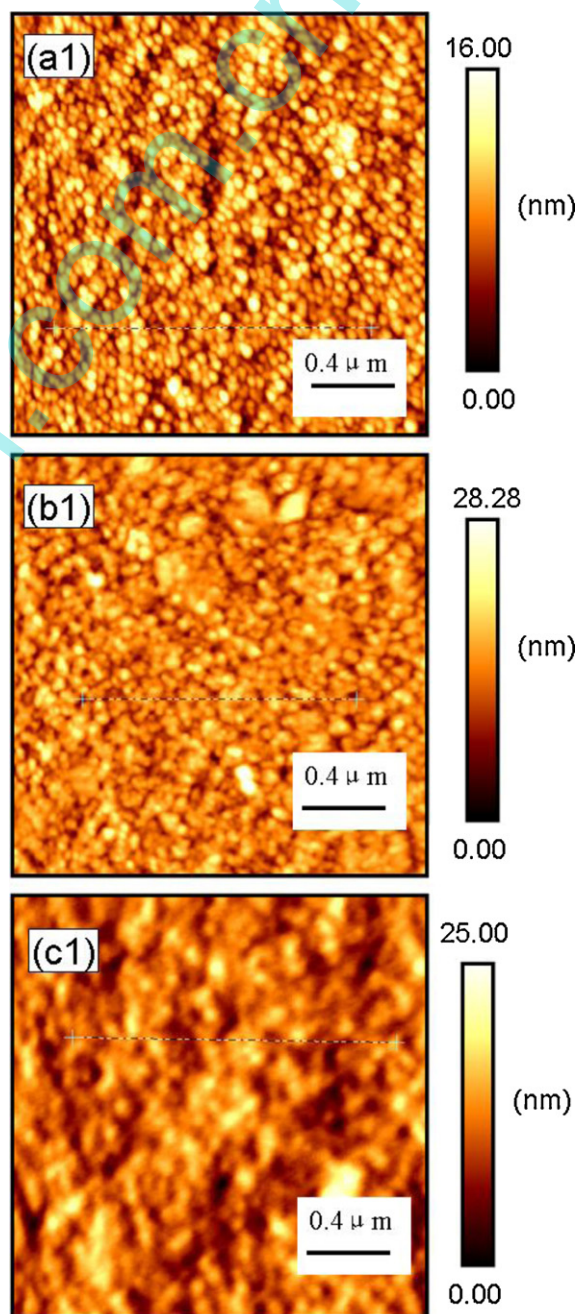
According to the data listed in Table 1, we can conclude that the wettability grown on polymer (PC and PET) substrates is stronger than grown on BK-7 glass. In the first layers, the aggregation of big Ag grains is shaped because of the strong wettability grown on polymer (PC and PET) substrates. During deposition the interaction of interlayer plays an important role. So, the surface grain sizes and morphology are formed as shown in Table 1 and Fig. 1.

#### 3.2. Height and grain sizes distribution

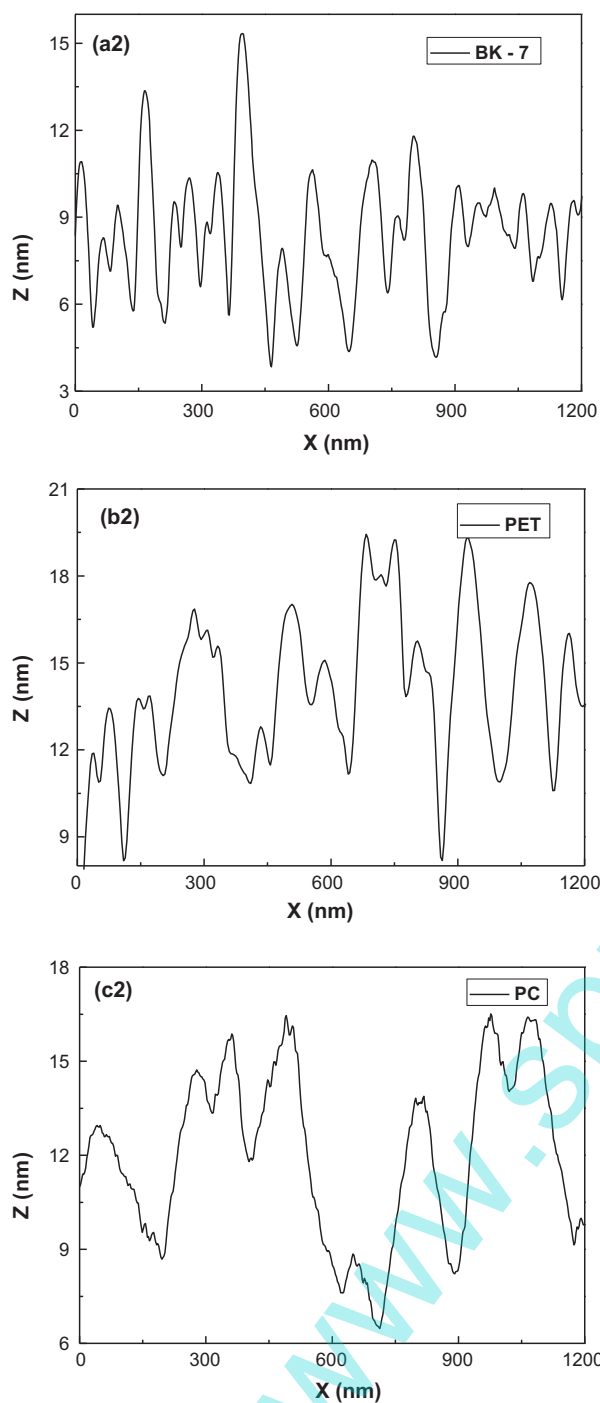
In order to further examine the grain stack during deposition, a height distribution along line in Fig. 1 is performed in Fig. 2. Comparing these three curves in Fig. 2, it was clear that the aggregation of grains, Ag 50 nm film grown on PC substrate, was strongest in the three films, forming a widest rugged profile shown in Fig. 2(c2). While for the film grown on BK-7 glass substrate there were some dispersed finely ravines, which indicated clearly that the aggregation of spherical grains was very weak (Fig. 2(a2)). The different of the grain stack has an important effect on the surface morphology.

The distribution graphs of surface grain sizes with 50 nm thickness are provided in Fig. 3. It was found that the distributions grown on BK-7 glass and PET substrates were similar (Fig. 3(a and b)). The grain sizes are convergence, and the large-sized grains are few. The max size grown on BK-7 glass and PET substrates are about 62 nm (ratio about 0.01%) and 76 nm (ratio about 0.1%), respectively. It is clear that the effect of the wettability on the morphology has no real distinction made between the grown on BK-7 glass and PET substrates when thickness is 50 nm. While for the film grown on PC substrate (Fig. 3(c)), the size scope is wide (6–120 nm), but there is on concentrative distribution area. The ratio of the small grain size

between 6 and 10 nm is appreciable, and the total ratio of the large grain size between 80 and 120 nm is about 1%, which reflects the existence of the effect of the wettability on the morphology of Ag 50 nm film grown on PC substrate.



**Fig. 1.** AFM images of Ag 50 nm films grown on different substrates: (a1) BK-7 glass, (b1) PET and (c1) PC.

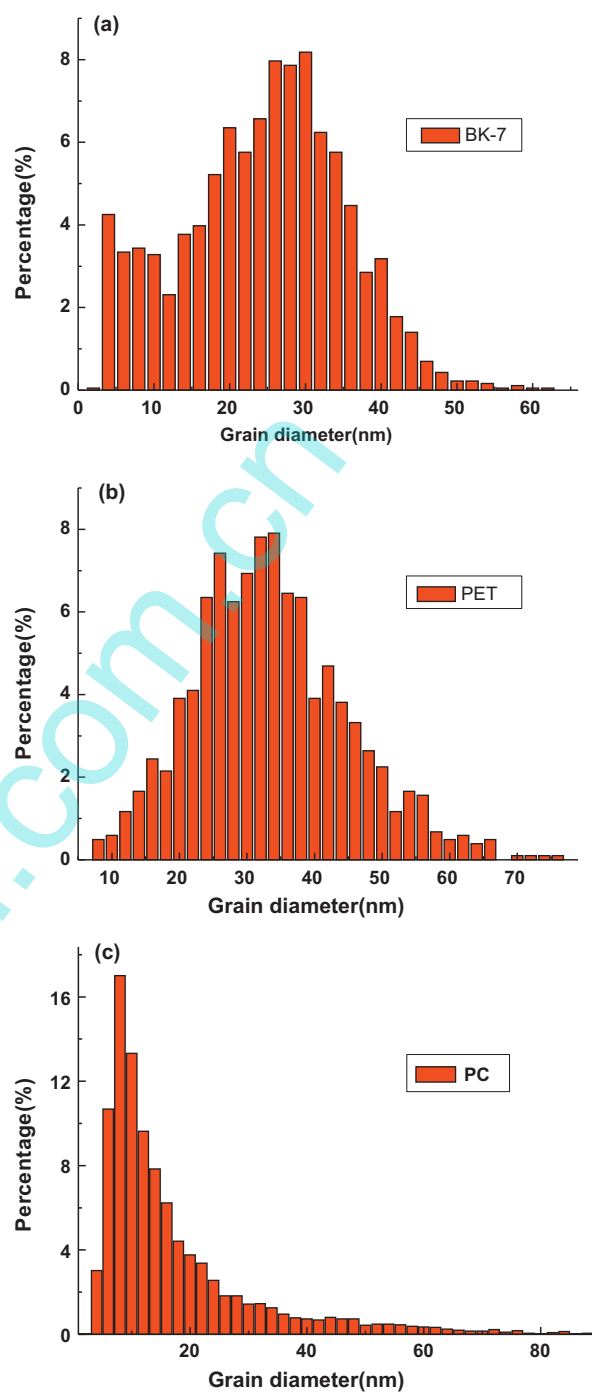


**Fig. 2.** Height distributions taken along the marked line in AFM images of Ag 50 nm films grown on different substrates: (a2) BK-7glass, (b2) PET and (c2) PC.

### 3.3. The optical properties

Fig. 4 shows optical properties of samples. The reflectance and transmittance of the Ag 0, 20, 30 nm films grown on BK-7 glass, PET and PC substrates are presented in Fig. 4(a1–a3) and (b1–b3), that of the Ag 50 nm films be seen in Fig. 4(c1–c2).

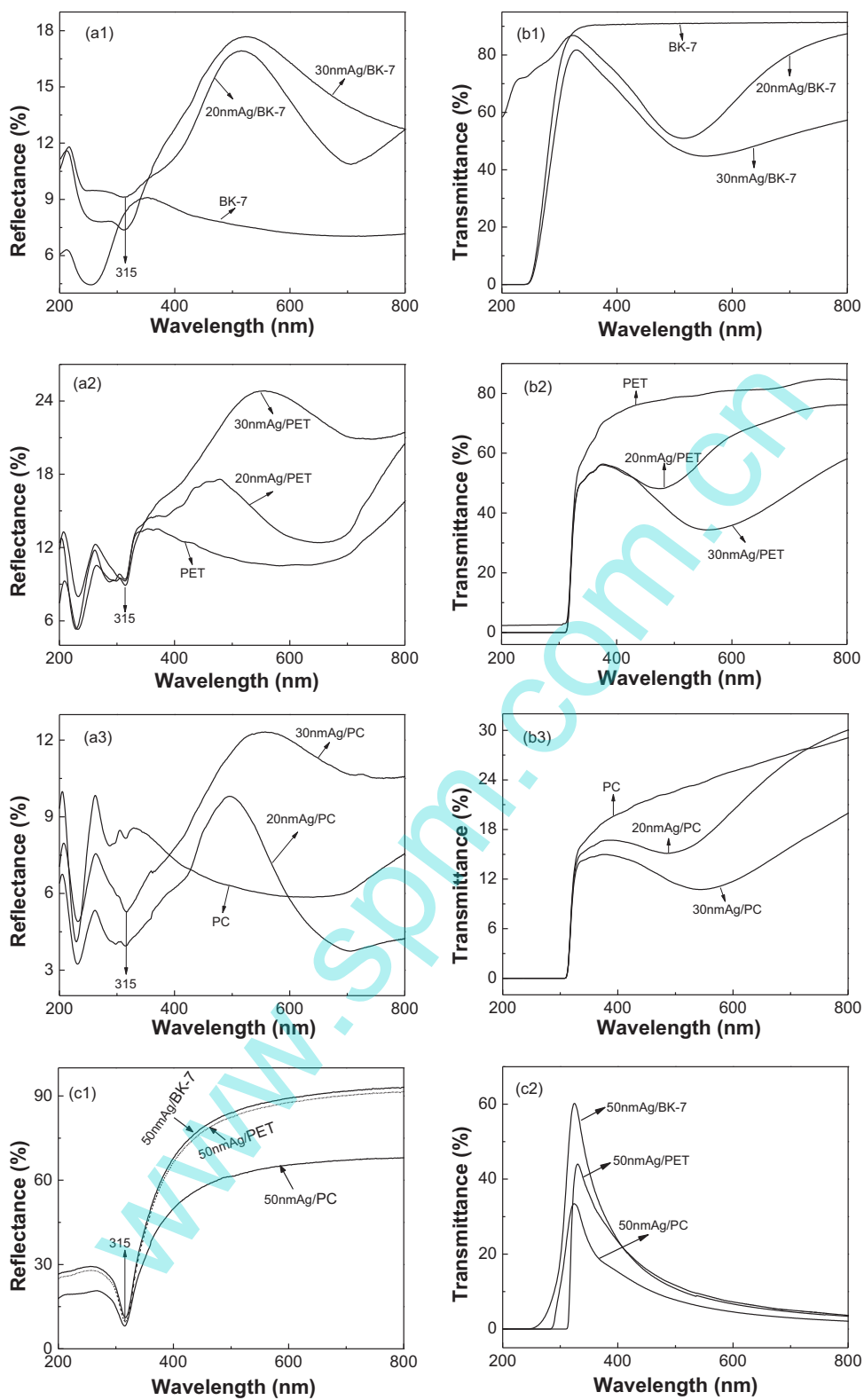
Comparing Fig. 4(a1–a3) and (b1–b3), we found that the effect of the bare substrate on the transmittance of Ag films was more obvious than the reflectance. And in short wavelength, it was quite possible that absorbance of Ag films grown on polymer (PC and PET) substrates was stronger than that of grown on BK-7 substrates because of their weak reflectance and transmittance. Observing



**Fig. 3.** Distribution graphs of surface grain sizes of Ag 50 nm films grown on different substrates: (a) BK-7glass, (b) PET and (c) PC.

all of the reflectance curves in Fig. 4(a1–a3) and (c1), in the Ag films grown on different substrate materials with different thickness, it was clear that the surface plasma resonance absorbance peak was appeared nearly at 315 nm wavelength. As indicated in Fig. 4(c1–c2), when thickness was above 50 nm the reflectance and transmittance curves would not be affected by thickness and substrate materials, which were close to that of bulk Ag [3,10].

Obviously, the strong wettability grown on polymer (PC and PET) substrates results in the difference of the optical properties from grown on glass substrates. It is quite possible that the nonlinear optical properties of Ag grains grown on polymer substrates are activated due to the strong wettability, which results in possibility



**Fig. 4.** Spectra of the Ag 0, 20, 30 nm films grown on different substrates: the reflectance grown on (a1) BK-7 glass, (a2) PET, and (a3) PC; the transmittance grown on (b1) BK-7 glass, (b2) PET, and (b3) PC; the Ag 50 nm films (c1) reflectance, and (c2) transmittance.

of the strong absorbance in short wavelength. The large RMS surface roughness and SAGS due to the aggregation of grain controlled by the strong wettability increase the surface optical scattering and decrease the optical reflectance. But the difference of the wettability does not affect the difference of the surface plasma resonance absorbance peak at 315 nm wavelength.

#### 4. Conclusion

The effect of the wettability on the morphology and optical properties of Ag films grown on was studied by a series of different thicknesses BK-7 glass, PET and PC substrates. It is found that the wettability of Ag grains with polymer is stronger than with glass. The aggregation of big Ag grains controlled by the strong wettability and the interaction of interlayer form a rougher surface morphology grown on polymer (PC and PET) substrates. Simultaneously, the strong wettability activates the nonlinear optical properties of Ag grains grown on polymer substrates, which results in the strong absorbance in short wavelength. The effect of the bare substrate on the transmittance of Ag films is more obvious than the reflectance. But the difference of the wettability does not affect the difference of the surface plasma resonance absorbance peak at 315 nm wavelength. And when the thickness is above 50 nm, the effect of the wettability on the morphology and optical properties of Ag films drops sharply.

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