Slot Die Coating of Silver Nanowires Solutions to Make Transparent Conductive Films

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Abstract

The subject of transparent conductive films (TCF) made by wet coating processes to replace the expensive indium tin oxide (ITO) films has attracted extensive attentions in recent years. One of the most promising approaches is to coat aqueous silver nanowires solutions on polyethylene terephthalate (PET) films. However, it is important to control the conductivity in both the machine direction (MD) and the transverse direction (TD). An experimental study was carried to make TCF by slot coating method. Solutions that contain silver nanowires mixed with carboxymethyl cellulose (CMC) and polyoxyethylene-polyoxypropylene block copolymer (Pluronic F-127) were coated on PET film. As expected, if the average shear rate inside the slot die is high, silver nanowires tend to orient in the MD. A surprising finding reveals that through proper arrangement, silver nanowires on the upper part of the coated film tend to orient in the TD. This observation was recorded through an optical microscope. Therefore it is possible to obtain TCF with uniform conductivities in both the MD and the TD.

Key word: slot die coating, silver nanowires transparent conductive film, conductivity, optical microscope

1.Experimental

1.1 Formulation

In this work, the aqueous solutions including silver nanowire (D=53.2nm, L=15.1um), carboxymethyl cellulose (Sigma Aldrich) and Pluronic F-127 (Sigma Aldrich) was used. The concentration of silver nanowire was 0.4% and was used as the main conductive materials. The carboxymethyl cellulose was about 0.2% and was used as a dispersant. The Pluronic F-127 was used as a surfactant to modify the wetting property.

1-2 Slot die coating

Slot die coating method was adopted. The range of coating speed was from 1 cm/s to 10 cm/s. The photo of the experimental set-up is shown in Fig.1.

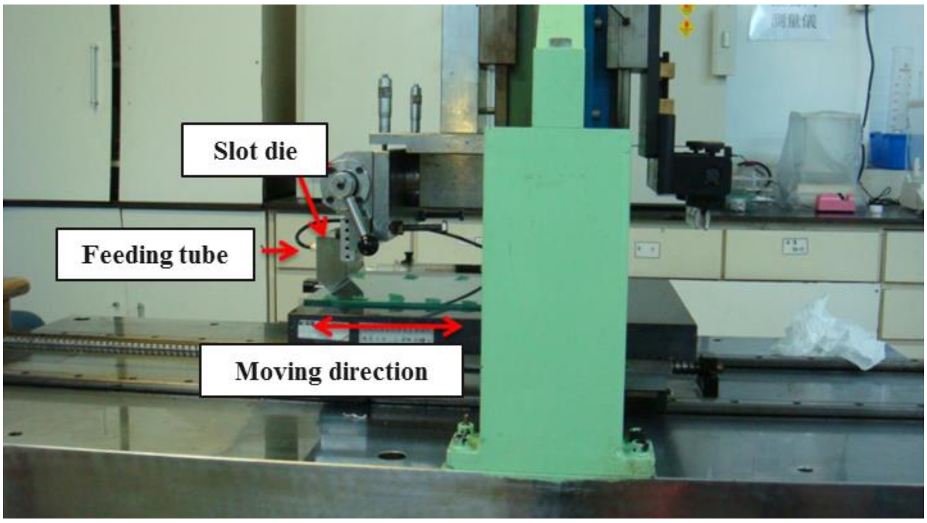


Figure 1. Photo of patch coater.

1-3 Measurements

The test solutions were coated on the polyethylene terephthalate (PET) films for analysis. Two major properties of the dried samples were measured. A four-point probe was used to detect the sheet resistance of the samples and a UV-visible spectrophotometer was used for transparency measurements. All physical properties were measured at fixed positions on the films. The coated samples were heated at 100˚C for 3 minutes. In order to measure the orientation of silver nanowires, the optical microscope images were taken and the parallel electrode connected with source meter was used to detect the resistance of the MD and TD. The photo of parallel sensor was shown in Fig 2. R_{TD} is the resistance measured when the parallel electrode is parallel to the coating direction, while R_{MD} is the resistance measured when the parallel electrode is orthogonal to the coating direction.

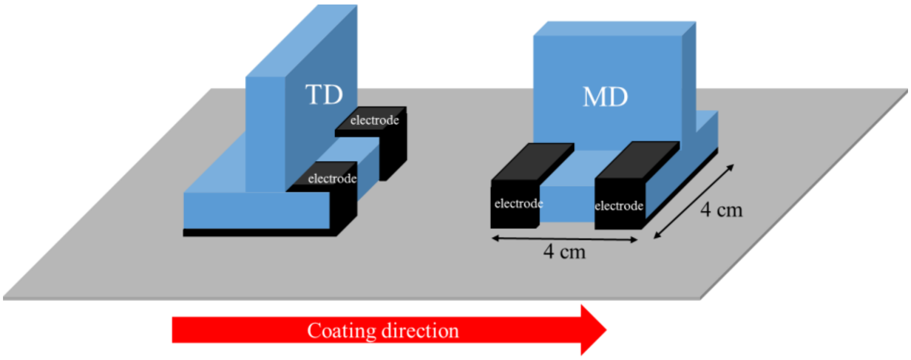
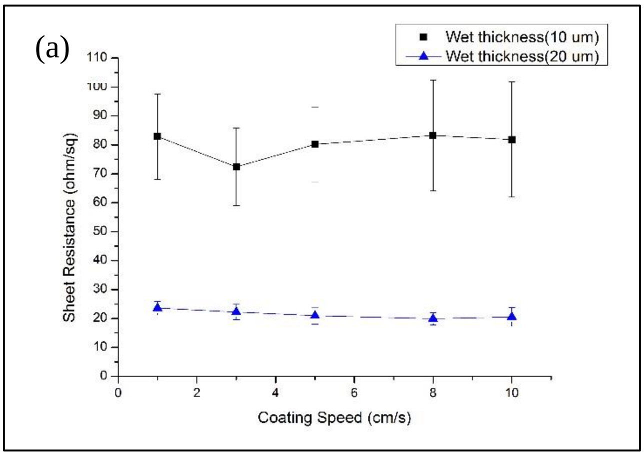


Figure 2.The photo of the parallel sensor.

1-4 Results and discussion

Figure 3 indicates that the sheet resistance and transmission were independent of the coating speed and were dependent on the coating thickness. Figure 4 shows that R_{TD}/R_{MD} was slightly increased as coating speed was increased. It means more silver-nanowires were oriented along the MD as the coating speed was increased.



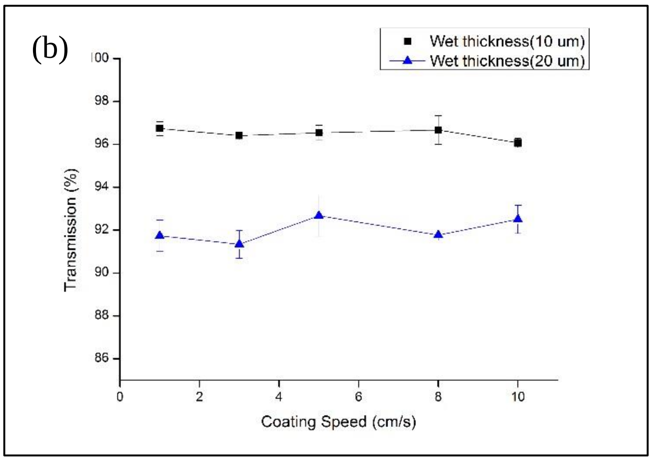


Figure 3. Optical-electronic properties of samples as a function of coating speed for slot die coating (a) sheet resistance vs. coating speed (b) transmission vs. coating speed.

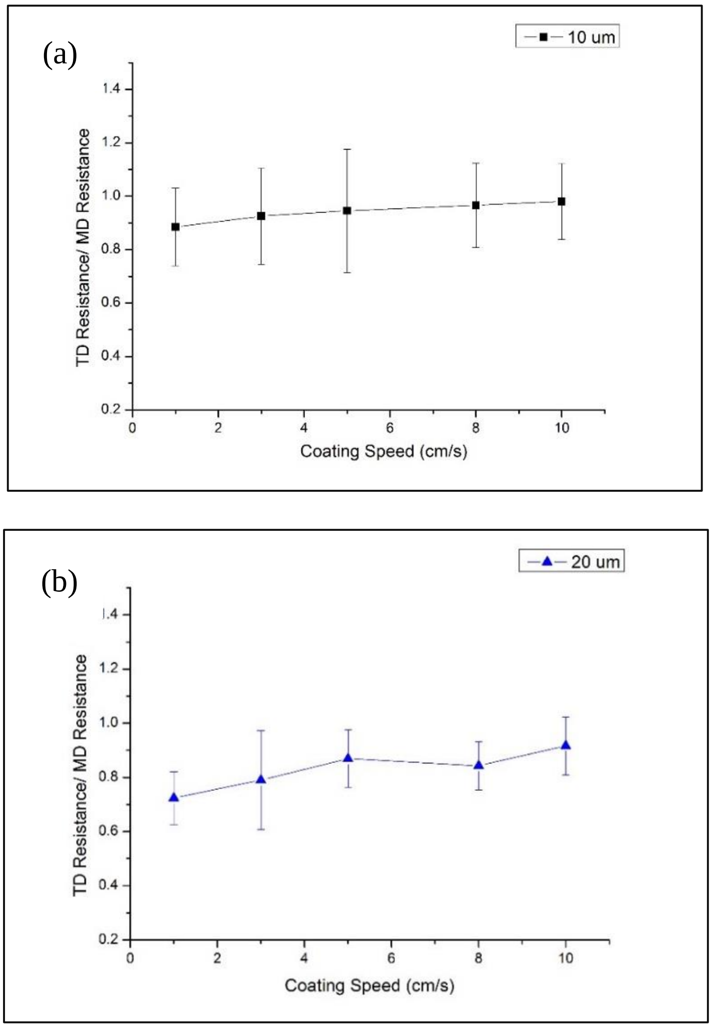


Figure 4. R_{TD}/ R_{MD} as a function of coating speed for slot die coating.(a) wet thickness=10 um (a) wet thickness=20 um.

1-5 Conclusion & Future work

It was found that the slot die coating method was able to produce TCF with transparency above 90% and sheet resistance close to 20 ohm/sq. Sheet resistance and transmission were independent of the coating speed but R_{TD}/R_{MD} was slightly increased as coating speed was increased. More silver-nanowires were oriented along the MD as the coating speed was increased.

It was found surprisingly that silver nanowires could move in the TD. The investigation on this finding is underway and will report during the meeting.

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