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Investigation of light transmission and scattering properties in silver nanowire mesh transparent electrodes

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ABSTRACT

Silver nanowire mesh is a promising replacement for indium tin oxide (ITO) transparent electrodes for optoelectronic devices. In this article, effective light scattering by Ag nanowires (Ag NWs) are investigated. Compared with commercial FTO and ITO, we demonstrated that Ag nanowires exhibit better optical transmission and light-scattering properties in all wavelength regions. Combined with the ease of preparation and low cost, our results indicated that Ag NWs are a promising candidate for use as a transparent conductive material for thin film solar cells.

1. Introduction

Transparent electrode (TE) thin film based on transparent conductive oxide (TCO) has been extensively used as an electrode in touch panel, light-emitting diodes and thin film solar cells [1–5]. The next generation of optoelectronic devices will require conductive electrodes, which are cheap, flexible and compatible with large-scale and rapidly manufactured methods [6].

In thin film solar cells, the thickness of the active layer is limited by the inferior charge-transporting properties to minimize the charge recombination loss [7,8]. To improve efficiency, it is important to structure light-trapping method to increase the absorbance. Thus, TCO films with a rough surface, such as F-doped SnO_2 (FTO), Al-doped ZnO (AZO), have been utilized as light-trapping electrodes to ensure effective light absorption in solar cells [6]. However, the scattering capability and transmittance of TCO films decrease towards longer wavelengths. Optical losses are mostly found in the red/IR region ($\lambda >$ 600 nm) due to free carrier absorption in the TCO film [7]. Currently, different electrode materials, such as conduction polymers [9], carbon nanotubes [10], graphene [10] and Ag nanowires (Ag NWs) [11], have been explored as potential anode materials to replace ITO in thin film solar cells.

In this article, we carefully examined the light transmission and scattering characteristics of Ag nanowires. In addition, we performed a comparison of the optical properties among Ag NW electrodes with ITO, and FTO transparent electrodes. We demonstrated that Ag nanowire electrodes with a high transmittance and effective light scattering broadband spectrum region (300–1000 nm), without free carrier absorption, showed potential as an emerging transparent conductive material for thin film solar cells.

2. Experimental methods

Ag nanowires were synthesized according to a previously described procedure [12,13] through a reduction in Ag nitrate in Poly (vinylpyrrolidone) (PVP) and ethylene glycol [14]. The NW were dispersed in methanol (10 mg mL^{-1}) and spin-coated at 2000 rpm for 30 s on top of glass substrates. Next, the Ag NW film samples were dried at 200 °C for 25 min.

3. Results and discussion

It is important to investigate the surface morphology of the film because it can affect the optical properties of the film. The surface morphologies of typical ITO, FTO and Ag NWs film are illustrated in Fig. 1. The AFM image of the ITO is shown in Fig. 1(a); the surface is relatively smooth, forms small crystals and has a surface

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root-mean-square (RMS) of approximately 2 nm. Fig. 1(b) reveals that the typical FTO film forms through hill like feature in the upper surface, resulting in an RMS of 42 nm. Fig. 1(c) shows the surface morphology of the Ag NW film, in which the surface presents a mesh network with an RMS of 22 nm. Fig. 1(g), (h) and (i) are the cross-sectional images of ITO, FTO and Ag NW films. The XRD pattern of the Ag NW is shown in Fig. 2b, the peaks at 38° and 44° correspond to (111) and (200) plane s of Ag (JCPDS 04–0783 face-centered structure). Fig. 2a shows the SEM images of Ag NWs, the diameters of Ag NWs are in the range of ~100 nm. Fig. 3.

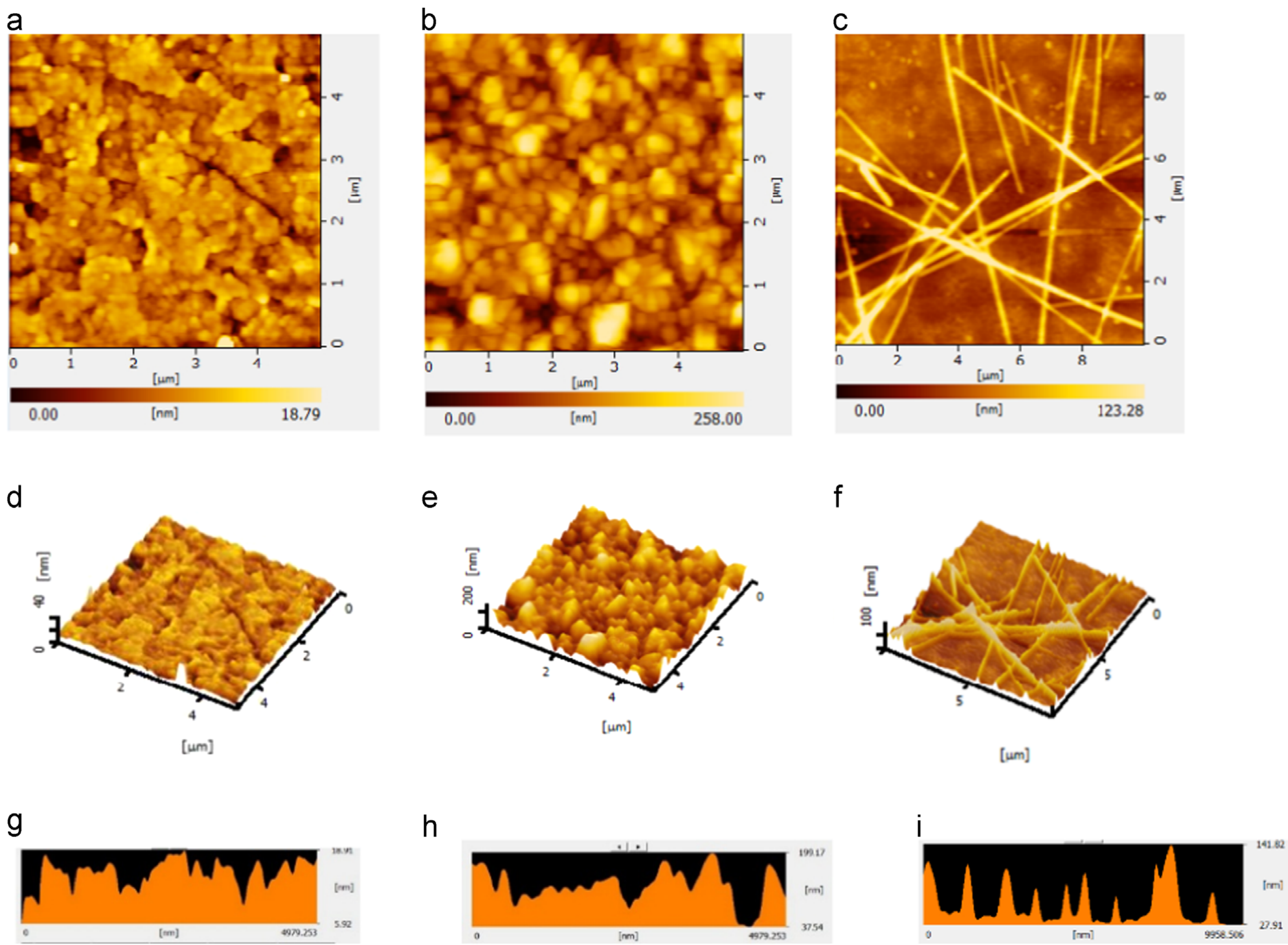

Fig. 1. AFM images of ITO (a, d, g), FTO (b, e, h), Ag NWs (c, f, i) thin films.

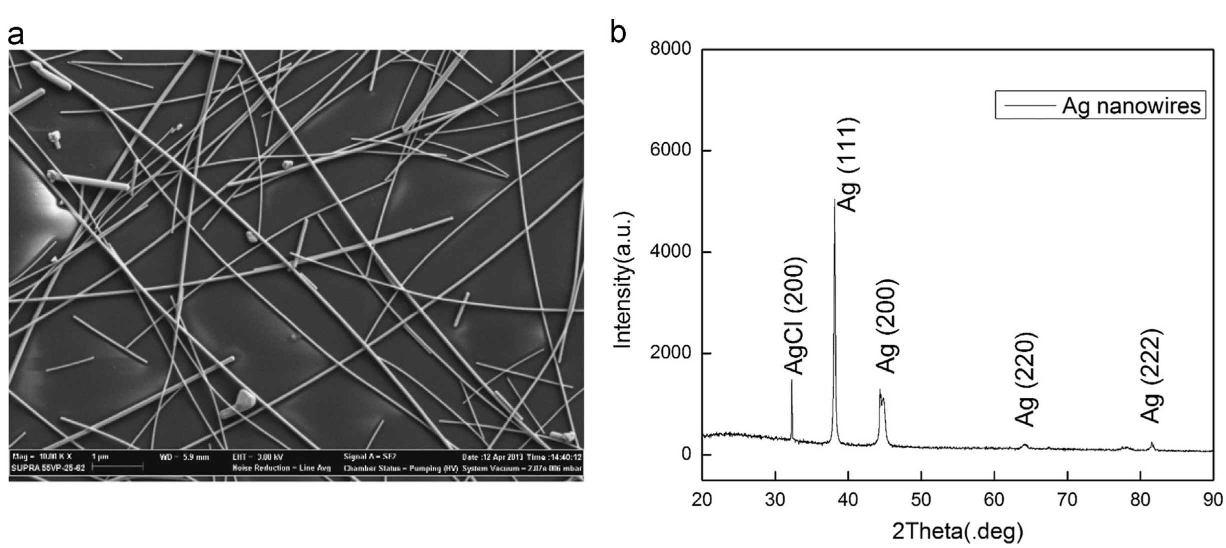

Fig. 2. SEM images (a) and XRD pattern (b) of Ag NWs.