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Pronounced optical gain attained in Ag/AZO structure for solar cell applications

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ABSTRACT

Recently plasmonic effect has attracted tremendous interests due to its ability of light trapping and improving the photovoltaic performances of solar cells. In this letter, we propose a solution method based fabrication route of Ag plasmons and realize a pronounced optical gain in ZnO:Al (AZO) thin film, which is strongly beneficial to harvest incident sunlight in thin film solar cells. Processing parameters, such as spinning speed, coating times and post-annealing temperature, could be regulated to optimize the plasmon effects of silver particles. The reflectance of silver particles coated AZO (Ag/AZO) is reduced by ~18%, and the transmittance is enhanced by ~40% simultaneously. The underlying mechanisms are discussed in combination with the microstructures of the silver particles.

1. Introduction

In the last several decades, nano noble metal materials, such as silver (Ag) and gold (Au), have attracted intensive attentions due to their wide applications in medical optical imaging [1], drugs [2] and solar cells [3] etc. Silver particles with a lower cost could be elaborately controlled to form surface plasmon polaritons (SPPs) with various shapes [4] and sizes [3] to trap light, which is the underlying mechanism for antireflection. As an example, Temple and Dligatch [5] proposed a structure of Ag/SiO_2/Si where the introduction of Ag layer with an optimized thickness of 5 nm was able to reduce the surface reflection by ~10%. On the other hand, Ag particles coated on the surface of AZO thin film can enhance the light scattering and lead to an increased transmittance of Ag/AZO [6]. For example, Theuring et al. [7] presented a sandwich structure of AZO/Ag/AZO whose transmittance was increased from ~70% to ~80% due to the introduction of the intermediate Ag layer. That is to say, the reflection (transmission) of window layers can be effectively minimized (enhanced) by applying Ag SPPs. However, it seems to be difficult to attain a pronounced optical gain via decreasing the reflection and simultaneously increasing the transmittance in the window layer, to harvest more incident sunlight [5,7,8] by using metal SPPs.

As for the fabrication of silver plasmons, physical methods, such as magnetron sputtering [9] and electron beam evaporation [5] are commonly used. However, these physical methods are practically limited by a high cost and a complicated processing procedure. Recently we have developed an easy chemical reduction method [10,11] to make the fabrication process to be easier, safer and more controllable. The morphologies and microstructures of the silver particles can be effectively tuned by the processing parameters. It was found that both the as-fabricated and thermally annealed silver particles significantly enhance the light transmission, and simultaneously reduce the reflectance on the AZO thin film surface due to the SPPs effect.

2. Experimental details

Silver nitrate ($AgNO_3$) was used as a raw material to prepare silver particles. Citric acid three sodium ($Na_3C_6H_5O_7 \cdot 2H_2O$), polyvinyl pyrrolidone (PVP) and deionized (DI) water were used as reductant, stabilizer and solvent, respectively. The substrate was 350 nm thick AZO thin film magnetron sputtering grown on glass substrate. The mixed solution of 18 mL DI water, 0.8 g PVP, 0.5 g $Na_3C_6H_5O_7 \cdot 2H_2O$ and 0.08 g $AgNO_3$ was stirred by a magnetic stirring apparatus to form a uniform precursor solution, and then introduced into a sealed reaction kettle to avoid the atmosphere exposure. The reaction kettle was put inside a thermostat set at the temperature of 180 °C for 20 h for the formation of silver colloid. Silver colloid was subsequently deposited on the AZO

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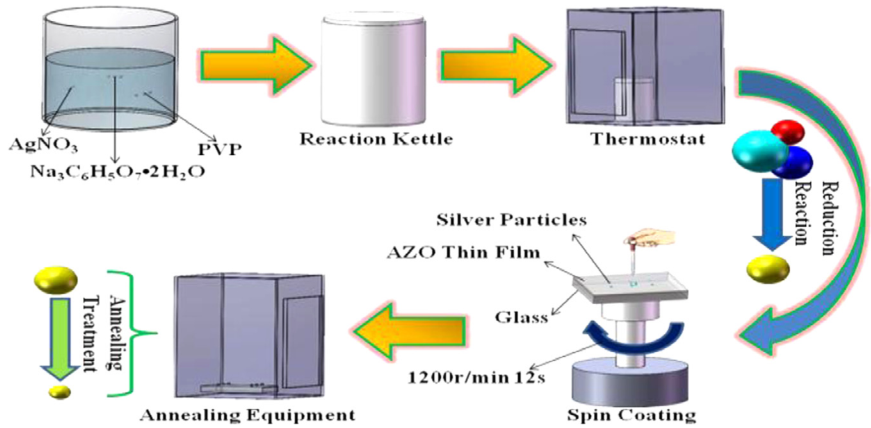

Fig. 1. The schematic fabrication flow of the silver particles.

substrate via a spin coater to form the Ag/AZO structure. Finally, as-fabricated Ag/AZO was thermally annealed in an annealing equipment as schematically shown in Fig. 1.

Light reflectance and transmittance spectra of Ag/AZO were measured by using Agilent UV/VIS/NIR spectrophotometer (Cary 5000). Scanning electron microscopy (SEM) measurements of Ag/AZO were taken on FEI Inspect F working at 20 kV. X-Ray diffraction (XRD) measurements were performed on Bede D1 whose working voltage, operating current and X-ray wavelength were set at 50 kV, 35 mA and 0.15402 nm, respectively.

3. Result and discussion

Fig. 2(a-d) show the XRD spectra of the bare and 17 times silver colloid coated AZO thin films: bare AZO without silver colloid coating (Ag-0/AZO) (a), coated AZO without post-annealing (Ag-17/AZO) (b), coated AZO with a 4-h post-annealing at 150 °C (Ag-17/AZO/annealing with 150 °C) (c), and coated AZO with a 4-h post-annealing at 200 °C (Ag-17/AZO/annealing with 200 °C) (d). Apart from the peak located at ~34.3° which is definitely recognized as the ZnO (002) plane shown in Fig. 2(a), another peak located at $2\theta=62.540°$ attributed to the AgO (−221) plane appears. The occurrence of AgO should be ascribed to the oxidation of Ag in air. In Fig. 2(c) there are three diffraction peaks, apart from ZnO (002) and AgO (−221), another standard (111) plane of Ag is

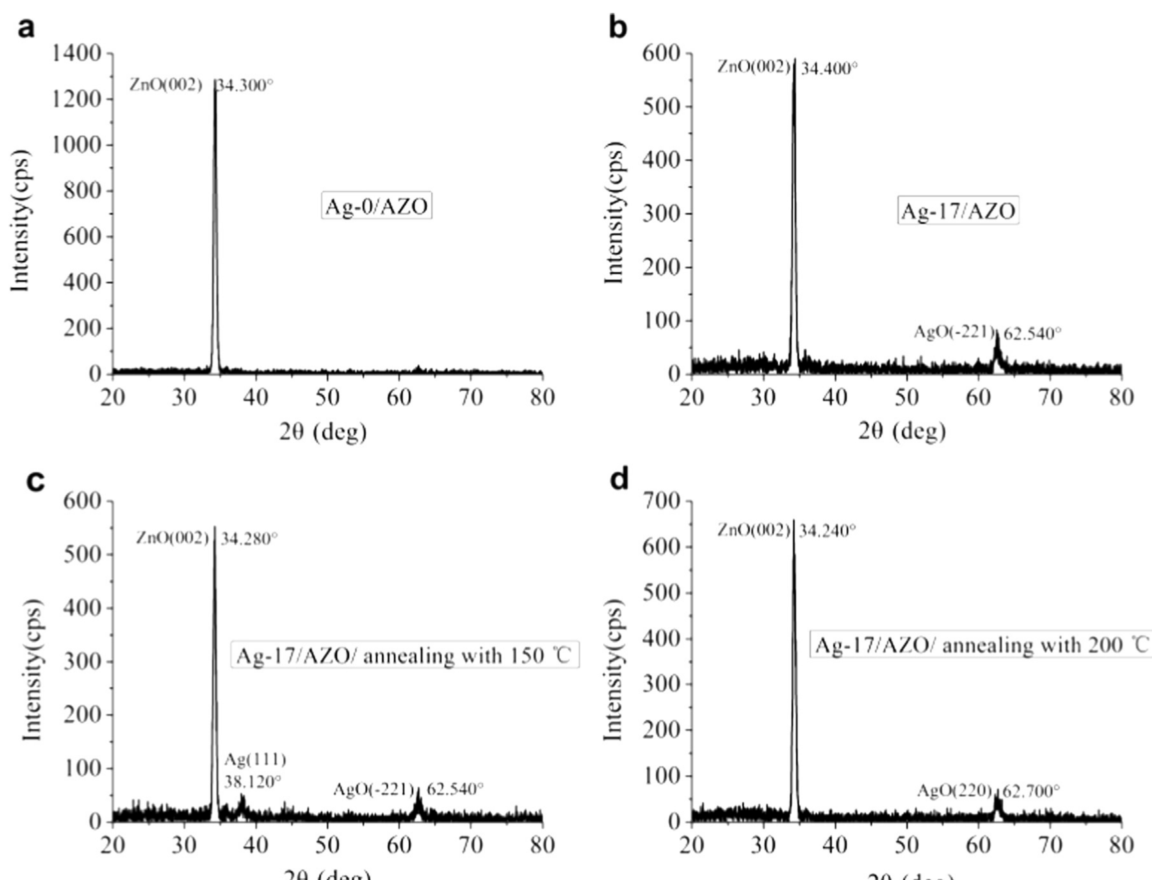

Fig. 2. XRD spectra of the bare and Ag particles coated AZO thin films (see text).