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Effect of gold nanoparticles on the performances of TiO_2 dye-sensitised solar cell

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ABSTRACT

TiO_2 blended with Au nanoparticles (NP) was hydrothermally synthesised under controlled conditions and characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM). The dye-sensitised solar cells (DSSC) were characterized using the UV–vis spectrometry and current-voltage (I-V) testing. The performance of TiO_2-Au DSSC is significantly higher than TiO_2 DSSC. The addition of Au NPs improves the light harvesting efficiency of the DSSC, thus improving the short circuit current density, J_{sc}, and the conversion efficiency of the DSSC. The excitation of localised surface plasmon resonance of the Au nanoparticles utilised the strong local field enhancement around the Au NPs to increase the absorption in the surrounding TiO_2 layer. It was demonstrated that the power conversion efficiency of the DSSC was improved by 28% with the addition of Au NPs.

1. Introduction

Dye-sensitised solar cells (DSSC) are receiving substantial attention in renewable energy research due to their ease and low cost of fabrication [1–3]. Studies have shown that deposition of Au nanoparticles (Au NPs) on titanium oxide (TiO_2) particles enhanced the photocatalytic electron transfer processes, leading to an improvement in photocurrent density and better photo-conversion efficiency [4,5].

In general, noble metal nanoparticles are incorporated to increase the sensitizer's light harvesting efficiency due to the plasmonic effect. Nanoparticles, such as the Au NPs, interact with the incident light in the visible region [6]. The desirable plasmonic characteristics of Au NPs that greatly influence the light harvesting efficiency include the localised surface plasmon resonance (LSPR), absorption intensity, plasmon bandwidth and stability [7–10].

However, little systematic thought has been given to the question of how Au nanoparticles might be used advantageously in DSSC with multi-layer TiO_2 of different particle sizes. Most of the researchers mainly focused on the effect of Au nanoparticles on DSSC with TiO_2 layers of the same particle size [11–16]. Therefore, the effect of Au nanoparticles incorporated TiO_2 layers comprised of different particle sizes is the subject of this study as described below.

Titanium oxide nanopowder blended with Au NPs were chemically synthesised by hydrothermal process and then converted to TiO_2-Au films by the conventional doctor blade technique for DSSC fabrication. The resulting performance of the fabricated DSSCs was studied.

2. Experimental methods

2.1. Materials and fabrication of TiO_2 powder with gold nanoparticles

The mixture of TiO_2 nanopowder and Au NPs was fabricated using titanium tetraisopropoxide (TTIP), triethanolamine (TEA), chloroauric acid ($HAuCl_4$), deionized water and ethanol by hydrothermal synthesis. TTIP was mixed with TEA and the mixture was added to a solution of water and ethanol. Then $HAuCl_4$ was added to the solution and stirred at room temperature overnight. The solution was heated at 180 °C for 24 h. The resulting slurry was centrifuged and washed several times with ethanol. The slurry was then dried at 60 °C overnight. The powder was ground in a mortar and sintered at 450 °C for 2 h. The same method was used to prepare TiO_2 nanopowder without the addition of $HAuCl_4$.

2.2. Materials and fabrication of DSSC

A fluorine-doped tin oxide (FTO) glass substrate was cleaned and dried. The prepared titanium oxide (TiO_2) or titanium oxide-gold (TiO_2-

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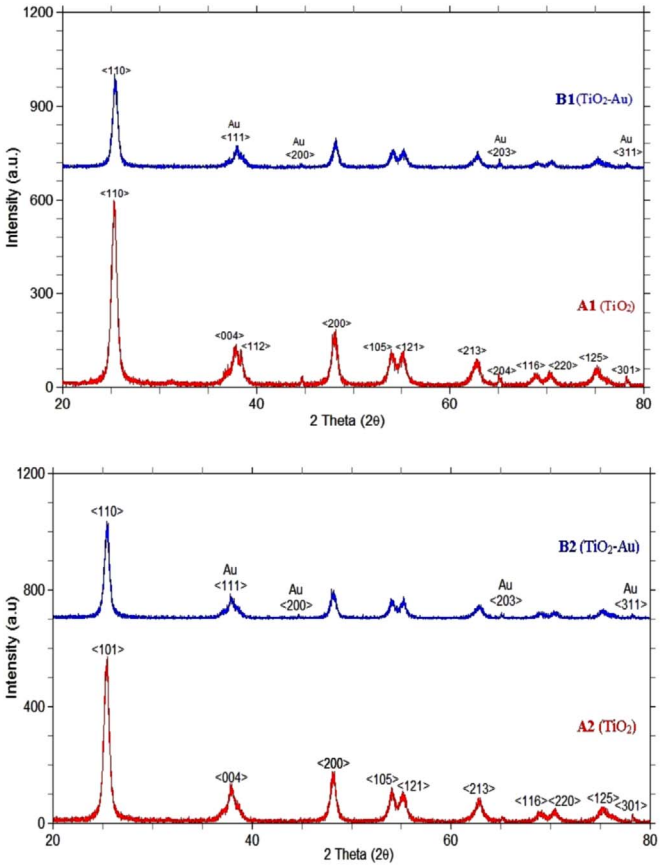

Fig. 1. XRD patterns of TiO_2 and TiO_2-Au powders.

Au) paste was deposited on FTO glass substrate by the doctor blade technique and sintered at 500 °C. The electrode was soaked in N719 dye solution for 24 h at room temperature to ensure complete dye uptake.

A hole was drilled in the FTO glass. Platinum paste was coated on the perforated glass by the doctor blade technique and heated at 400 °C for 15 min. Photo and counter electrodes were assembled into a sandwich-type cell and sealed using thermoplastic solvent. The electrolyte was introduced into the cell through vacuum backfilling. Finally, the hole was sealed by the thermoplastic sealant and a covering glass. In this study, we fabricated DSSCs with different combinations of active layer. Smaller particles (sample A1 and B1) serve as active layer that enhances the DSSC performance by high dye loading, whilst, bigger particles (sample A2 and B2) serve as opaque active layer that possesses some haze effect and sufficient dye loading.

2.3. Measurements

The characteristics of the TiO_2 layer greatly influenced the performance of the DSSC. Scanning electron microscope (SEM, JEOL JSM-6701F) and energy dispersive x-ray (EDX) analyses were used to study the morphology and element weight ratios of the TiO_2 layer. X-ray diffraction (XRD, Lab X XRD-600) was utilised to identify the crystallographic phase of the TiO_2 layer. UV–Vis spectroscopy (Cary 110) was employed to investigate the dye loading capacity. I-V testing (Newport Oriel I-V Test Station PVIV-3A) was used to compute the DSSC parameters such as short circuit current density, J_{sc}, open circuit voltage, V_{oc}, and conversion efficiency, η.

3. Results and discussion

3.1. XRD

The XRD patterns for TiO_2 and TiO_2-Au powders are shown in Fig. 1. Upon comparison to JCPDS-021–1272, it was confirmed that all

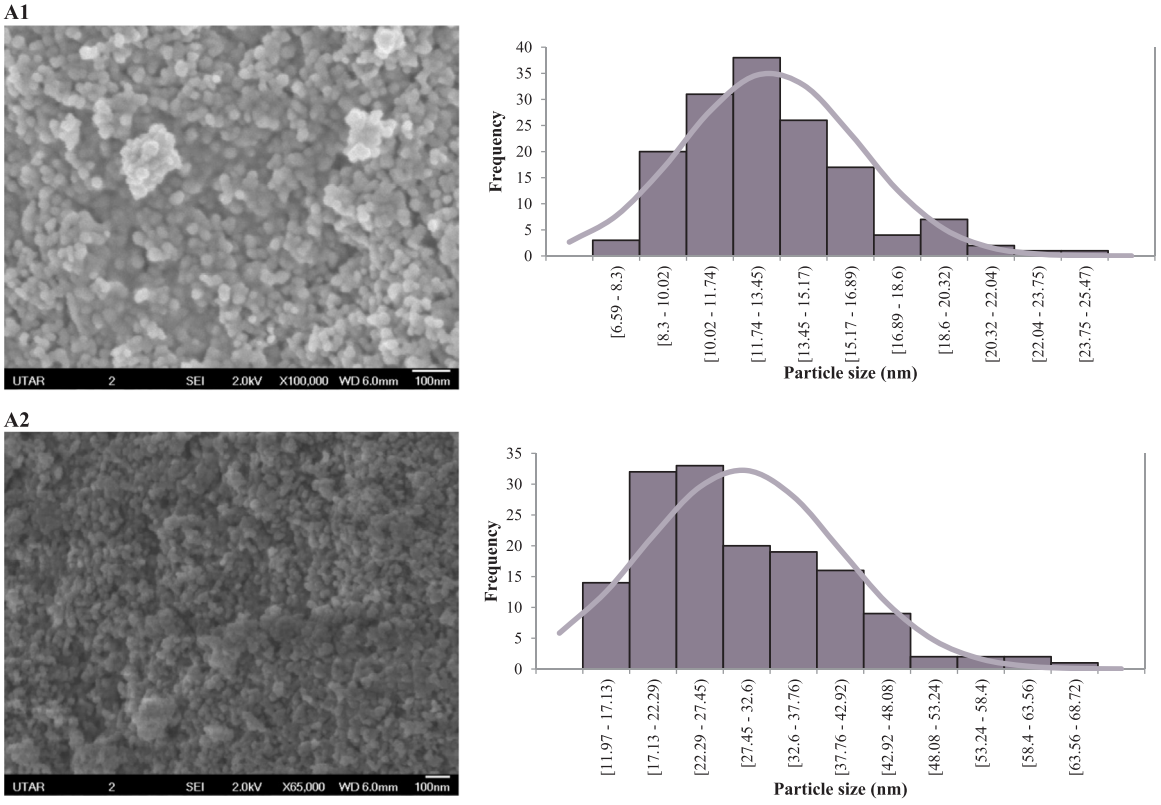

Fig. 2. SEM morphology and histogram of measured particle sizes for samples A1 and A2.