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Effects of gold nanoparticles inlaid in the photo-electrode on the properties of dye-sensitized solar cells

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ABSTRACT

In this study, we prepared gold nanoparticles by electrochemical synthesis and inlaid in the photo-electrode of dye-sensitized solar cells (DSSCs) to study the surface plasma resonant (SPR) and light-scattering effects on the properties of dye-sensitized solar cells. The analyses of field emission scanning electron microscopy (FE-SEM) show that the average diameter of gold nanoparticles is 50 nm. The results of ultraviolet–visible absorption spectra show that the absorption wavelength is about 533 nm for gold nanoparticles. The conversion efficiency with different amounts of gold nanoparticles in TiO_2 photo-electrodes is 5.42%, 5.92%, 6.06%, and 5.51% with the amounts of 0 μL, 300 μL, 400 μL, and 500 μL, respectively. The best conversion efficiency of the dye-sensitized solar cells with gold nanoparticles added is 6.06%, and is higher than that the cells without gold nanoparticles, which is 5.42%. In addition, in order to study light-scattering effects on the photo-electrode, different thicknesses of large particle size TiO_2 (~250 nm) coated onto photo-electrode to form double layer structure. The best conversion efficiency of the dye-sensitized solar cells with gold nanoparticles added and with the thickness of 3.3 μm light scattering layer is 7.10%, which is higher than that of the cell without light-scattering layer, which is 6.06%. This result indicates that the effect of gold nanoparticles on the photo-electrode can increase the conductivity and reduce the recombination of charges in the photo-electrode, and the light-scattering structure can enhance light transmission path in TiO_2 films and the absorption of photons in the photo-electrode, resulting in the increase of the photoelectric conversion efficiency for DSSCs.

1. Introduction

Recently, a new type of solar cell based on dye-sensitized nanocrystalline titanium dioxide has been developed by O'Regan and Grätzel [1]. The most attractive features of this technology are the reduced production costs and the ease of manufacture. Until now, the most efficient dye-sensitized solar cell (DSSC) structures are fabricated using TiO_2 nanoparticles on a glass substrate [2–6]. The maximum working voltage of a DSSC on the difference between the Fermi levels of the electrolyte and the TiO_2. A shift in the Fermi level can improve the open circuit potential of a DSSC. The role of gold nanoparticles is to act as a medium between the dye and TiO_2, to increase the electron transmission speed and the maximum voltage. Gold nanoparticles adsorbed on the surface of TiO_2 shift the Fermi level, allowing the electrons from the dye to be excited with low energy consumption, resulting in faster electron transfer and an improvement in the overall conversion efficiency of the dye-sensitized solar cell [7]. The specific surface area and light reflective properties of the nanoparticle film are both related to the size of the TiO_2 particles. Small sized TiO_2 particles possess a large specific surface area, but have poor light reflective performance, in contrast, large TiO_2 particles have the stronger light reflection properties, but the specific surface area is smaller. We prepared a double layer structure by coating large TiO_2 particles onto TiO_2/Au (P25) thin film layers to increase the light scattering and light transmission path in the film, improve the absorption efficiency of the dye molecules at long wavelengths, thereby increasing the photocurrent output [8].

2. Materials and methods

2.1. Synthesis of gold nanoparticles

We used an electrochemical synthesis method to prepare the gold nanoparticles. Cleaned pieces of platinum and gold were used as the cathode and anode, respectively. The electrodes were separated by a Teflon spacer by about 0.5 cm. The electrolyte solution was prepared using C_{16}TABr (3 mL, 0.08 M) and TTABr (25.2 mg). We put this mixture in an ultrasonicator at 38 °C for 5 min, followed by the addition of 950 μL of acetone. Subsequently, the electrodes were immersed in the mixture. The electrochemical synthesis was performed at a constant current of

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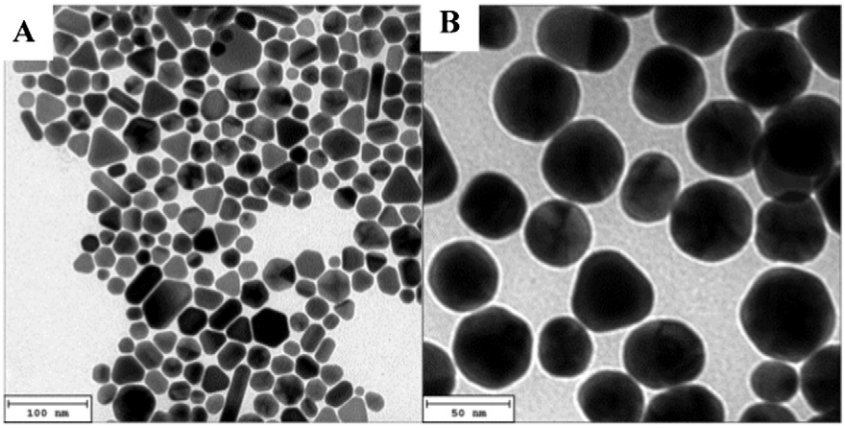

Fig. 1. TEM images of gold nanoparticles with different magnifications.

5 mA; the gold and platinum pieces were connected to the anode and cathode, respectively. Centrifugation of the gold nanoparticle suspended in the same volume of deionized water. Following centrifugation, toluene was added to the solution, and the ultrasonicator we used 5 min to separate the gold nanoparticles.

2.2. Assembling the DSSC

We used the scraper method to prepare the photo-electrode on a fluorine-doped tin oxide glass substrate. The TiO_2 coatings were prepared from commercial TiO_2 particles (P25). The diameter of the commercial TiO_2 particles and scattering layer TiO_2 particles were about 25 nm and 200–300 nm, respectively. The TiO_2 paste was prepared using TiO_2 powders, 4-tert-butylpyridine, and gold nanoparticles. We use gold nanoparticles in place of deionized water as a solvent. The concentration of the TiO_2 paste was 10 wt.%. Following the addition of gold nanoparticles, the TiO_2 film was scraped to the desired thickness on the substrate. After drying, we used mechanical pressure (279 kg/cm^2) to press the TiO_2 film, and annealed it at 450 °C for 30 min to fabricate the photo-electrode. The size of the TiO_2 film electrodes used was 0.25 cm^2 (0.5 cm × 0.5 cm). Finally, we kept the photo-electrode immersed in a mixture containing a 3×10^{-4} M solution of N3 dye and ethyl alcohol at 45 °C for 1.5 h in the oven. The electrode was assembled into a sandwich type open cell using a platinum plate as the counter electrode.

3. Results and discussion

Fig. 1(A) shows that the gold nanoparticles prepared in this experiment were polymorphic, with most of the particles being triangular, hexagonal or rod-shaped. Fig. 1(B) shows a high magnification of the gold nanoparticles; the average diameter of the gold nanoparticles was 50 nm. Fig. 2(A), (B), and (C) shows the TEM images of the triangular, hexagonal, and rod-shaped nanoparticles; Fig. 2(D), (E), and (F) is the corresponding SAED images. The SAED images indicate that the gold nanoparticles prepared by this experiment were all single crystal structures. Gold nanoparticles are affected by the surface plasma resonance effect, therefore gold nanoparticles of different sizes have different color mechanisms. The solution color of gold nanoparticles in these results is purple. The color of a gold nanoparticle suspension is strongly dependent on the nanoparticle size owing to the surface plasma resonance (SPR) effect. In this case, the suspension was purple, consistent with an absorption wavelength of about 533 nm, as shown in Fig. 3 [9].

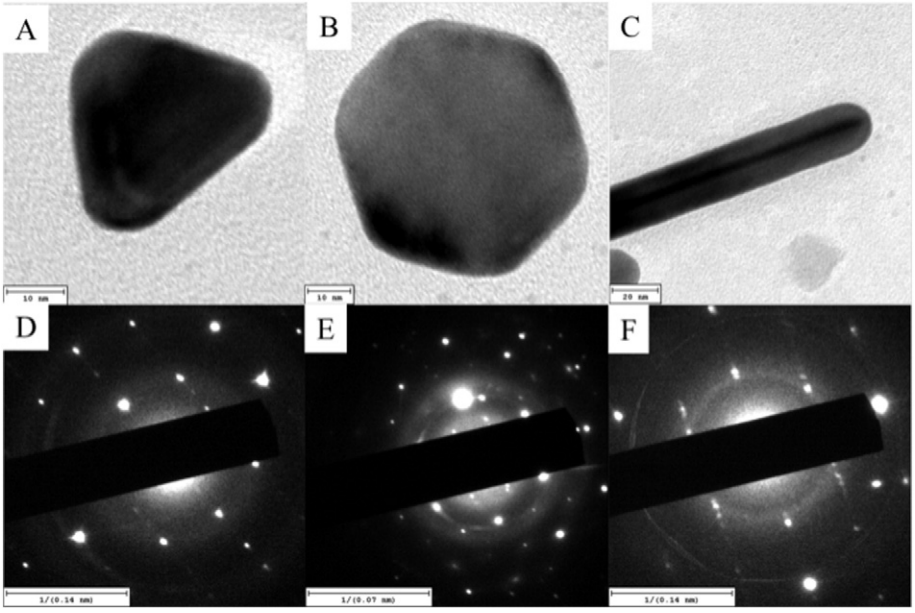

Fig. 2. Single particle of high magnification TEM images and the corresponding of the SAED: (A) triangle (B) hexagonal (C) rod.