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Plasmonic effects of quantum size gold nanoparticles on dye-sensitized solar cell

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Abstract

Surface plasmonic resonance is the effect of electron oscillation in a structure stimulated by incident light. When noble materials such as Au or Ag are added into the titania structure of the sensitized solar cell, the plasmonic effect of such materials will result an improved performance of the device. Different size of plasmonic materials will produce a variety of result. Here we demonstrated the effect of extremely small size of Au nanoparticles on the performance of dye-sensitized solar cell (DSSC). In this work, Au nanoparticles with average diameter of 5 nm were mixed into commercial TiO2 powders (average diameter 25 nm) for the fabrication of photoanode. Commercial N749 dye (black dye) was used as the sensitizer in a sandwich-type DSSC. The small size of Au nanoparticles is thought to be responsible for the plasmon resonance shift to higher energy. Inclusion of 5-nm Au nanoparticles in the titania has increased the efficiency by 50% compared to that without Au nanoparticles. The improvement was analyzed using data acquired from electrochemical impedance spectroscopy (EIS) measurements.

Selection and Peer-review under responsibility of Conference Committee Members of 5th International Conference on Functional Materials & Devices (ICFMD 2015).

Keywords: Gold nanoparticles; Plasmonic; Dye-sensitized solar cell; Electrochemical impedance spectroscopy

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1. Introduction

As the global demand for energy consumption is increasing from year to year, it is crucial to ensure the continuity of the energy supply to avoid any massive energy disruption. Currently, majority of the energy supplies are from fossil fuel. The usual fossil fuel derived energy is very dependent on the supply of crude oil and coal, which are non-renewable. Fortunately, as the earth receives abundant sunlight throughout the year, it is wise to harvest such alternative resource for energy conversion and consumption. One of the direct ways of harnessing solar energy is through solar cell. The recent development of solar cell technologies has provided much hope in the renewable energy field. Some of the widely studied solar cell technologies are dye sensitized-solar cells (DSSCs) and quantum dot-sensitized solar cells (QDSSC) [1-5].

Since the introduction of DSSC in early 90's, it has created much interest in the past few years due to their ease of fabrication and low cost [1-4]. To date, the highest reported efficiency of DSSC is about 13% [6]. Recently, DSSC structure with high performing perovskite as sensitizer has emerged as a new breakthrough in the solar cells field where efficiency as high as 20% has been reported [7-9].

The main working mechanism of DSSC relies on the photon absorption by the sensitizers followed by the transfer of photogenerated electrons within the circuit. The absorption process can be enhanced with the inclusion of noble metal nanoparticles in the TiO_2 mesoporous structure. Noble materials such as Ag or Au nanoparticles are thought to enhance the photocurrents of DSSC as a result of localized surface plasmon resonance (LSPR) of the nanoparticles [10]. In general, surface plasmon resonance is the effect of electron oscillation in a structure stimulated by incident light. The effect of the LSPR on Ag or Au nanoparticles results in enhanced light absorption and scattering which ultimately enhances the performance of DSSC.

In this work, gold nanoparticles with average diameter of 5 nm were mixed into commercial TiO_2 powders (average diameter 25 nm) to produce a paste for the photoanode of DSSC. Au was selected due to its advantages as high conductor, and chemical and thermal stability [11]. Compared to Ag nanoparticles, Au nanoparticles are quite stable in iodide-based electrolyte. Commercial N749 dye (black dye) was then used as the sensitizer in a sandwich-type DSSC. Although there are few works reported on the plasmonic effect of gold nanoparticles in DSSC, such effect has not been reported on gold nanoparticles having quantum size of 5 nm or less [12]. Such small size is thought to result in plasmon resonance shift to higher energy [13].

2. Experimental

2.1. Sample preparation

Fluorine doped tin oxide (FTO) (sheet resistance 8 Ω square^{-1}, Solaronix) was used as a substrate for both photoanode and counter electrode. 0.38 M di-isopropoxytitanum bis(acetylacetonate) in ethanol was spin-coated at 3000 rpm for 10 s on the photoanode FTO. This was followed by sintering at 450°C for 30 min to form a compact layer.

TiO_2 paste was prepared from commercial TiO_2 powder (Degussa P25) by grinding 0.20 g powder with 2 ml of 1 M nitric acid, 0.10 g of polyethylene glycol and two drops of triton X-100. The paste was then spread on top of the compact layer by doctor blade method. The newly deposited layer on the FTO was sintered at 450°C for 30 min.

For samples with the inclusion of Au nanoparticles, the TiO_2 paste was added with 5 nm Au nanoparticles in suspension (Sigma-Aldrich). The amount of Au nanoparticles added are described in Section 3. The mixture was then sonicated and stirred for about 20 minutes to ensure homoegenous distribution of the Au nanoparticles within the TiO_2 particles. All the as prepared photoanodes were soaked overnight in 0.2 mM black dye (N749, Solaronix) in ethanol and acetonitrile (1:1) solution.

Solar cell assembly was prepared by sandwiching the liquid electrolyte between the sensitized TiO_2 electrode and Pt counter electrode. Counter electrode was prepared by spin coating a Pt catalyst (Solaronix) on a FTO. The Pt-coated FTO was then sintered at 450°C for 30 min. The iodide-based liquid electrolyte used was prepared from 0.6 M 3-propyl-1-methylimidazolium iodide, 0.1 M lithium iodide, 0.05 M iodine and 0.5 M 4-tert-butylpyridine in acetonitrile. A parafilm spacer was used to contain the liquid electrolyte within the cell assembly.