SURFACE PLASMONIC EFFECTS OF SILVER NANOWIRE ON THE ENHANCEMENT OF TiO_2 BASED DYE-SENSITIZED SOLAR CELLS

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Abstract

Nanoscale metal structures embedded in DSSC devices could also potentially be beneficial in improving the light absorption, as well as the charge separation and charge collection processes. In this research, TiO_2 was used as a photoelectrode and eosin y is used as photosensitizers. Using a Mayer rod coating method, a highly viscous titanium dioxide (TiO_2) paste was deposited on a FTO glass substrate. Metal nanowire such as silver nanowire (Ag NWs) was coated on the TiO_2 active layers to enhance the photon absorption and charge separation efficiency. The structural properties of the Ag NWs coated TiO_2 active layer were studied by using XRD and SEM techniques. Photovoltaic parameters such as short circuit current, open circuit voltage, fill factor FF, and efficiency were determined under light intensity of 11 mW/cm^2.

Keywords : DSSC, XRD, SEM, Photovoltage parameter.

Introduction

A solar cell is a device that converts sunlight into electricity. Materials used in photovoltaic devices are mainly semiconductors including, among others, crystalline silicon, III-V compounds, copper indium selenite /sulfide, and cadmium telluride(Gratzel *et al*, 2005). Low-cost solar cells have been the subject of intensive research work for the last decades. Amorphous semiconductors were announced to be one of the most promising materials for low-cost energy production. Recently dye sensitized solar cells (DSSCs) emerged as a new type of low cost solar cells with simple preparation procedures. The DSSC operation is based on the sensitization of wide bandgap semiconductors such as TiO_2 and ZnO. The performance of the cell is mainly dependent on the dye used as sensitizer in addition to many parameters, like the photoelectrode materials, the redox and the back electrode(Kontos *et al*, 2008). The absorption spectrum of the dye and its anchorage to the surface of TiO_2 or ZnO are the most important parameters determining the efficiency of the DSSC.

The thickness of the photoelectrode film and the metal-TiO_2 nanocomposites were found to be major contributors to the improvement of efficiency(Sengupta *et al*, 2016). It has been found that when a metallic nanoparticle interacts with the light having wavelength much larger than the size of particle, it generates collective oscillations of valence electrons known as surface plasmon resonance (SPR). Metal nanoparticles, especially silver (Ag) and gold (Au), are able to enhance light absorption and broaden the light spectrum of the dye through surface plasmon resonance (SPR)(Zhang *et al*, 2009). This metal nanoparticle can function as a light-scattering mechanism that can increase the number of optical pathways, allowing light to stay longer and increase light absorption]. Compared to Au, Ag nanoparticles (AgNP) have a high scattering efficiency and energy band. Therefore, AgNP is one of the best candidates to enhance power-conversion efficiency by utilizing the SPR effect.

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In this work, metal nanowire is fabricated on TiO_2 photoelectrode to improve the power-conversion efficiency. DSSCs were prepared by using TiO_2 electrode, Ag NWs layer, eosin-y dye, and graphite counter electrode. I-V characteristic and the corresponding output power were determined. The efficiency of DSSC corresponding to with and without silver nanowires is calculated.

Materials and Methods

2.1 Synthesis of TiO_2 Paste

Commercially available TiO_2 powder was prepared by ball milling to reduce powder size. Milling time was 12 hours. This ball milled powder was mixed with ethanol and sonicate it with water bath-sonicator for 24 hours to obtain fine grain size. The TiO_2 pastes were prepared in two steps. First 2 g of TiO_2 powder was mixed with 1 mL acetylacetone and the mixture was grounded with agate motar for half an hour. This paste was again grounded for 5 hours with addition to appropriate amount of distilled water, ethylene glycol, acetic acid, acetonitrile and ethanol. The solution was heated to evaporate distilled water and ethanol slowly. Finally TiO_2 paste was obtained.

2.2 Synthesis of Silver Nanowire (Ag NWs)

Silver nanowire were synthesized by reducing $AgNO_3$ as metal precursor salt in Ethylene Glycol (EG) which was used as not only reducing agent but also solvent and PVP as a capping agent. First, 30 mL of EG in a flask was heated at 170°C in a heating mantle with stirring rate 150 rpm for 30 minutes. After 30 minutes, mixed $CuCl_2$/ethylene glycol solution and mixed PVP/ethylene glycol was added to prepared solution, followed by $AgNO_3$ /ethylene glycol drop wise to the solution. After 3 hours adding all reagents, the mixture turned silvery brown indicating the appearance of silver nanowire. The product was diluted with acetone (1:5 by volume) and centrifuged at 3000 rpm for 20 min. This centrifugation procedure could be repeated three times with ethanol until the supernatant became colorless. The collected precipitates (silver nanowires) redispersed in ethanol for coating over TiO_2 layer.

2.3 Iodide electrolyte solution

To mix iodide solution, dissolve 0.127 g of iodine in 10ml of ethylene glycol. Next add 0.83 g of potassium iodide, stir and store in dark container.

2.4 Preparation of Dye Sensitized Solar Cells

Transparent conducting FTO coated glass sheets were cut into pieces of dimensions 2 cm x 2 cm. The substrates were cleaned in a detergent solution using an ultrasonic bath for 15 min, rinsed with water, acetone and ethanol, and then dried with air blow. Thin layers of the prepared TiO_2 past were spread on the transparent conducting FTO coated glass by employing rod coating method. In this experiment, adhesive Scotch tape (3M, Scotch Magic Tape) with thickness of approximately 52 μm was placed on the edges of the conductive sides of the FTO glass to create a 1 x 1 cm^2 rectangular area for TiO_2 paste deposition. A small amount of TiO_2 paste was then applied on the masked top edge of the FTO glass and spread across the unmasked area using a Mayer rod (#12). Then, the Scotch tape was removed, leaving an uncoated area of the FTO glass, which was used as the electrical contact for solar measurement. Samples were then dried in an oven at 70°C for 20 min. The samples were sintered at 600°C for 1 h then were cooled down to

70°C. For AgNWs coated TiO_2 layer, the film was dried in an oven at 150°C for removal of unwanted chemicals. Finally the film was placed in dye solutions for 24 h under dark condition. The dyed TiO_2 electrode and a graphite coated counter electrode were assembled to form a solar cell by sandwiching a electrolyte solution.

2.5 Characteristic Techniques

The morphological properties of all samples were examined by scanning electron microscopy (FESEM, Hitachi S- 4700). The structural properties were investigated by X-ray diffraction (XRD, Rigaku X-ray diffractormeter). The photovoltaic properties of DSSCs were measured under a light intensity of 11 mW/cm^2.

Results and Discussions

The phase composition and the crystallite size of the prepared TiO_2 and graphite samples were estimated by X-ray diffraction analysis. The peaks of TiO_2 samples at 600°C were identified by comparison with PDF-71-1166 according 2θ which confirmed that an anatase structure at 2θ was 25°.

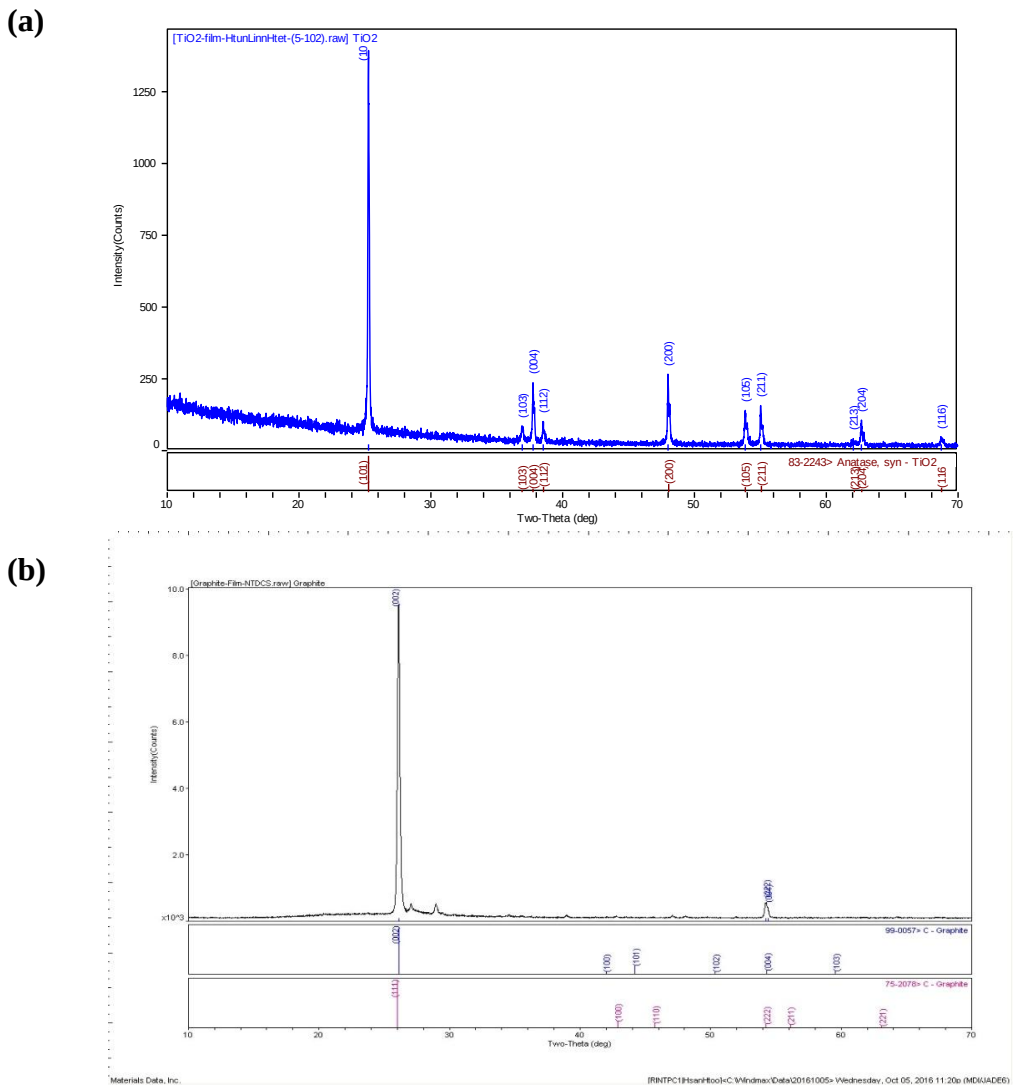

Figure 1 XRD patterns of (a) TiO_2 photoelectrode (b) graphite counter electrode film

The particle size of nanomaterial is related to the diffraction peak broadening. X-ray diffraction spectra of synthesized TiO_2 nanoparticles were taken and particle size and phase composition were determined. The lattice parameters were observed a=b= 3.846 and c= 9.578. The nanocrystalline anatase structure was confirmed by sharp peaks obtained corresponding to the planes (101), (103), (004), (200), (105), (211), (213), (204), (116) and (220) indicated the tetragonal structure of TiO_2 nanoparticles. All peaks obtained were in good agreement with the PDF card no. 71-1166. The average crystalline size is calculated by using Debye Scherrer equation. is 33.63 nm. Figure 1(b) shows the XRD pattern of graphite film which was used as counter electrode in DSSC solar cell. The peaks of graphite were identified by comparison with PDF-99-0057 according 2θ which confirmed that an graphite structure at 2θ was 26°.

The surface morphology and the size of the TiO_2 particles were analyzed by using scanning electron microscopy (SEM). Figure 2(a) shows the top-view SEM image of the prepared TiO_2 sample. As analysis of SEM image, it was smooth and crack free layer. This image consisted of some pores and circular feature in microstructure. All grains were clearly formed and uniformly distributed. The density of film was high. Agglomeration of grain was thicker and compact form in microstructure. The average grain size of TiO_2 sample was 0.16 μm. The SEM image shown in Figure 2(b) confirms that crystalline silver nanowires were surrounded by TiO_2 materials as indicated by the relatively bright contrast. Further, this result indicated that TiO_2 nanoparticles were embedded within the AgNWs, implying the successful formation of AgNWs coated TiO_2 nanoparticle.

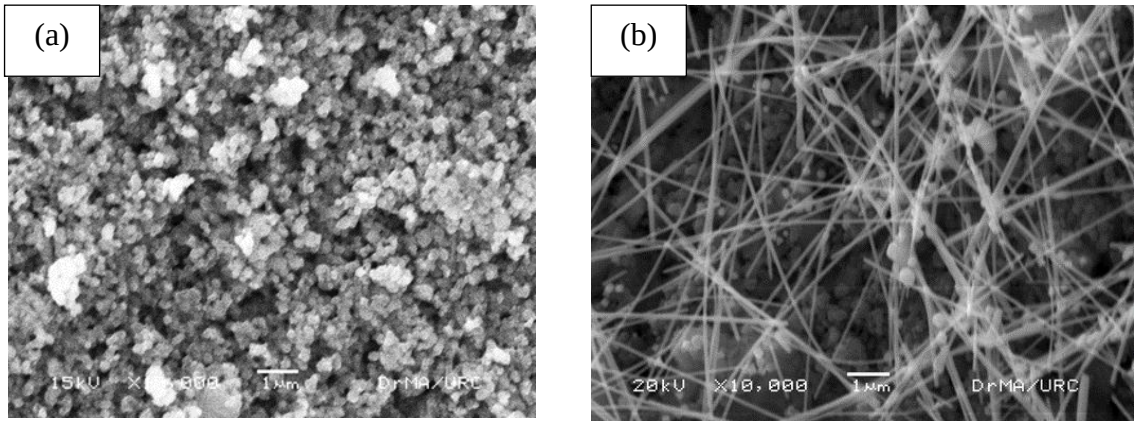

Figure 2 The SEM images of (a) pure TiO_2 nanoparticles and (b) TiO_2 nanoparticles coated with Ag NWs, which has been coated on the FTO conductive glass

The performance of photoelectrochemical solar cells with and without Ag NWs coating were monitored through electrical current and voltage outputs under 11 mW/cm^2 illuminations. More details regarding the photovoltaic performance parameters such as photo current density(Jsc), Photovoltage(Voc), Fill factor (FF), photoconversion efficiency (η) are summarized in Table 1.Figures 3 show the current-voltage (I-V) characteristic curves of the assembled DSSCs sensitized with and without silver nanowires. It is clear from these figures that the DSSC with Ag NWs coating exhibit the better I-V response. The conversion efficiency of all fabricated cells were observed to be about 0.372% for DSSC with silver nanowire coated photoelectrode and 0.12% for DSSC without silver coated photoelectrode. From these results, it was found that the conversion efficiency was increased with silver coating.

Table 1 Photovoltaic parameter of DSSCs

	I_{sc}(μA)	V_{oc} (mV)	I_m(μA)	V_m(mV)	FF	η (%)
Pure TiO_2	110	640	50	280	0.193	0.12
TiO_2 with Ag NWs	160	690	90	450	0.372	0.373

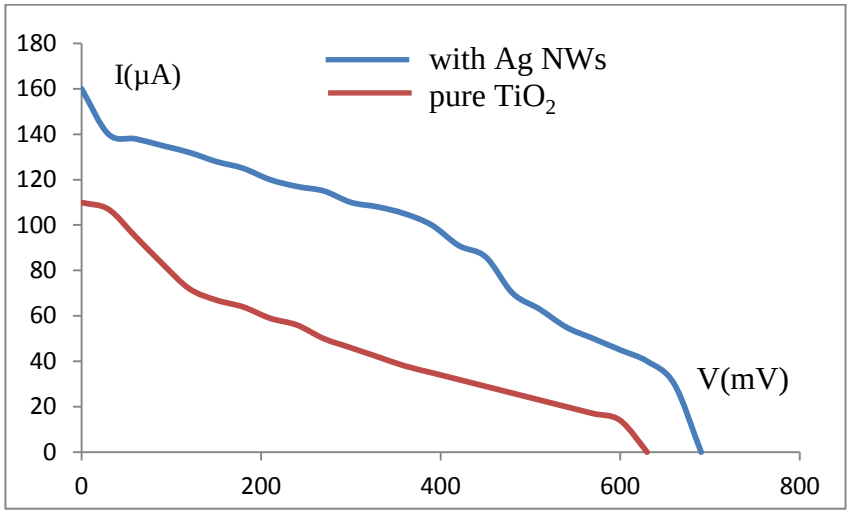

Figure 3 Current and voltage characteristics of the DSSC with and without silver nanowires

Conclusion

Growth of TiO_2 electrodes DSSC with and without Ag NWs coating and their solar cell properties have been successfully implemented. X-ray diffraction pattern showed the different diffraction peaks corresponding to different plane. All the peak heights and peak positions were good agreement with library file of JCPDS. The average grains size of the particles was 160 nm. The circular features in microstructure were uniformly distributed in SEM image. The current density and cell voltage characteristic curve for TiO_2 DSSC with Ag NWs coating showed better performance where the efficiency of the cell obtained as 0.373%.

Acknowledgements

The authors greatly indebted to Professor Dr Khin Khin Win, Head of Department of Physics, University of Yangon, for her kind permission to carry out this work. The authors acknowledge to Professor Dr Ye Chan, Universities' Research Centre, University of Yangon, for his advice and suggestions to this research and kind permissions to carry out laboratory facilities in URC.

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