Perspectives in Science (2016) 8, 577—579

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Synthesis and characterization of Ag nanowires: Improved performance in dye sensitized solar cells☆

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Received 13 February 2016; received in revised form 12 June 2016; accepted 13 June 2016
Available online 5 July 2016

KEYWORDS
Dye sensitized solar cells;
Silver nanowires;
Surface plasmon resonance;
Photoanode

Summary Development of highly efficient dye-sensitized solar cells (DSSCs) with good photovoltaic parameters is an active research area of current global interest. Recently, one dimensional nanomaterial, such as nanorods and nanotubes has replaced the nanoparticles used in DSSCs anode because of their ability to improve the electron transport leading to enhanced electron collection efficiency. In the present work, rapid synthesis of silver nanowires (AgNWs) was done. The XRD characterization was performed to confirm the formation and size of synthesized AgNWs. It was observed that FWHM of the diffraction peaks was increased with AgNWs concentration in TiO_2. The synthesized TiO_2AgNWs nanocomposite was used as the photo anode of Dye sensitized solar cell. The *I*—*V* characteristics of the solar cell were drawn using standard conditions. It was observed that TiO_2AgNWs based solar cells have significantly increased photocurrent density resulting in improved conversion efficiency as compared to pure TiO_2 based DSSC.

Introduction

In the global requirement towards harvesting solar energy Dye-sensitized solar cells (DSSCs) development by simple methods offer enormous potential. A DSSC consists of anode, cathode, dye and electrolyte. There are numerous ways of designing DSSC which may be done by changing anode material, cathode materials, natural and synthetic dye of different types and changing the electrolyte. For the DSSC anode preparation, nanomaterials of varying dimensions are used, such as nanoparticles, nanorods, nanotubes, nanofibres, and quantum dots, one dimensional materials show improved performance since they are able to enhance the electron transport thus help in enhancing DSSCs efficiency (Jeong and Kim, 2011; Regan and Gratzel, 1991; Yang et al., 2015; Umar, 2009; Lee et al., 2009; Jin et al., 2010). The performance enhancement was also observed by using doped metal nanoparticle or nanocomposites causing improved dye

☆ This article belongs to the special issue on Engineering and Material Sciences.

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http://dx.doi.org/10.1016/j.pisc.2016.06.025

absorption by localized surface plasmons. Researchers have worked on Ag islands on top of thin film of TiO_2 prepared by thermal evaporation which resulted in enhancement of the optical absorption of the dyes and increased photocurrent (Wen et al., 2000). TiO_2/Au and TiO_2/Ag nanocomposite particles were as a photo anode of DSSC and showed the performance enhancement as compared to of the conventional DSSC because of Schottky barriers (Chou et al., 2009). The plasmon-enhanced properties in due to thickness of TiO_2 layer in the photo anode DSSCs were also examined (Standridge et al., 2009).

In the present work TiO_2AgNWs nanocomposite was synthesized and used for the photo anode. The configurations FTO/TiO_2/dye/electrolyte/pt/FTO and, FTO/TiO_2AgNWs/dye/electrolyte/pt/FTO were compared. It was demonstrated that the addition of silver enhanced optical absorption of the dye by localized surface plasmons which has contributed to increased photocurrent and an improved efficiency.

Experimental

Materials

Titanium (IV) isopropoxide, polyvinylpyrrolidone (PVP, Mw = 55,000 g/mol), silver nitrate, silver chloride, ethanol and nitric acid were purchased from Sigma—Aldrich and used as received.

Synthesis of silver nanowires

Rapid synthesis of silver nanowires (AgNWs) with high quality is performed this procedure, 190 ml of glycerol solution containing 6 g of PVP was mixed and gently heated to 80 °C until all PVP was dissolved, and cooled to room temperature, then added into a round-bottom flask. $AgNO_3$ powder (1.58 g) was then added to the solution with vigorous stirring until the powder was fully dissolved. Subsequently, 58.5 mg of NaCl (5 mmol/l in total solution) was dissolved in 0.5 ml H_2O and added into 10 ml of glycerol. The latter was added into the flask and the reaction temperature of the mixture was rapidly raised to 210 °C within 20 min, roughly 8 °C/min, keeping the magnetic stirrer at 50 r/min in the aerobic condition. When the reaction was stopped and the flask cooled down to room temperature, the deionized water was added into the flask by a 1:1 volume ratio, and then the mixture was centrifuged at 8000 r/min until all visible products were collected. The transparent supernatant was discarded and the as-obtained AgNWs were washed with DI water three times to remove the PVP residue. During the reaction process, the colour of the solution changed from pale white to light brown, red, dark grey, and eventually grey green (at about 200 °C) (Yang et al., 2015).

DSSC fabrication

TiO_2 nanoparticles were synthesized using sol—gel method and 10 wt% AgNWs were added to TiO_2 to form the nanocomposite. Dye sensitized solar cells were prepared using TiO_2AgNWs nanocomposite deposited FTO coated glass as working electrode for 1 cm^2 area, natural dye, Beet root (*Beta vulgaris*), and synthetic dye (methyl orange) as photo sensitizers, the Iodide electrolyte and the Platinum sputtered FTO glass was used as counter electrode.

The photo anode of DSSC was prepared using the TiO_2AgNWs nanocomposite. For the TiO_2AgNWs nanocomposite paste preparation the nanocomposite powder (500 mg) grinded in a mortar-pestle while adding solvent (about 5 ml acetic acid) drop wise, in ambient conditions followed by adding 10 ml ethanol. The paste was grinded for about 20 min and sonicated for 15 min to homogenize TiO_2AgNWs nanocomposite. Few drops of PEG (polyethylene glycol) and Triton X-100 were added and the mixture was again grinded to form a thick and shiny paste. Before pasting the nanocomposite the FTO glass were cleaned using ethanol, propanol and DI water sonicated for 30 min and air dried.

The paste was deposited on the above FTO glass by doctor blade method with the help of a glass rod. The developed anodes were dried for 10 min at room temperature. The samples were sintered at 450 °C for 30 min in ambient air, and then cooled down to room temperature. The prepared photo anodes were immersed in both dye solutions in separate beakers for 24 h rinsed with distilled water air dried and used for DSSC, the same procedure was used to fabricate the reference cell of TiO_2 anode.

Results and discussion

The XRD patterns suggested that metallic AgNWs with FCC structure was successfully produced through the reaction. The peaks at 36.5°, 42.3°, 63.7° and 76.6° are assigned to the diffraction from the (111), (200) (220) and (311) planes of Ag, respectively which is consistent with the literature (JCPDS card number 87-0717).

Fig. 1 shows the XRD patterns of pure TiO_2 nanoparticles. The diffraction peaks at 2θ values of 24.48°, 36.99°, 47.30°, 53.14°, 54.34° and 61.99°, 68.1°, 74.3° correspond to the crystal planes of (101), (004), (111), (105), (211) (204), (116) and (220) respectively, indicating formation of anatase phase of TiO_2 and for TiO_2AgNWs nanocomposite a similar pattern is observed except that some extra diffraction peaks at 2θ values of values of 43.56°, 63.94° and 76.89°, corresponding to the crystal planes of (200), (220) and (311), respectively due to presence of silver metal. The decrease in FWHM along with increase in peak intensity suggests that incorporation of Ag into the TiO_2 lattice results in increase in grain size of nanoparticles.

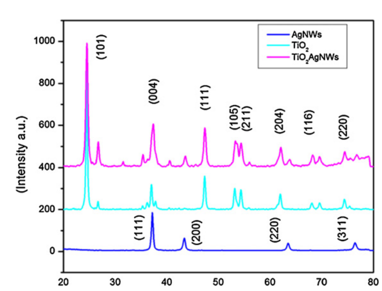

Figure 1 XRD patterns of TiO_2, Ag and TiO_2AgNWs nanocomposite.

Table 1 Comparative DSSC parameters.

Dye	Anode material	V_{oc} (mV)	J_{sc} (mA/cm^2)	V_m (mV)	I_m (mA/cm^2)	Efficiency, η (%)	Fill factor
Methyl orange	TiO_2	0.544	4.21	0.42	3.76	1.57	0.68
Methyl orange	TiO_2AgNWs	0.532	6.77	0.40	5.61	2.44	0.67
Beet root	TiO_2	0.56	2.16	0.4	1.14	0.45	0.37
Beet root	TiO_2AgNWs	0.56	3.6	0.40	1.9	0.76	0.37

The UV—visible absorption spectra of pure TiO_2 AgNWs andTiO_2AgNWs nanocomposites were observed in Fig. 2. The absorption spectrum of pure TiO_2 shows absorption peak at 302 nm and for the TiO_2Ag nanocomposite; the absorption peak is at 323 nm. The absorption peak of pure TiO_2 is at lower wavelength than absorption peak of TiO_2 AgNWs thus showing red shift. The absorption spectrum of silver nanowires has peak at 438 nm.

I—*V* characteristics of the solar cell were calculated using a 100 mW/cm^{2,} Oriel solar simulator at 25 °C. Figs. 3 and 4 shows *J*—*V* curves of DSSC using pure TiO_2 and TiO_2AgNW nanocomposite. It was observed that the open circuit voltage was same for the DSSC using pure TiO_2 and TiO_2AgNWs nanocomposite anode. The conversion efficiency of solar cell was enhanced in DSSC using TiO_2AgNWs nanocomposite from 1.57% to 2.44% for methyl orange dye and 0.45% to 0.76% for beet root dye (shown in inset) giving 35% improvement for methyl orange and 40% improvement in beet root dye. However, there is no change in fill factor. A higher light harvesting efficiency of nanocomposite anode based DSSC as compared to pure TiO_2 anode, was obtained. Which was reflected in a higher photocurrent, open-circuit voltage and a higher efficiency of the nanocomposite based photovoltaic cell. As shown in Table 1.

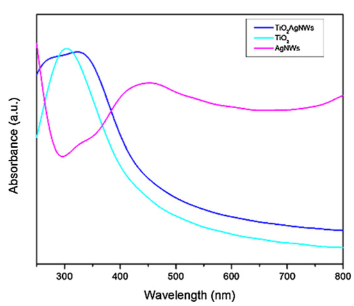

Figure 2 UV—vis spectrum of TiO_2, Ag and TiO_2AgNWs nanocomposite.

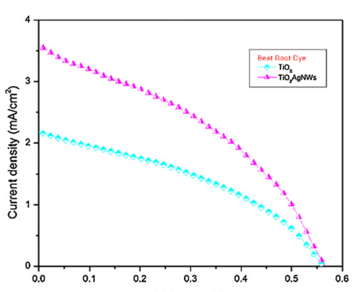

Figure 3 *J*—*V* curves of DSSC using pure TiO_2 and TiO_2AgNWs for beet root dye.

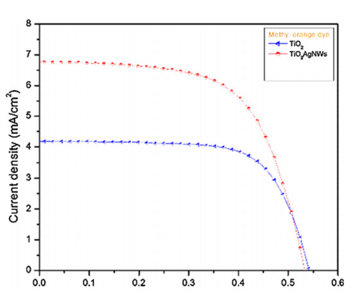

Figure 4 *J*—*V* curves of DSSC using pure TiO_2 and TiO_2AgNWs for methyl orange dye.

Conclusions

Dye sensitized solar cell with a photo anode of TiO_2AgNWs nanocomposite was fabricated and characterized. Compared with the pure TiO_2 based DSSC, the efficiency of the TiO_2AgNWs nanocomposite based DSSC was improved by 40% as compared to conventional DSSC using only TiO_2 anode. The addition of AgNWs was found to be determining factors for the performance of the dye-sensitized solar cell.

Conflict of interest

Authors declare that there is no conflict of interest.

Acknowledgments

The authors gratefully acknowledge the support from the Centre of Excellence in Materials Science, Department of Applied Physics, Aligarh Muslim University, Aligarh and Centre of Energy Studies, IIT Delhi, India.

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