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PERFORMANCE VARIATION OF NANOSTRUCTURE DYE SENSITIZED SOLAR CELLS WITH SPUTTERED GOLD AND SPRAYED GRAPHITE COUNTER ELECTRODES

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Dye-sensitized solar cells have been fabricated using nanostructure TiO_2 sensitized with Ruthenium dye. In order to investigate the effect of different counter electrodes on the fabricated cells efficiencies, gold and graphite coated electrodes were prepared by sputtering and spraying method for use as counter electrodes. Photovoltaic parameters like short circuit current (I_{SC}), open circuit voltage (V_{OC}), fill factor (FF) and power conversion efficiency (η) were evaluated for fabricated cells. Although the FF for both cells was found to be 70%, short circuit current(I_{SC}) and open circuit voltage (V_{OC}) for cells operating with graphite and gold coated counter electrodes were increased from 1.44 to 2.13 mA/cm^2 and 360 to 370mV respectively. Overall conversion efficiencies (η) for fabricated cells found to be 3.63% for cell operated with graphite and 5.51 % for gold counter electrodes.

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Keywords: Dye sensitized solar cell, nanostructure TiO_2, power conversion efficiency (η), gold sputtered counter electrode.

1. Introduction

Dye-sensitized solar cells (DSSC) have become an attractive and cheap device for the conversion of solar energy into electrical energy since Gratzel and O'Regan reported the prototype of dye solar cell in 1991 [1-7]. A typical DSSC consists of a layer of nanostructure TiO_2 (titanium dioxide) covered with sensitizing dye and electrolyte containing a redox mediator (I^-/ I_3^-) placed between photoelectrode and counter electrode[8]Fig.1. The total efficiency of the dye-sensitized solar cell depends on the optimization and compatibility of its constituents. By using nanostructured TiO_2 for the photoelectrode the active area for dye adsorption increases resulting an efficient light harvesting [9]. Front and counter substrates are coated with a transparent conducting oxide (TCO). Type of TCO most commonly used in DSSC is Fluorine doped tin oxide on glass substrate (FTO). The TCO glass at the counter electrode is coated with a few atomic layers of an electron transfer catalyst to complete the redox reaction in the electrolyte [10].

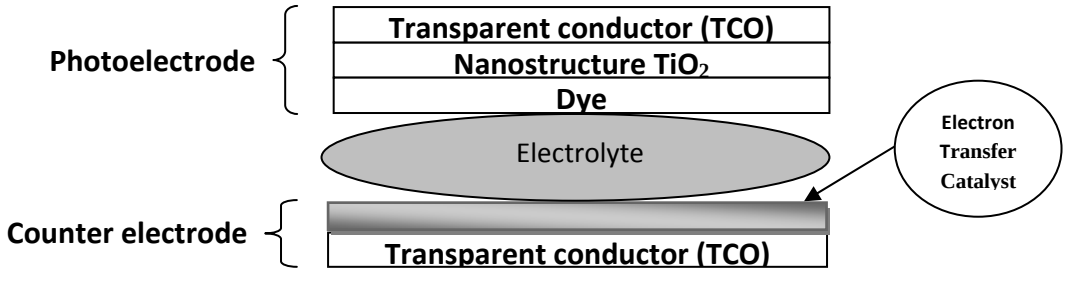

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Fig.1 Schematic of a DSSC

Electron kinetics in the nanostructure TiO_2 layer on TCO plays an important role in the operation of a dye solar cell. The excitation of the dye upon irradiation is followed by injection of the resulting electrons into the conduction band (CB) of the semiconductor, from where they reach the cell photoelectrode. The electron injection from the excited dye to TiO_2 takes place in femtosecond while the time scale for the back electron transfer is several orders of magnitude slower, indicating the charge separation in this cells achieved on kinetic grounds. Regeneration of dye electrons occurs through electron donation from a redox electrolyte in contact with the dye. This typically occurs through an organic solvent containing an iodide/triiodide couple. Triiodide is reduced in turn at the counter electrode, while electron migration from the photoelectrode to the counter electrode completes the circuit. The voltage generated is equal to the difference between the Fermi level of the electron in the solid TiO_2 and the redox potential of the electrolyte [11, 12].

Our aim was to investigate and measure the performance of a dye sensitized solar cell operated with two different counter electrodes under the same operating conditions.

2. Experimental

2.1. Preparation

Glass substrates (TCO 10-10, 2.5 cm × 2.5 cm Solaronix) were cleaned in an ultrasonic bath (Elmasonic E 60H) with acetone and ethanol (50:50 V/V%) at 60°C for 1 hour. TiO_2 paste (Ti-Nanoxide D-l series, Solaronix) was stirred for 1 hour in the ultrasonic bath and was deposited on TCO glass having resistance of 20 Ω/cm^2 by tape casting technique. The prepared photoelectrode was placed in the oven (Memert UFE 500) and sintered in 120°C for 24 hours. The working electrode (TiO_2 electrode) was immersed in dye (Ruthenium 535-bisTBA Solaronix) solution for 24 hours. Dye solution was prepared by dissolving 20 mg of Ruthenium 535-bisTBA in 100 ml ethanol 99.9% (Merck). Gold layer was applied on TCO glass by sputtering method [13]. Gold counter electrode with 30 nm thickness was prepared by reactive sputtering (SCDOOS model) under 14 mA for 240 s. The target distance from the glass substrate was 5 cm. The graphite counter electrode was produced by spraying graphite 33 (Kontakt Chemie) on the glass substrate. The graphite counter electrode was then put in the oven at 150°C for 24 hours.

2.2. DSSC fabrication

The immersed TiO_2 electrode in dye Ruthenium 535-bisTBA was removed and rinsed with ethanol and was dried at room temperature for 1 hour. The dye-covered TiO_2 film and the counter electrode were assembled into sealed sandwich-type cells by heating with a hot-melt of ionomer films (Surlyn 1702, Du-Pont) used as spacers between the electrodes. A drop of electrolyte MPN-100 (Solaronix) was put on each of the drilled holes in the counter electrodes of the assembled cells.

Performance of the DSSC was evaluated by recording I–V characteristics with a 10 kΩ potentiometer as the variable load under simulated AM 1.5 solar conditions at 100 $mWcm^{-2}$ as shown in Fig .2.

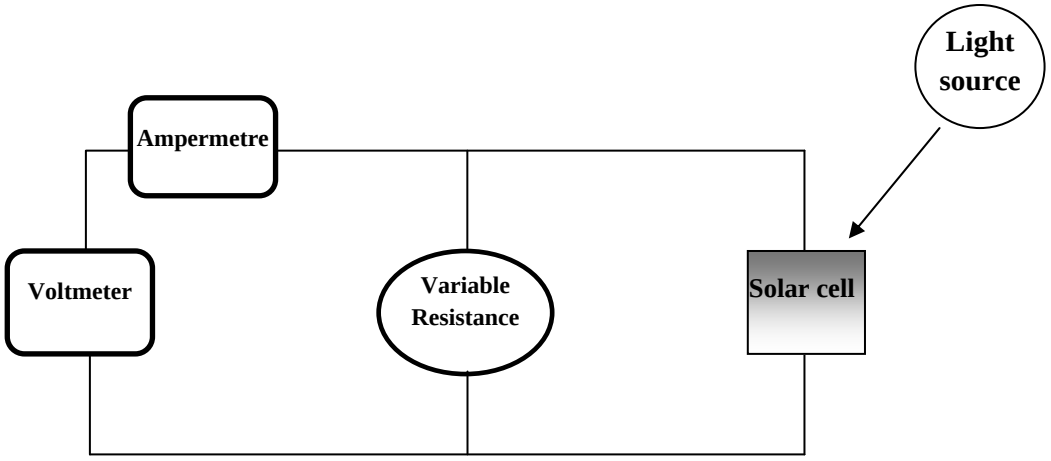

Fig.2 Experimental setup for measuring the current– voltage characteristics.

3. Results and discussion

The scanning electron microscopy (SEM Philips XL30) image of the top view of nanostructure TiO_2 film coated on TCO electrode shows sponge-like structure of electrode after sintering process Fig.3. The film is about 8 μm thick and the spherical TiO_2 nanoparticles were homogenously distributed within the TiO_2 layer. As it is shown in Fig.3 no fracture on the surface of the coated layer is seen indicating excellent inter-particle connectivity.

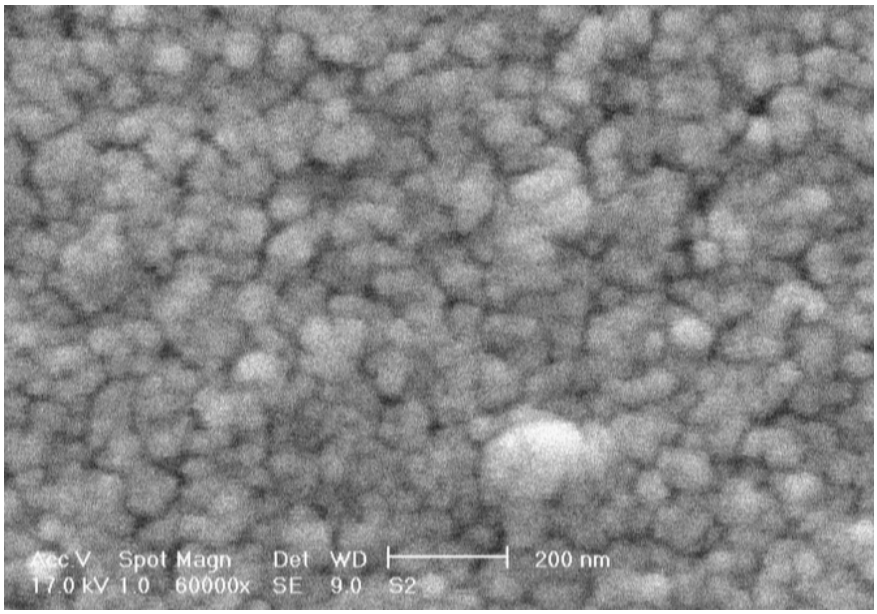

Fig.3 Top view of SEM image of TiO_2 film coated on FTO glass

To investigate the morphological characteristics of nanocrystalline TiO_2, atomic force microscopy (AFM) was used. Detailed surface characteristics were obtained in the corresponding AFM images (1 μm × 1μm surface plots), shown in Fig. 4. Analysis of the AFM images confirmed that the TiO_2 films consist of interconnected grain particles with an average diameter of 33.27 nm. The fractal Tio_2 films are endowed with a high real surface extension, which could be very beneficial for the photosensitization process, as a large amount of surface sites is available for the binding of the dye molecules. Furthermore, the porous photoelectrode surface permits a better wetting of the film by the composite electrolyte and finally results in a perfect penetration of the I^-/I_3^- redox couple into the film pores, which in turn favors the interaction between the oxidized dye and regeneration of the sensitizer's ground state[14]

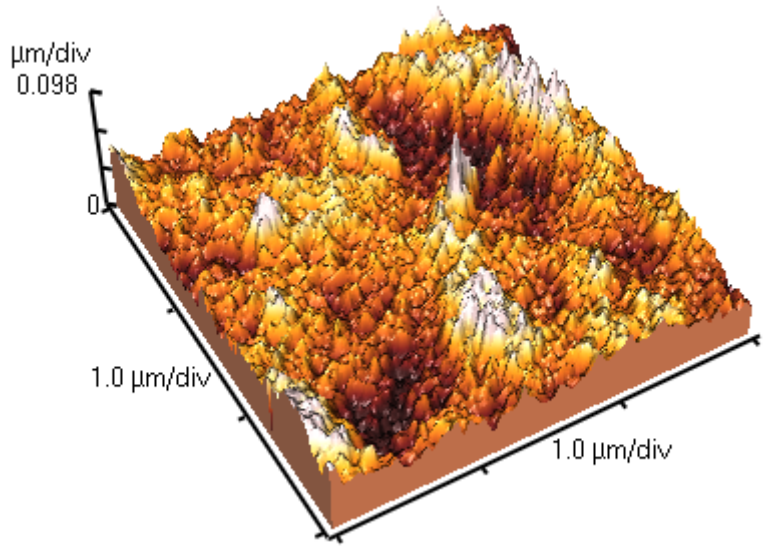

Fig. 4 Three-dimensional surface plot AFM picture of the nanocrystalline TiO_2 film

The absorption spectra of nanocrystalline TiO_2 covered with Ruthenium 535-bisTBA dye is illustrated in Fig.5. An intense absorption band in visible region with a peak at 522 nm is observed which makes the photoelectrode a good candidate for light harvesting. This absorption is caused by chelating of dye on nanostructure TiO_2 [15].

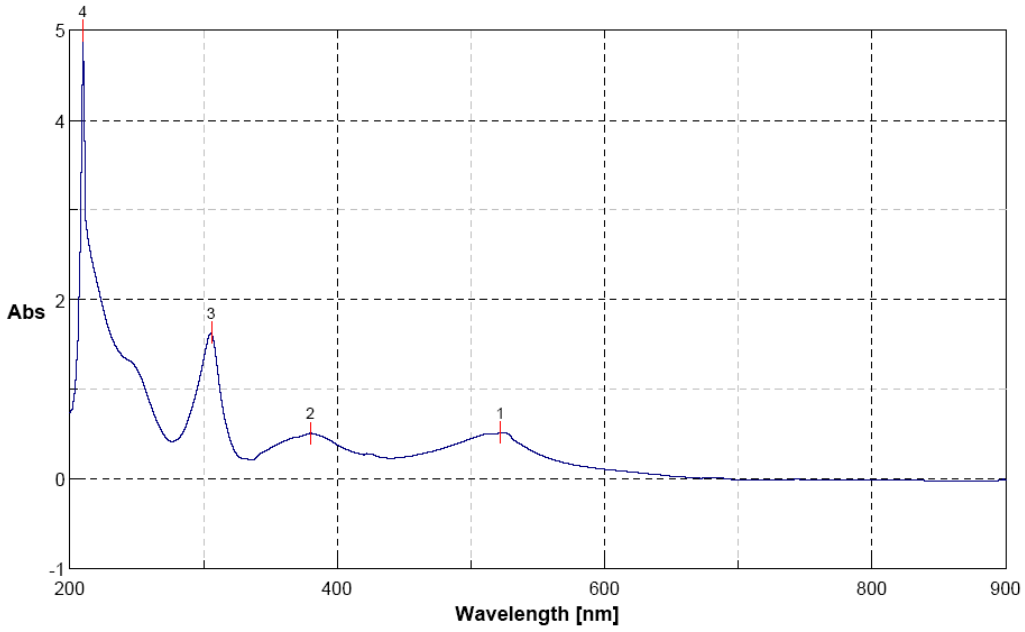

Fig.5 Spectral response of TiO2 electrode coated with Ruthenium 535-bisTBA dye

The I-V curve for two fabricated cells with different counter electrode is shown in Fig .6.

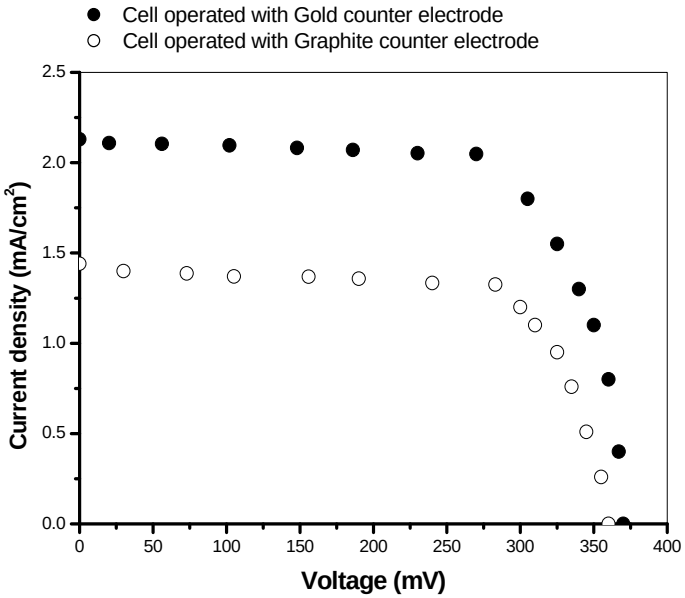

Fig. 6. Photovoltaic response of fabricated DSSCs under illumination.

The fill factor for DSSC was calculated from equation 2 where P_{max} is the maximum electrical power obtained; I_{SC} and V_{OC} are the short-circuit current density and open-circuit voltage, respectively.

$$FF = \frac{Pmax}{ISC \times VOC} \tag{2}$$

The conversion efficiency of the dye sensitized solar cell is obtained from equation 3. Where I is the intensity of incident light; A is the active area illuminated by halogen lamp [16].

$$\eta = \frac{ISC \times VOC \times FF}{I \times A} \tag{3}$$

The values of V_{OC}, I_{SC}, FF and cell efficiency (η) for both cells with different counter electrode of active area 1cm^2 illuminated by a halogen lamp with an incident light of 100 $mWcm^{-2}$ are shown in Table2. As seen in table the FF values for both cells with different counter electrode are equal, and types of counter electrode used in this work have no effect on FF. The use of gold sputtered counter electrode facilitates the electron transfer process to regenerate the electrolyte in the cell explaining the higher I_{SC}, V_{OC} and η values over the graphite sprayed counter electrode.

Table.2 Photovoltaic performance for fabricated cells.

Fabricated DSSC	**V_{OC} (mV)**	**I_{SC} (mA/cm^2)**	**FF**	**η**
Cell operated with graphite counter electrode	360	1.44	70	3.63
Cell operated with gold counter electrode	370	2.13	70	5.51

4. Conclusions

Photovoltaic performance of fabricated DSSC operated with gold coated over graphite coated counter electrode has shown an increase in I_{SC}, V_{OC} and η. It was shown that the type of counter electrodes used in this study has no effect on fill factor of fabricated DSSC. The higher efficiency and higher short circuit current for gold counter electrode could be related to faster electron transfer at the counter electrode. Also the light reflection by gold surface could minimize the loss of light in the cell.

Acknowledgement

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