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Photovoltaic performance of curcumin as sensitizer in a solid-state solar cell

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ABSTRACT

The sensitization of ZnO nanoparticles thin film with a natural substance curcumin and its use as photoanode in a solid-state dye-sensitized solar cell (SS-DSSC) employing TiO_2 nanofiller modified polyethylene oxide (PEO) polymer electrolyte is reported. The diffuse reflectance spectrum (DRS) of the curcumin dye adsorbed ZnO thin film has exhibited a strong absorbance in the wavelength range of 380–520 nm, indicating a good adsorption of curcumin dye molecules on the ZnO thin film surface. The photovoltaic performance of the SS-DSSC is evaluated under simulated solar light intensity of 600 W/m^2. The SS-DSSC with ZnO thin film electrode sensitized by curcumin has delivered a photocurrent density (J_{sc}) of 331×10^{-6} A cm^{-2} and overall energy conversion efficiency (η) of 0.13%. The high charge transfer resistance exhibited by the solid-state PEO polymer electrolyte is responsible for the low J_{sc} *value* of the cell. The stability of the SS-DSSC is proved through chronoamperometry study.

1. Introduction

Increasing energy demand, rapid depletion of fossil fuels and serious environmental issues, caused by the excessive use of fossil fuels induce great responsibility among the scientific community towards the exploration of sustainable, environmental friendly and economically viable alternative energy technology [1]. Among the different alternative energy technologies emerged in the past, the field of photovoltaics has gained significant attention, owing to their ability of producing electrical energy directly from the everlasting energy source, the *Sun* [2,3]. The complete commercial production of electricity with an aid of silicon semiconductor solar cells is still under dilemma, due to their expensive and energy intensive production technology [4–6]. In this context, the dye-sensitized solar cell (DSSC) holds advantages in terms of low-cost, simple fabrication, relatively good efficiency, non-polluting and flexibility, which have brought the DSSC as a credible alternative to silicon solar cells [7]. The DSSC has been developed in the last two decades by modifying its associated components and as a consequence, the DSSCs with impressive performances have emerged [8–10].

The highest energy conversion efficiency achieved for the state-of-art DSSC is 12.3%, which is relatively comparable to the practical efficiency of classical silicon solar cells [10]. However, intense research efforts are under progress towards improving the efficiency and stability of DSSC further and reducing the high cost of its associated components. One of the important components regarded as backbone of the DSSC is dye. Therefore, it is essential to select a suitable dye for obtaining good photovoltaic performance. An ideal dye should absorb sun light as much as possible in the visible and infrared region of the solar spectrum, possesses suitable surface attachment groups and have high molar extinction coefficient. Polypyridine ruthenium metal complex dyes fulfill the first two criteria and hence they are realized as superior sensitizer for TiO_2 semiconductor photoanode based DSSCs [11–14]. However, they have few serious draw backs such as slightly expensive, scarcity of ruthenium metal and low molar extinction coefficient when compared with metal-free organic dyes.

ZnO has been equally considered as a promising semiconductor photoanode material as that of TiO_2 owing to its bulk electron mobility for its small electron effective mass, similar bandgap energy to TiO_2 and easy synthesis of various peculiar nanostructures [6]. The ruthenium metal complex dyes generally don't show good photovoltaic performance in solar cells having ZnO nanoparticles semiconductor photoanode. This is mainly due to the aggregation tendency of ruthenium metal complex dyes on

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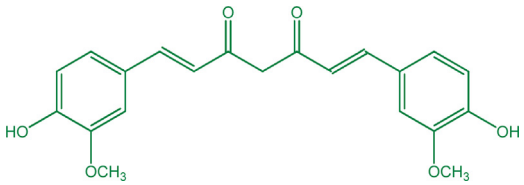

Fig. 1. Molecular structure of curcumin dye.

the ZnO surface and formation of Zn^{2+} complex with the dye legands, which greatly reduce the charge injection efficiency and increase the charge recombination reactions [15–17]. In the search of suitable sensitizer for ZnO, metal-free organic dyes occupy the place of ruthenium metal complex dyes because of their higher molar extinction coefficient, non-aggregation tendency, ease of synthesis and low-cost [18–22]. Higher molar extinction coefficient of metal-free organic dyes provides good light-harvesting efficiency (LHE) that leads to better photocurrent generation in DSSCs [23].

Liquid electrolytes are commonly employed in DSSCs owing to their high conductivity which results in good photovoltaic performance. However, they hold many serious technological problems like leakage and evaporation of solvents, desorption of dye molecules and corrosion of electrodes in DSSCs because of their volatile nature. Several solid and quasi-solid state polymer electrolytes developed in the past were employed as alternatives to the liquid electrolytes [24–29]. Solid-state polymer electrolytes generally show inferior photovoltaic performance than liquid electrolytes because of the inadequate drenching of photoanode surface by the highly viscous polymer electrolyte and lower charge conductivity. However, the use of TiO_2 as nanofiller improved the solid polymer electrolytes performance, due to the enhancement in their electrical conductivity and mechanical properties [30,31]. Based on the above facts, in the present investigation, the photovoltaic performance of a metal-free organic dye curcumin (Fig. 1) sensitized ZnO nanoparticles photoanode based solid-state solar cell employing TiO_2 nanofiller modified polyethylene oxide polymer electrolyte has been examined.

2. Experimental

2.1. Chemicals used

High pure zinc acetate dihydrate and oxalic acid dihydrate were purchased from Merck. TiO_2 (Degussa P25) nanoparticles were supplied by Evonik Industries, Germany. Poly(ethylene oxide) (M_W = 50,00,000) and curcumin were received from Aldrich. All other chemicals used in this work were of analytical grade. Unless otherwise stated, double distilled water was used for the preparation of aqueous solutions and washings.

2.2. Preparation of ZnO nanoparticles

The ZnO nanoparticles were prepared according to the reported procedure [32]. Briefly, equal volumes of aqueous solutions of 0.1 M zinc acetate dihydrate and 0.1 M oxalic acid dihydrate were mixed and stirred for about 12 h at room temperature. The white precipitate thus obtained was filtered, washed with acetone and water several times to remove impurities and dried in a vacuum oven at 120 °C for 6 h in order to remove water molecules completely. Finally, the ZnO nanoparticles were calcined at 450 °C in a muffle furnace for 1 h.

2.3. Preparation of TiO_2 nanoparticles modified PEO polymer electrolyte

The TiO_2 nanoparticles (Degussa P25) modified PEO polymer electrolyte was prepared by adopting a reported procedure [30]. Briefly, 0.0383 g of TiO_2 nanoparticles were dispersed in 50 mL of acetonitrile containing I^-/I_3^- redox couple (0.1 g KI and 0.019 g I_2). To the above mixture, 0.264 g of PEO was slowly introduced under constant stirring and the stirring was continued for 24 h at ambient temperature. The resulting product was then placed in a vacuum oven to evaporate the solvent until to give a viscous paste.

2.4. Characterization studies

Absorption spectrum of the curcumin dye was recorded using a Shimadzu UV-2550 UV–vis spectrophotometer. Diffuse reflectance spectrum (DRS) of curcumin dye adsorbed ZnO nanoparticles thin film was obtained using ISR-2200 DRS accessory of UV–vis spectrophotometer. Oriel class-A solar simulator (M–91195A, Newport) was used as a light source. A computer-controlled Autolab PGSTAT302 N electrochemical workstation was used for the photocurrent–voltage (*I–V*), photocurrent–time (*I–T*) and open-circuit voltage decay (OCVD) measurements.

2.5. DSSC fabrication and its performance evaluation

ZnO thin film was prepared on a FTO conducting glass substrate (Pilkington, TEC-7, sheet resistance ~ 6–8 Ω/□) by following a well known doctor blade technique [11]. The formed thin film was dried in air for 15 min and then kept at 400 °C in a muffle furnace for 10 min and the same process was repeated three times to obtain an optimum thick film (~10 μm). Afterwards, the film was sintered in a muffle furnace at 450 °C for 30 min and allowed to cool to 80 °C. The hot film (80 °C) was immersed in 5×10^{-4} M ethanolic solution of curcumin dye and kept at room temperature for 24 h. The curcumin-adsorbed ZnO photoanode was withdrawn from the dye solution under a stream of N_2 gas and was immediately wetted with TiO_2 nanofiller modified PEO polymer electrolyte. Platinum counter electrode was prepared on FTO conducting glass using 7×10^{-3} M H_2PtCl_6 solution in 2-propanol, where Pt^{4+} ions were reduced thermally at 400 °C in a muffle furnace. Finally, the counter electrode was placed on the polymer electrolyte wetted side of the dye adsorbed photoanode to form a sandwiched SS-DSSC. The cell parameters of the SS-DSSC were evaluated under simulated solar irradiation of 600 W/m^2.

3. Results and discussion

3.1. UV–vis absorption study

The observed UV–vis absorption spectrum of curcumin dye is shown in Fig. 2. The curcumin dye showed strong absorption in the wavelengths ranging from 350 to 490 nm of the solar spectrum, which indicated that it can effectively absorb the high intensity part of the solar spectrum. The absorption maximum of the curcumin dye was situated at around 423 nm. Even though the dye has narrow absorption in the visible region, its intense absorption in the 350–450 nm range indicates that it can potentially trap the high energy photons and sensitize wide bandgap semiconductor effectively and thus we can expect good performance when used as a sensitizer in solar cell.

3.2. Diffuse reflectance spectral characterization

The observed diffuse reflectance spectrum (DRS) of curcumin dye adsorbed ZnO nanoparticles thin film is shown in Fig. 3. From