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Photovoltaic characteristics of natural light harvesting dye sensitized solar cells

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ABSTRACT

In this work of research, anthocyanin as a natural dye obtained from raspberry fruits, was used and tested as a photon harvesting/electron donating dye in titanium dioxide nanoparticle-based DSSCs. A working photoelectrode made from TiO_2 nanoparticles with an average particle size (10–40 nm) that is coated on Florine doped tin-oxide substrate, was prepared via a simple and low cost hydrothermal method. A detailed structural and morphological analysis of the TiO_2 photoactive electrode was investigated by X-ray diffraction (XRD), diffuse reflectance spectrometer, transmission electron microscope (TEM) and scanning electron microscope (SEM). Complete photovoltaic characteristics including (current, voltage, outpower, and responsivity) of the natural anthocyanin based dye sensitized solar cell have been investigated under different illumination intensity ranging from 10 to 100 mW.cm^{-2}. The cell responsivity and efficiency of the fabricated solar cell under different illumination intensity were found to be in the range ($R = 15.6$–23.8 mA.W^{-1} and $\eta = 0.13$–0.25) at AM = 1.5 conditions. This study is important for enhancing the future applications of the promising DSSC technology.

1. Introduction

Dye-sensitized solar cell (DSSC) which converts the solar energy to electricity is the third generation of solar cells attracting much attention and interest [1–3]. This much attention and interest is due to the increased demand for cheap clean sources of energy. As, the fossil fuels will run out and produce many gas pollutants like carbon dioxide, Sulphur dioxide and carbon monoxide contributing to the global warming and air pollutions [1,4], solar cell is one of the promising alternative clean sources of energy. Due to the high production cost of the highest efficiency Si silicon p-n junction solar cell [5], it is important to search for cheaper types of solar cells with good efficiency. In 1991, Michael Gratzel and his co-workers created a low-cost DSSC with TiO_2 and a ruthenium based dye and the highest obtained efficiency of this type is 13% [6]. DSSC has many advantages such as low cost, easy fabrication, relatively high efficiency, good suitability for large area production and environmental compatibility [1,3,7,8].

To date, the most effective and stable dyes used for DSSC are based on ruthenium and osmium metal-organic complexes, which require multi-step preparation procedures and careful chromatographic purification. Thus, for practical and fundamental reasons, many researchers have studied the possibility of achieving solar energy conversion exploiting nanocrystalline TiO_2 sensitization using natural dyes which are cheap and eco-friendly materials [9–12].

In this work, anthocyanin, as a natural dye extracted from raspberry fruits, was used and tested as a photon harvesting/electron donating dye in TiO_2 nanoparticle-based DSSCs. To the best of our knowledge, this is the first time to study and investigate the photovoltaic characteristics including (current, voltage, outpower, fill factor and responsivity) of the natural anthocyanin based dye sensitized solar cell in details under different illumination intensities. Where, studying the photoelectric properties is of an emergency need to enhance the future potential applications of the technology converting sunlight energy to electricity.

2. Experimental Techniques

2.1. Chemicals

Chemical agents (including Ti[OCH (CH3)$_2$]$_4$, I_2, LiI, 4-tert-butylpyridine (TBP) and N(n-C_3H_7)$_4$I), the OP emulsification agent (Triton X-100), polyethylene glycol 20,000 and cyanoacrylate adhesive were purchased from Shanghai Chemical Agent Ltd. - China and used without further purifications. The organic solvents like ethanol, methanol and acetonitrile were distilled before usage. FTO (fluorine-doped tin oxide) transparent conducting glass was bought from Hartford Glass Co - USA. Anthocyanin dye extracted from raspberry fruits was used as natural dye sensitizer (Fig. 1).

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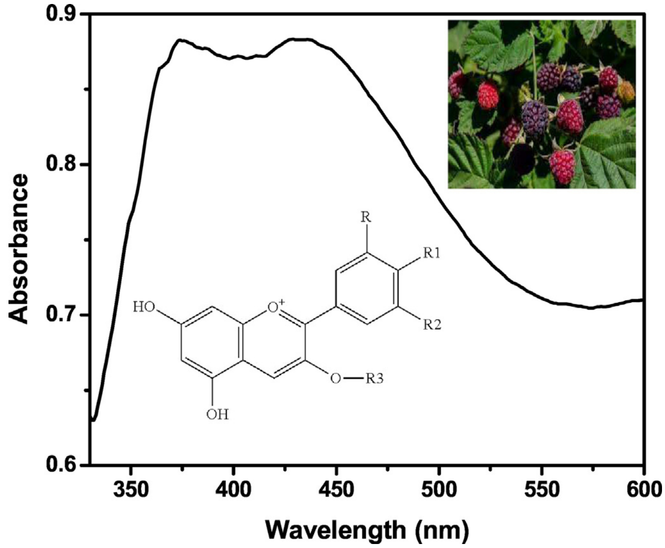

Fig. 1. UV–vis absorption spectrum of the Raspberry natural dye sensitizer; Inset: the chemical structure and photo image of the anthocyanin dye extracted from raspberry fruits.

2.2. Preparation of the TiO_2 Electrode

Nanoporous TiO_2 film was prepared according to our previous works [13,14]. Tetrabutyl titanate (20 ml) was rapidly added to distilled water (200 ml). The produced white precipitate was filtered and washed three times with distilled water. Then, nitric acid aqueous solution (200 ml, 0.1 M) was added to the filtered cake with stirring at 80 °C till production of a translucent blue white liquid. This liquid was autoclaved at 200 °C for 12 h to form milky white slurry which was concentrated to 1/4 of its volume. Then, polyethylene glycol PEG-20,000 (10 wt% slurry) and a few drops of the Triton X-100 was added to form the titania past.

2.3. Preparation of Dye Solution

A 10–12 fresh raspberry fruits were collected and dip coated in 20 ml water for one day. The aqueous solution was then filtered to get a clear red liquid which is the anthocyanin dye without further purification.

2.4. Fabrication of Dye-Sensitized Solar Cells

The titania past was painted on the FTO using a doctor blade technique three times to form TiO_2 thick film (about 3–5 μm). Then, the porous film was sintered by firing in air at 450 °C for half an hour. After reaching to 80 °C, the film was sunk in the dye for 1 day. After that, the sensitized film was washed with pure ethanol. The active area of the DSSCs was approximately 0.25 cm^2. Sputtered Pt over FTO was used as counter electrode. Finally, drop of the electrolyte was put between the two electrodes and sealed together using a cyanoacrylate to avoid leakage of the electrolyte.

2.5. Characterization and Measurements

The surface morphology of the TiO_2 film electrode was investigated by X'pert Philips X-ray diffraction (XRD) with Cu Kα radiation, 40 kV and 30 mA and scan rate 5^o/min, scanning electron microscope (SEM) Quanta 250 FEG, with 30 kV and magnification 14× up to 1,000,000 and transmission electron microscope (TEM), JEM-2000 EX (JEOL, Tokyo, Japan). The diffuse reflectance (UV–Vis/DR) of the TiO_2 film electrode was recorded on JASCO V-550 spectrometer (Japan) equipped with an integrating sphere accessory for diffuse reflectance spectra, Barium sulfate was used as a reference.

The photovoltaic characteristics of the natural DSSC including (current, voltage, outpower, and responsivity) were recorded with computerized Keithley (K2635, USA) source-measure. TE7NMARS Solar power meter (TM 206, Taiwan) certified by ISO 9001, was used to measure the solar radiation intensity in $mWcm^{-2}$. Solar energy conversion efficiency (η) measurements were done by a xenon lamp (CHF XM500, Trusttech Co., Ltd. - China) and the intensity was set to 1 sun (100$mWcm^{-2}$) by a calibrated c-Si solar cell. The light intensity was measured using a TM-206 solar power meter. All the measurements were carried out at room temperature.

3. Results and Discussions

3.1. Characterization of the TiO_2 Film Electrode

Generally, the photovoltaic performance of DSSC is related to the surface characteristics of the TiO_2 nanoparticles. The particle sizes and surface potential of the nanoparticles control the amount the dye adsorbed on the photoanode. This determines the total number of photogenerated carriers and hence the photovoltaic characteristics of the DSSC [13].

Fig. 2(a) presents the TEM image of the titania paste used in preparation of the TiO_2 electrode. It shows two uniform sizes of TiO_2 nanoparticles; viz., (8–10 nm) and (20–40 nm). This mixed morphology provides a well porous interconnected network structure of the TiO_2 electrode required for highly efficient dye-absorption [15]. The SEM image (Fig. 2(b)) of the film electrode shows a uniform morphology of

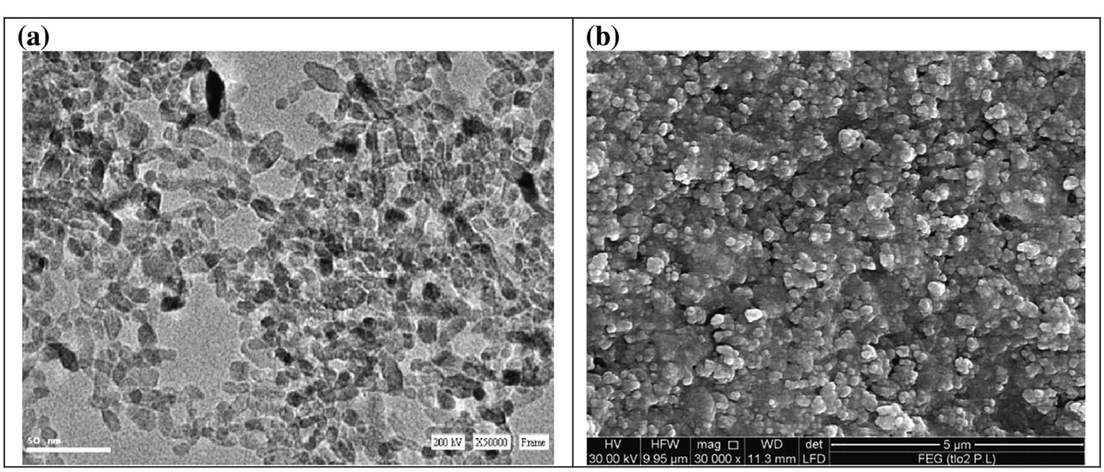

Fig. 2. (a) TEM image of the titania past; (b) SEM image of the TiO_2 film.