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Study on TiO_2 photoelectrode to improve the overall performance of dye-sensitized solar cells

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ABSTRACT

Due to the complexity of dye-sensitized solar cell modules, the conversion efficiency increased slightly over the years of development. The TiO_2 photoelectrode, as core part in the module, plays an important role in the overall performance. Here, we conducted series of associative experiments on modification of the TiO_2 photoelectrode to achieve a better performance. The paste was prepared using conventional P-25 powder, and the conversion efficiency was found to be increased from the initial 1.41% to 2.48% by optimizing paste additives. Further, a merchandised paste with smaller particle size was introduced to fabricate a double-layer cell with the P-25 paste, followed by a surface treatment with $TiCl_4$. The final result was observed to be quite satisfactory with a sharp increase in the conversion efficiency of 6.51%.

1. Introduction

In 1991, O'Regan and Grätzel introduced TiO_2 nanoparticle as photoanode for assembled dye-sensitized solar cell (DSSC), with a practical conversion efficiency of 7.1% [1]. From then on, the dominance of the photovoltaic field by inorganic solid-state junction devices was challenged by the third generation of cells, based on nanocrystalline oxide with interpenetrating network junctions [2]. The presence of a bulk junction having an interface with a huge area, benefit from modern nano-fabrication technology [3,4], endows these systems with intriguing optoelectronic properties.

The performance of the DSSC is affected by many factors, such as photoelectrodes[5], counter-electrodes [6], dye-sensitizer [7] and electrolyte [8]. As the most important part in the module, the TiO_2 photoelectrodes have been studied widely. To obtain a high conversion efficiency, the parameters such as film surface modification [9,10], particle size controlling [11,12], double or multi-layered structure [13,14] and mixing of other metal oxides [15,16] have been optimized. However, due to the lack of continuity among these methods, the current efficiency remains still around 11% as reported [17], which is about one third of the theoretical value for a single band gap junction [18].

In the present work, an attempt was made to improve efficiency by a systematic modification of TiO_2 paste and TiO_2 film structure. The TiO_2 pastes, TiO_2 films and platinize FTO counter-electrodes, were prepared and tested under illumination after assembling. The *I–V* behaviors demonstrated the effectiveness of the modification of TiO_2 paste and TiO_2 film by the optimization of paste additive, introduction of a double-layer and film surface treatment.

2. Experimental

2.1. Chemicals and instrument

TiO_2 powders (P-25) with an average particle diameter of 21 nm were purchased from Degussa (Germany). A kind of translucent TiO_2 paste with better dispersity and smaller average particle diameter of 13 nm was procured from Solaronix (Switzerland). Polyethylene glycol (PEG) with different molecular weights of 4000 and 20,000, and titanium tetrachloride (both were from Tianjin Kemiou Chemical Reagent Co., Ltd.), and all other reagents were of analytical grade and used without further purification.

Herein, both the electrolyte contained 0.3 M DMPII, 0.5 M LiI, 0.05 M I_2, and 0.5 M tert-butyl pyridine (4-TBP) mixed with dry acetonitrile and the dye sensitizer N719 were from Solaronix, Switzerland.

Field Emission Scanning Electron Microscope (FESEM, SIRION 200, FEI, Netherlands) was used to characterize the morphologies of the films. X-ray diffraction (XRD) patterns obtained on a X-ray diffractometer (PANalytical B.V.) using Cu Kα radiation at a scan rate (2θ) of $0.05^\circ\ s^{-1}$. UV–Vis diffuse reflectance spectra (DRS) were obtained using a Scan UV–Vis–NIR spectrophotometer (Lambda 35, PerkinElmer, USA) equipped with an integrating sphere assembly. A 500 W xenon lamp (NEWPORT M-9119X source units laid on AM 1.5 filter) with a light intensity of 1 sun (100 mW cm^{-2}) was used to evaluate the *I–V* characteristics of the cells.

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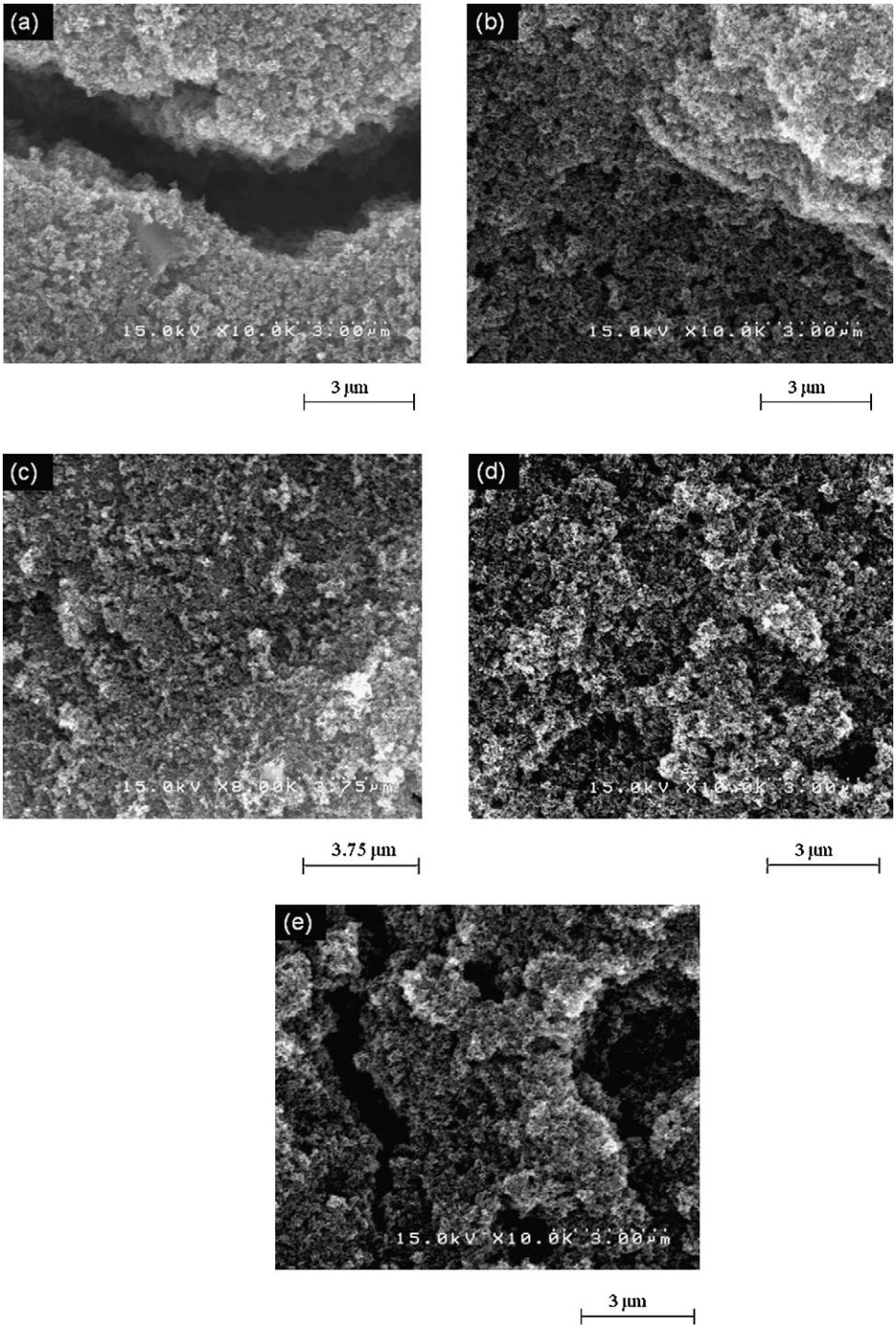

Fig. 1. FESEM images of TiO_2 films with PEG-4000 at the amount of 0 g(a), 0.25 g (b), 0.5 g (c), 0.75 g (d) and 1.0 g(e).

2.2. Fabrication of TiO_2 photoelectrode and dye absorption

Nanoporous TiO_2 films with single or double layers were fabricated by conventional doctor blade method. Therein, the TiO_2 paste was prepared by grinding 0.5 g P-25 powder with some amount of PEG, 0.5 mL Triton-X 100 and 3 mL terpinol in a mortar. After dried the prepared films at room temperature for several minutes and sintered at 450 °C for 1 h at a heating rate of 2 °C/min, the TiO_2 films were immersed into a ruthenium N719 solution for 24 h to adsorb the dye thoroughly. For a sample with the surface treatment, before the dyes adsorbed, the sintered films were soaked in 0.04 M $TiCl_4$ solution at 80 °C for 6 h, dried at room temperature for several minutes and then heated at 450 °C for 1 h. Finally, cleaned the film by anhydrous alcohol to remove any dye that not be adsorbed. The active area of the DSSC was 0.13 cm^2 (diameter 0.4 cm).

2.3. Platinization of counter-electrode

Electrochemical deposition was used to platinize FTO conduct glass which is used as a counter electrode. The electrolyte for the platinization was consisted of 0.15 g $H_2PtCl_6{\cdot}6H_2O$, 1.5 g $(NH_4)_2HPO_4$ and 4.5 g Na_2HPO_4 in 30 mL deionized water. The