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High efficiency dye-sensitized solar cells (9.3%) by using a new compact layer: Decrease series resistance and increase shunt resistance

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ABSTRACT

A novel and simple barrier layer has been successfully used to improve the performance of dye-sensitized solar cells (DSSCs). The power conversion efficiency of DSSCs with a novel and simple barrier layer is 9.3%, which is an increase of 14.6% compared to the cell without a novel barrier layer (8.11%).

1. Introduction

Dye-sensitized solar cells (DSSCs) have been extensively studied as a promising alternative to conventional solar cells that use a p–n junction because of their high sustainability, low cost, environmentally friendly components, and simple fabrication process compared to silicon solar cells [1]. High-efficient and stable DSSCs require different functional materials with optimized properties in order to achieve the best performance in all processes including photon absorption, charge separation, carriers transport, and dye regeneration. One of the critical interfaces lies between the transparent conductive oxide (TCO) electrode and the mesoporous TiO_2 nanoparticle film because it effects on both series resistance and shunt resistance. Ideal solar cells have a series resistance near zero and an extreme shunt resistance. The primary method of combating reduction of electrolyte at the TCO surface is TCO surface passivation (using a compact layer) which increases shunt resistance. In addition to increasing the shunt resistance of the device, compact layer also is able to decrease the series resistance by improving the electrical contact between the TiO_2 photoanode and the TCO surface [2]. Researches indicated that deposition a proper wide band gap semiconductor of tens to hundreds of nanometers between the TCO and the mesoporous TiO_2 nanoparticle film can significantly improve the solar cell efficiency [3–6]. It is essential to minimize electron backflow from TCO electrode to the electrolyte and suppressing carrier recombination at the TCO surface [7,8]. Many methods were applied to prepare TiO_2 barrier layer including spray-pyrolyzed [9,10], sputter deposited [11,12], and sol–gel prepared [13]. Spray-pyrolysis requires high temperatures for deposition (450 °C), specialized sprayers, and produces non-uniform films [14]. It is hard to work with $TiCl_4$ solution because it releases HCl gas and hydrolyzed to TiO_2 immediately. Sputter deposition requires high vacuum systems, pure titanium metal for its implementation. Also produces films that are weakly bonded to the substrate [14].

Herein, we report a new simple and an effective compact layer to improve the efficiency of dye-sensitized solar cells. This compact layer effectively can decrease series resistance and increase shunt resistance that may sufficiently improve overall efficiency. We prepare different volume/volume percent of Tetraethyl orthotitanate in isopropanol from 3% to 20% (v/v %) and apply different simple methods to deposit barrier layer including brushing, doctor blade and dip-coting. These methods do not require specialized equipment, uses inexpensive chemicals, and are processed at low temperatures.

2. Experimental

2.1. Materials

The chemical reagents including Isopropanol, Tetraethyl orthosilicate, Tetraethylorthotitanat ($C_8H_{20}O_4Ti$), used in our

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experiments were purchased from Merck. Commercially-available TiO_2 powder of P25 (av. 30 nm by Brunauer–Emmett–Teller (BET), 80% anatase (d=21 nm) and 20% rutile (d=50 nm) was prepared from Degussa, Germany. I^{3-}/I^- electrolyte, N719, Pt solution, surlyn were purchased from Dyesol. All the mentioned chemicals were used as received without further purification.

2.2. Synthesis of SiO_2 nanoparticles

Co-precipitation method was used to prepare SiO_2 NPs. Typically 5 ml Tetraethyl orthosilicate was added in 10 ml water and 25 ml ethanol. Then 0.5 ml ethylenediamine was added as catalyst and AcAcPen as capping agent. Then was drayed at 100 °C. Finally it was calcination at 600 °C for 2 h.

2.3. Prepare compact layer

Compact layer solutions were prepare by simply mix the different v/v volume of TEOT in isopropanol. Then these were applied on FTO by doctor blade, dip-coating, and brushing methods.

2.4. Deposition of TiO_2 nanoparticles

TiO_2 P25 was deposited on FTO according to our previous works [15–17]. Briefly, this deposited by Electrophoretic Deposition (EPD) methods. Power was supplied by a Megatek Programmable DC Power Supply (MP-3005D). The applied voltage was 10 V. The optimal concentrations of additives in the electrolyte solution as follows: I_2 120 mg/l, acetone 48 ml/l, and water 20 ml/l.

2.5. Deposition of scattering layer

Same EPD method was used to deposit scatter layer. Here as synthesized SiO_2 nanoparticles were used instead of P25.

3. Result and discussion

XRD of as synthesized SiO_2 NPs is shown in Fig. 1a. As seen, pure SiO_2 NPs with uniform size were fabricated. Herein, SiO_2 NPs were used as scattering layer.

Fig. 1b shows a typical mechanism which compact layers improve efficiency of DSSCs. As shown in Fig. 1b, compact layer decreases Rs by improve conductivity between TCO and mesoporous TiO_2. Carriers can collected sufficiently when Rs decreased in DSSCs. Herein we used doctor blade method to deposit compact layer and investigate volume/volume percent of TEOT in isopropanol.

SEM of as prepared compact layer on FTO is shown in Fig. 1c which indicates that compact layer is uniform morphology (compact layer prepared by using 3% of TEOT).

For this, 5 different volume/volume percent of TEOT in isopropanol (3%, 5%, 10%, 15%, and 20%) were prepared. Then devices including compact layers were fabricated and compared with reference cells (devices without compact layer). According to Fig. 2a and Table 1, solar cells including compact layer with 3% v/v and 5% v/v of TEOT show the much better performance than reference cells. The best efficiency for cell base on the compact layer with 3% TEOT was 9.11 (Average efficiency of 9.01 for 4 devices) while the best efficiency for reference cell was 8.11 (Average efficiency of 8 for 4 devices). It shows ~12% improvement compare to reference devices. Notably, the fitted value of RCT for cell containing compact layer is found ~141 $\Omega\,cm^2$, while the corresponding value for reference cell is ~73 $\Omega\,cm^2$.

This significant increase in RCT and decrease in RCE show that the compact layer is more favorable to suppress the charge recombination process that arises from electrons in TCO film with I_3^- in electrolyte solution which leads to increase J_{sc}.

It still has a better performance by increasing the v/v percent of compact solution to 5%. Devices were fabricated with 5% TEOT as compact layer showed 8.7% efficiency (Average efficiency of 8.6 for 4 devices). When solutions with v/v percent more than 5 were applied as compact layer, PCE of devices were decreased, although FF was improved.

To the best of our knowledge, this is the first time that such a simple and effective compact layer is used for DSSCs. In the period from 2006 to 2010 physical methods such as sputtering were used to produce compact layer [11,12]. After that, researcher introduced the new compact layer base on chemical methods because of easy fabrication [14,18–20]. For instance in 2012 Brian A. Logue from US introduced the colloidal compact layer [14]. Chang Ming Li in 2013 introduced the compact layer base on tailor and functionalize TiO_2 compact layer by acid treatment. Finally, Jun Li in 2014 improved traditional $TiCl_4$ treatment [20–23]. Preparing a clear solution of $TiCl_4$ is not easy. It hydrolyzed to TiO_2 immediately. In addition it releases HCl gas which is toxic.

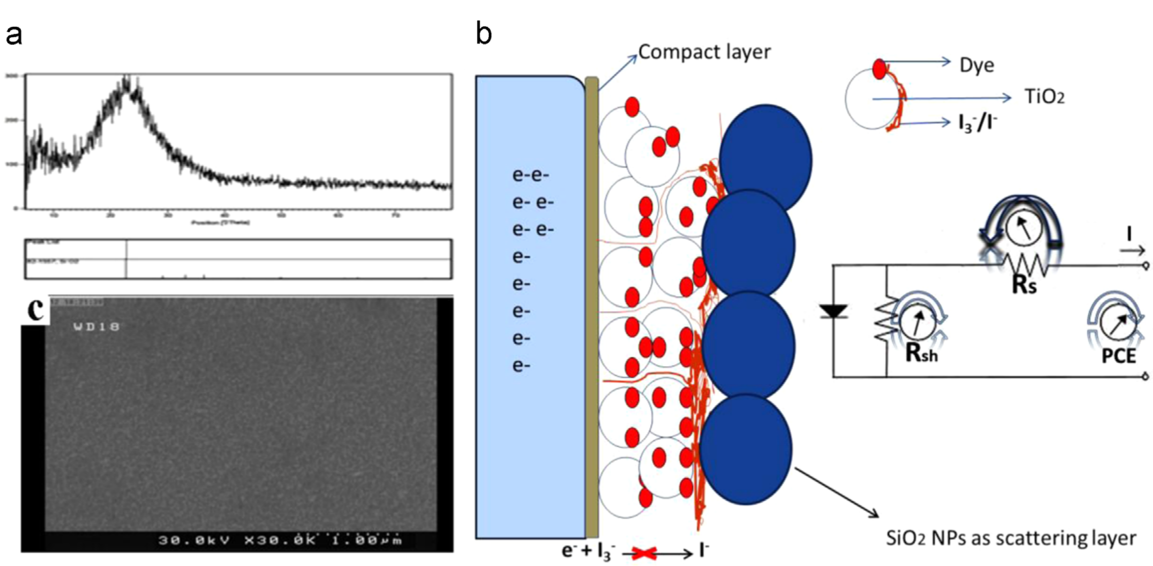

Fig. 1. (a) XRD of as synthesized SiO_2 NPs and (b) typical mechanism which compact layers improve efficiency of DSSCs, (c) SEM of as prepared compact layer on FTO.