



Short communication

A platinum film with organized pores for the counter electrode in dye-sensitized solar cells



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HIGHLIGHTS

- A Pt film with nano-pores could be electro-deposited using a PS template.
- The DSSC with a templated Pt film shows a high power-conversion efficiency.
- The high efficiency is attributed to the high surface area of the templated Pt.
- An efficiency of 8.89% is achieved for the DSSC under 1 sun condition.

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ABSTRACT

A platinum (Pt) film is electro-deposited into the voids of a polystyrene (PS) template on an FTO glass. After the removal of the template by heating, the Pt film forms a novel submicron structure with organized pores in it (designated as e-PtOP). The FTO glass with this Pt structure is used as the counter electrode (CE) for a dye-sensitized solar cell (DSSC). Higher surface area, and thereby higher electro-catalytic ability of the e-PtOP render higher short-circuit current density for the pertinent DSSC (18.94 mA cm⁻²) than that of the cell with a Pt film obtained without PS template (16.63 mA cm⁻²). A thin layer of Pt is further sputtered onto the e-PtOP to render an increased fill factor of the DSSC with the corresponding CE. Consequently, the power-conversion efficiency of this cell is thus enhanced from 6.03 to 8.89%, with reference to the cell with a Pt film obtained without PS template.

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1. Introduction

The dye-sensitized solar cell (DSSC) consists of a dye-adsorbed nanocrystalline TiO₂ photoanode, an electrolyte, and a counter electrode (CE). Conventionally, a platinum (Pt) layer is coated on a conductive substrate of the CE not only for obtaining a superior catalytic surface on the substrate, but also for minimizing the voltage loss due to charge transfer overpotential at the CE [1,2]. The Pt-coated CE of DSSCs could be of two types: one from a composite of Pt and other material, such as NiP [3], acetylene-black (AB) [4], SnO₂ [5], carbon black [6], polypyrrole [7], and multi-wall carbon nanotube (MWCNT) [8], and the other from Pt nano-clusters [9–14], composed of only Pt nanoparticles.

It is anticipated that a Pt composite combines the advantages of both Pt and its composite material. Low Pt-loaded Pt:SnO₂ paste, mixed with ethylcellulose/terpineol, was coated on a transparent conducting oxide glass to reduce Pt agglomeration and thereby to increase catalytic surface area of the film [5]. An improved electro-catalytic ability of CE based on a thin film consisting of Pt nanoparticles and MWCNTs was observed due to its large surface area [8]. In addition, pulse current [9] and initial pulse potential [10] electrodeposition techniques were used to obtain Pt nanoparticles and round textured Pt clusters, respectively; the films of these particles and clusters showed high surface areas, and enabled high performances to DSSCs.

In this work, we have prepared an electro-deposited Pt film with organized pores (hereafter designated as e-PtOP) on the FTO glass, by using polystyrene (PS) template. The morphology of this film was intrinsically unique and never reported before. The DSSC with the e-PtOP showed a higher photocurrent density and power-conversion efficiency (η) than the cell with the Pt film electro-deposited without

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the PS template (hereafter designated as e-Pt). Moreover, the e-PtOP was further treated by sputtering Pt on it. After this sputtering treatment, the pertinent DSSC showed an excellent η of 8.89%.

2. Experimental

The FTO glass (sheet resistivity = $10 \Omega \text{ sq.}^{-1}$, NSG America, Inc.) was vertically placed in a container containing a colloidal suspension with 0.05 wt% monodispersed particles of carboxyl-PS (average size = 300 nm, Invitrogen Life Technologies). The container was placed in an oven at 55°C ; with the evaporation of the solvent, and due to capillary forces, the carboxyl-PS spheres had compactly self-assembled on the FTO glass. The FTO glass with the solvent-evaporated PS template was then cleaned with ethanol and annealed at 80°C for 2 h to promote necking of the PS spheres, which is necessary for the structural stability of the template [15].

Pt films were deposited on FTO glasses, with and without the PS template, by cyclic voltammetry (CV) method, using a three-electrode system (CH Instruments) [16], and the obtained electrodes were used as the CEs of DSSCs. The FTO glass with solvent-evaporated PS template, a Pt wire, and an Ag/Ag^+ -electrode were

used as the working, counter, and reference electrode, respectively. The working electrode was immersed into an ethanol solution containing 10 mM dihydrogen hexachloroplatinate (H_2PtCl_6). Pt nanoparticles could be deposited in the voids of the PS template by cycling the potential from -1.0 to 1.0 V (vs. Ag/Ag^+) [16], at a scan rate of 50 mV s^{-1} . The Pt-deposition was stopped at an applied charge density of 1.0 C cm^{-2} . After the electrodeposition, the FTO glass with Pt-filled PS template was annealed at 385°C for 15 min to remove the carboxyl-PS [1]. In comparison, an e-Pt film was electro-deposited, under the same conditions, however without using the PS template.

The N719 dye-absorbed TiO_2 photoanode was prepared according to the literature [8], and coupled with the CE (e-PtOP or e-Pt) within a distance controlled by a $25 \mu\text{m}$ -thick spacer (Surlyn[®], Solaronix). The electrolyte containing 0.6 M 1,2-dimethyl-3-propylimidazolium iodide, 0.1 M LiI, 0.05 M I_2 , and 0.5 M 4-*tert*-butylpyridine in ACN/3-methoxypropionitrile ($v/v = 1:1$), was injected into the space between the two electrodes by capillary force. Photocurrent density–voltage (J – V) curves of the DSSCs were obtained by employing a potentiostat/galvanostat (PGSTAT 30, Autolab, Eco-Chemie, the Netherlands). The DSSC was illuminated

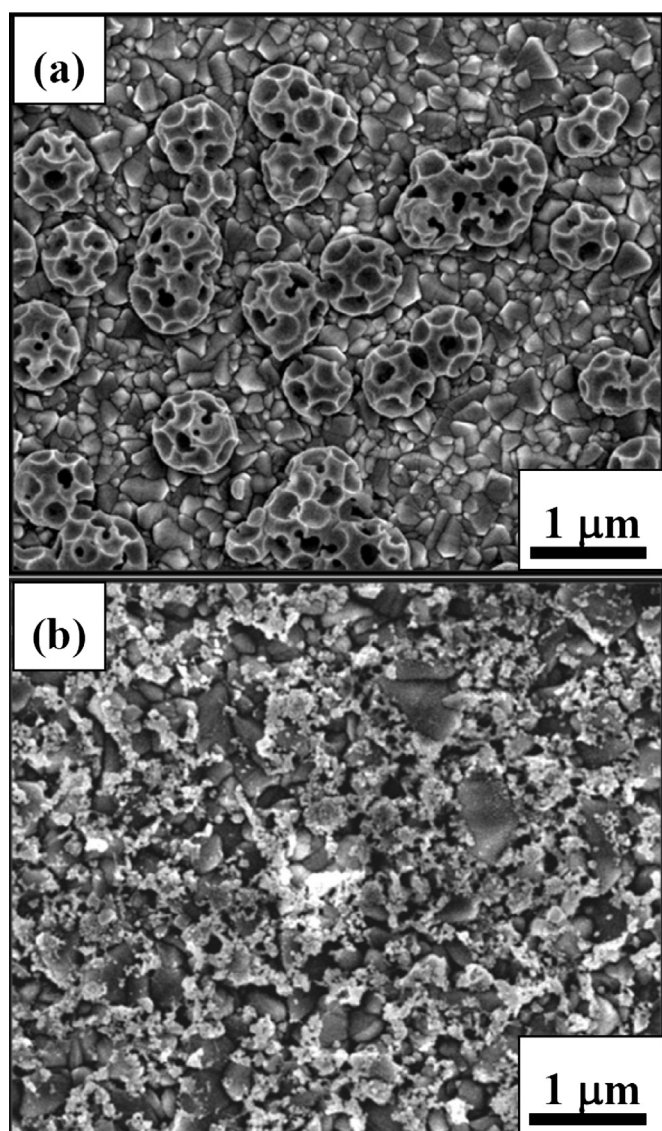


Fig. 1. SEM images of (a) e-PtOP and (b) e-Pt.

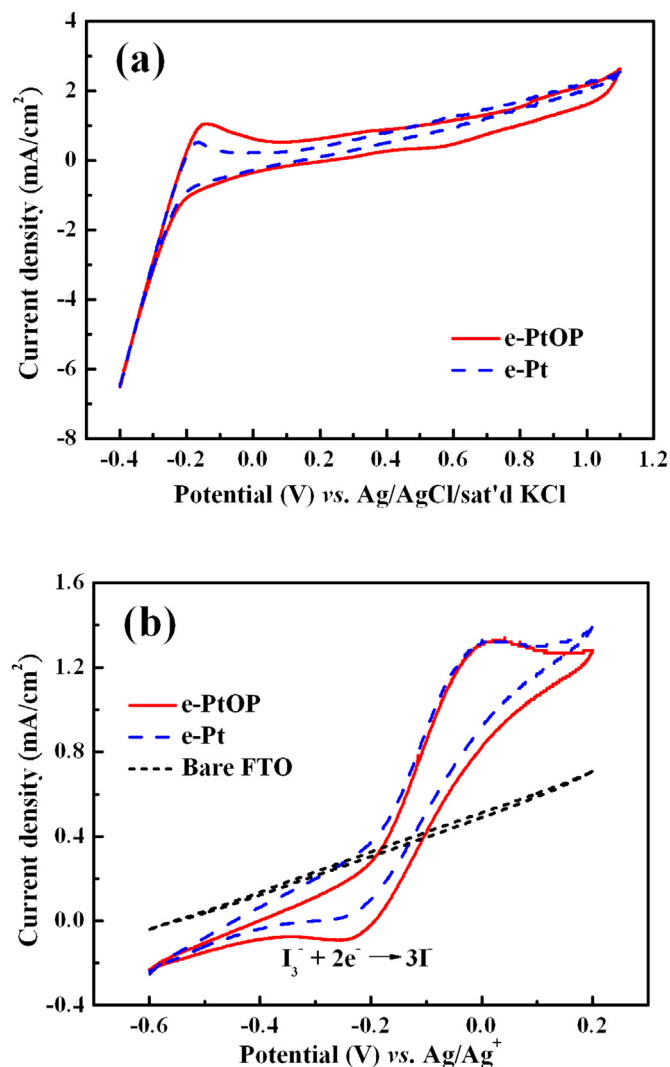


Fig. 2. (a) CVs of the e-PtOP and e-Pt obtained in $0.5 \text{ M H}_2\text{SO}_4$ at a scan rate of 50.0 mV s^{-1} and at fixed charge density of 1.0 C cm^{-2} . (b) CVs of the e-PtOP and e-Pt, in ACN solution containing 10.0 mM LiI, 1.0 mM I_2 , and 0.1 M LiClO_4 .

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