



# High performance platinum nanofibers with interconnecting structure using in dye-sensitized solar cells



Yaoming Xiao <sup>a, b, \*</sup>, Gaoyi Han <sup>a, b</sup>

<sup>a</sup> Institute of Molecular Science, Innovation Center of Chemistry and Molecular Science, Shanxi University, Taiyuan 030006, PR China

<sup>b</sup> Key Laboratory of Materials for Energy Conversion and Storage of Shanxi Province, Taiyuan 030006, PR China

## ARTICLE INFO

### Article history:

Received 4 May 2016

Received in revised form

25 June 2016

Accepted 30 June 2016

Available online 11 July 2016

### Keywords:

Dye-sensitized solar cell

Platinum nanofiber

Interconnecting structure

Electrospinning method

Film forming technique

Electrocatalytic activity

## ABSTRACT

Platinum nanofibers (PtNFs) with interconnecting structure are prepared by a simple electrospun method and novel film forming technique, which are used as the counter electrode (CE) materials for the dye-sensitized solar cells (DSSCs). Electron microscope images demonstrate that PtNFs are constituted by Pt nanoparticles. Cyclic voltammetry measurements indicate that PtNF CE has an excellent catalytic activity for the reduction of triiodide to iodide. DSSC based on PtNF CE achieves an enhanced photovoltaic conversion efficiency of 9.31% compared to that of DSSC based on Pt CE (7.32%) prepared by the thermal decomposition, owing to the three-dimensional interconnecting nanostructure has abundant catalytic surfaces, large contact area with the electrolyte, and lots of electronic transmission channels. DSSC efficiency based on PtNF CE remains 90.08% after continuous scanning 1000 s under an open system without any sealing in ambient atmosphere, and 83.19% of the efficiency is remained after 1000 h under a strictly packaging for the device application.

© 2016 Elsevier B.V. All rights reserved.

## 1. Introduction

Dye-sensitized solar cell (DSSC) has attained momentous interests as a promising type of renewable energy device, with the most efficient model utilizing a mesoporous dye-sensitized titanium dioxide (TiO<sub>2</sub>) photoanode, a counter electrode (CE), and an iodine based electrolyte between the two electrodes [1–4]. In a DSSC, the major task of CE is to speed up the reduction of triiodide (I<sub>3</sub><sup>-</sup>) to iodide (I<sup>-</sup>) with electrons to complete the electric circuit, and a CE with a highly catalytic activity reduces the DSSC's internal series resistance, resulting in a high fill factor [5,6].

Despite vast efforts in the past decades to develop low platinum (Pt) composite catalysts [7,8] and Pt-free catalytic materials [9–16], Pt remains the optimal choice for the catalytic material in the DSSC. For example, Pt–Ru nanofiber alloys were prepared by a hydrothermal method and employed as CEs for DSSCs, and the DSSC based on PtRu<sub>3</sub> alloy CE obtained 6.80% of the efficiency [17]. Recently, we prepared cubic Pt nano-crystals with slender tentacles by a hydrothermal method in the oleylamine, which had good electrocatalytic activity toward I<sub>3</sub><sup>-</sup> in DSSCs, and the CE achieved

9.24% of the photovoltaic conversion efficiencies, higher than that of the thermal decomposition Pt CE (7.26%) [18]. Therefore, design and synthesis of Pt catalyst with particular nanostructure is still a challenge to further improve its intrinsic activity [19–21].

Electrospinning is a facile and scalable method to produce nanofibers or ultrafine fibers [7,22,23]. Qiao and coworkers fabricated Pt-carbon nanofibers by using an electrospun method, and based on which the DSSC produced about 8% of the efficiency [7,24]. However, the pure Pt nanofibers (PtNFs) by the facile electrospun method were lack of enough attention and research. Herein, we prepared the pure PtNFs with an interconnecting nanostructure by the simple electrospun method. The PtNFs based CE had an excellent catalytic activity for the reduction of triiodide to iodide, and the DSSC with the PtNFs CE achieved an enhanced photovoltaic conversion efficiency of 9.31%, which was higher than that of the DSSC with the thermal decomposition Pt (TDPT) CE (7.32%).

## 2. Experimental

### 2.1. Materials

Chloroplatinic acid (H<sub>2</sub>PtCl<sub>6</sub>·6H<sub>2</sub>O), polyvinylpyrrolidone (PVP, Mw = 1,300,000), isopropyl alcohol, iodine, lithium iodide, lithium perchlorate, tetrabutyl ammonium iodide, 4-*tert*-butylpyridine,

\* Corresponding author. Institute of Molecular Science, Innovation Center of Chemistry and Molecular Science, Shanxi University, Taiyuan 030006, PR China.

E-mail address: [ymxiao@sxu.edu.cn](mailto:ymxiao@sxu.edu.cn) (Y. Xiao).

ganidine thiocyanate, and acetonitrile were purchased from Shanghai Chemical Agent Ltd., China (Analysis purity grade). Dye N719 was purchased from Dyesol, Australia. The above agents were used without further purification.

## 2.2. Electrospun preparation of PVP-H<sub>2</sub>PtCl<sub>6</sub> fiber films

Chloroplatinic acid (with a quantity of  $0.30 \times 10^{-6}$ , or  $0.60 \times 10^{-6}$ , or  $0.90 \times 10^{-6}$ , or  $1.20 \times 10^{-6}$  mol) was severally dissolved into 1.0 mL isopropyl alcohol, then 100 mg PVP was added and stirred well to obtain the electrospun mixture. The electrospun mixture was offered by a stainless-steel syringe pipette needle with a rate of about  $1.0 \text{ mL h}^{-1}$ , carrying a potential of +15.0 kV. PVP-H<sub>2</sub>PtCl<sub>6</sub> fibers were collected on a sheet of electrically grounded aluminum foil placed 15 cm below the syringe tip. The resultant fibrous films based on different quantity of H<sub>2</sub>PtCl<sub>6</sub> were peeled off from the collector and then dried at room temperature under ambient atmosphere, and named as a, b, c, and d.

## 2.3. Preparation of PtNF CEs

The CE was prepared by following four steps: First, the four PVP-H<sub>2</sub>PtCl<sub>6</sub> fiber films (a, b, c, and d) were severally cut into an appropriate size ( $0.5 \text{ cm} \times 0.6 \text{ cm}$ ); Second, the cleaned F-doped tin oxide (FTO) substrate ( $1.5 \text{ cm} \times 2 \text{ cm}$ ,  $12 \Omega \text{ sq}^{-1}$ , NSG, Japan) was treated by water vapor to form a very thin water film; Third, the tailored PVP-H<sub>2</sub>PtCl<sub>6</sub> fiber film was quickly adhered on the moisture FTO surface. As we all known, PVP and H<sub>2</sub>PtCl<sub>6</sub> are water soluble, when pasting the PVP-H<sub>2</sub>PtCl<sub>6</sub> fibers onto the surface of the humid FTO glass, the lower surface of the PVP-H<sub>2</sub>PtCl<sub>6</sub> fibers is partly dissolved in the water, and then acts as the adhesion agent to enhance the adhesion between PVP-H<sub>2</sub>PtCl<sub>6</sub> fibers and FTO substrate. Finally, the achieved samples were sintered at  $450 \text{ }^\circ\text{C}$  for 30 min under air atmosphere, and named as PtNF-a, PtNF-b, PtNF-c, and PtNF-d, respectively. For comparison, a thermal decomposition Pt (TDPT) CE was employed, which was prepared by dipping H<sub>2</sub>PtCl<sub>6</sub> isopropanol solution with a concentration of 0.50 wt% onto the FTO surface, and then heated at  $450 \text{ }^\circ\text{C}$  for 30 min.

## 2.4. Assembly of DSSCs

TiO<sub>2</sub> photoanodes were prepared by a blade-coating method according to our previous works [3,18]. Then TiO<sub>2</sub> photoanodes were sensitized by immersing them into a 0.3 mM N719 dye of ethanolic solution for 24 h. After that the DSSC was assembled by sandwiching redox electrolyte between dye-sensitized TiO<sub>2</sub> photoanode and FTO supported TDPT or PtNF CEs under an open system without any sealing. The redox electrolyte composed of 0.10 M lithium iodide, 0.10 M iodine, 0.60 M tetrabutyl ammonium iodide, 0.50 M 4-*tert*-butyl-pyridine, and 0.10 M ganidine thiocyanate in acetonitrile.

## 2.5. Characterizations and measurements

The surface morphologies of the PtNF CEs were observed using a field emission scanning electron microscopy (FESEM, JEOL-JSM-6701F) operating at 10 kV and a transmission electron microscope (TEM, JEOL-JSM-2100) operating at 200 kV. The specific surface area was measured by Brunauer-Emmet-Teller (BET) nitrogen adsorption-desorption (Micromeritic ASAP 2020 Instrument). Cyclic voltammograms (CVs) were carried out with a three-electrode configuration in an acetonitrile solution consisting of 0.05 M lithium iodide, 0.01 M iodine, and 0.05 M lithium perchlorate, using a computer-controlled potentiostat (Autolab Type III), the resultant CE acted as the working electrode, a Pt-foil as counter

electrode, and a Pt-wire as reference electrode. Electrochemical impedance spectroscopy (EIS) for the symmetrical CEs (CE//electrolyte//CE) was performed conducted by using a Zahner Zennium electrochemical workstation at a constant temperature of  $20 \text{ }^\circ\text{C}$  in ambient atmosphere under a dark condition, and the impedance data covered a frequency range of  $0.1\text{--}10^5 \text{ Hz}$  with 5 mV of amplitude and 0 V bias potential. Using a Z-view program, the fitted EIS parameters were obtained. The incident monochromatic photon-to-current conversion efficiency (IPCE) curves of DSSCs were carried out with a Zennium CIMPS-pcs2 (Zahner) system established with the tunable light source (TLS03). The photocurrent density-voltage characteristic of the DSSC was carried out using a CHI660D under an air mass (AM) of 1.5 G simulated sunlight using a solar simulator (CEL-S500, Beijing Ceaulight Science and Technology Ltd., China). The active cell area and the incident light intensity were  $0.30 \text{ cm}^2$  and  $100 \text{ mW cm}^{-2}$ , respectively. Impedance, photocurrent density, and open-circuit potential as a function of time for the DSSC held at 0 V forward bias was measured using the CHI660D system under AM1.5 simulated sun light. In which the frequency for the Impedance-Time test was set at 1000 Hz.

## 3. Results and discussion

Fig. 1a–d show the FESEM images of PtNFs based on different quantity of H<sub>2</sub>PtCl<sub>6</sub>·6H<sub>2</sub>O. PtNFs are established by many Pt nanoparticles interconnecting together with each other. The forming processes of this interconnecting nanostructure might be caused by two factors: first, the electrospinning PVP-H<sub>2</sub>PtCl<sub>6</sub> fibers are made up of cross structure during the collecting process on the aluminum foil; second, the water vapor step to form the PVP-H<sub>2</sub>PtCl<sub>6</sub> NF film adhered on the moisture FTO surface will bring about partial dissolution of the PVP-H<sub>2</sub>PtCl<sub>6</sub> fibers, therefore forming the interconnecting nanostructure after the sintering process. The electrospun mixture with low concentration of Pt source leads to form a small number of interconnected Pt nanoparticles (Fig. 1a). The more quantity of Pt source results in the easier forming three-dimensional (3D) nanofiber structure with more interconnected Pt nanoparticles (Fig. 1b–d). Fig. S1 shows FESEM image of the coralline-like TDPT CE with a great numbers of openings on FTO glass substrate, in which the openings could reduce its active surface area. Moreover, TEM images demonstrate that PtNFs have interconnecting morphology and Pt nanoparticles size of about 10–40 nm (Fig. 2). The composition of PtNFs was analyzed using a powder X-ray diffraction (XRD, BRUKER D8-ADVANCE) (Fig. S2). The three main XRD peaks—(111), (200), and (220)—are located for the PtNFs [18,25,26].

Fig. 3 compares CV of CE materials to evaluate the catalytic activity of electrodes. Two typical pairs of peaks in the iodine-based solution are observed for all the CEs, the relative negative pair is assigned to the redox reaction of  $\text{I}_3^- + 2\text{e}^- \leftrightarrow 3\text{I}^-$ , which is the effective redox reaction in the DSSC [3,27]. The positive pair is attributed to the redox reaction of  $3\text{I}_2 + 2\text{e}^- \leftrightarrow 2\text{I}_3^-$ , which has little effect on the performance of the DSSC. The peak current densities from the relative negative pair show an order of PtNF-c > PtNF-d > TDPT > PtNF-b > PtNF-a, indicating the same order of the catalytic activity for the CEs [28,29]. The peak-to-peak separation ( $E_{pp}$ ) is depended on the rate of electron transfer and the porosity of electrode [30]. The  $E_{pp}$  decreases in the order of TDPT (805 mV) > PtNF-a (734 mV) > PtNF-b (671 mV) > PtNF-d (644 mV) > PtNF-c (612 mV) (Table 1), indicating the PtNF-c CE shows the lowest overpotential loss. The largest electrocatalytic activity of the PtNF-c CE is probably due to its 3D interconnecting nanostructure, which results in abundant catalytic surfaces, large contact area with the electrolyte, and a large number of electronic transmission channels, as demonstrated in FESEM and TEM results.

Download English Version:

<https://daneshyari.com/en/article/1264680>

Download Persian Version:

<https://daneshyari.com/article/1264680>

[Daneshyari.com](https://daneshyari.com)