



Short Communication

High efficiency dye sensitized solar cell made by carbon derived from sucrose



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ABSTRACT

Carbon materials represent an attractive alternative to platinum based counter electrodes in DSSCs. Graphitic carbon produced from carbonization of sucrose has been used for making counter electrode for DSSCs. It was observed that increment in thickness of carbon counter electrode improves the performance of DSSCs. Electrochemical impedance spectroscopy, Tafel polarization and cyclic voltammetry measurements suggest that sucrose derived carbon based counter electrode shows fast reduction rate of I_3^- compare with platinum based counter electrode. DSSCs based on sucrose derived carbon exhibit high power conversion efficiency (PCE) of 9.96% and fill factor (FF) of 0.72 which is higher than PCE of 9.39% and FF of 0.67 of the cells with platinum (Pt) based counter electrode.

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1. Introduction

Solar energy conversion through use of photovoltaic cells is considered to be one of the most attractive option to address the increasing energy and environmental challenges globally. As a potential alternative to silicon-based solar cells, dye sensitized solar cells (DSSCs) have attracted a lot of attention in recent years due to ease of fabrication [1–9]. A typical DSSC consists of three components, a nanocrystalline titanium oxide (TiO_2) based electrode (photoanode), a counter electrode and an electrolyte usually containing a I^-/I_3^- redox couple confined between the two electrodes [10]. An efficient counter electrode should possess the desirable characteristics of good conductivity, highly catalytic activity, and excellent chemical stability. Counter electrode in DSSCs is usually made of platinum typically coated over a fluorine-doped tin oxide (FTO) conducting glass substrate. Pt has good conductivity and possesses an excellent catalytic activity for I_3^- reduction [11,12] but studies have shown that it degrades rapidly in contact with liquid electrolytes containing I^-/I_3^- . The high cost of Pt has caused many researchers to focus on alternative of Pt. Extensive research for suitable material to replace Pt counter electrode has been reported in the literature. Many materials such as carbon based materials, conducting polymers [13,14] inorganic compounds [15–17] and

metal chalcogenides [18–20] are used as counter electrode materials in DSSCs, but carbon based materials such as, carbon black [21], graphite [22], polyaniline/carbon composite [23], carbon nanotubes (CNT) [24], functionalized graphene [25], graphene based carbon nanotubes [26], electrospun carbon nanofibers [27,28] have been touted as a possible replacement for Pt due to their relatively low cost, electrical conductivity, high reactivity for triiodide reduction and corrosion resistance to towards I_2 [29]. Carbon based materials provide large effective surface areas due to their porous or rough morphology, leading to a large number of reduction sites and hence low charge transfer resistance. To obtain the porous or rough morphology of the carbon based counter electrode, the thickness of the counter electrode should be a few microns compared to few tens of nanometers for Pt [30]. Literature suggests that increment in thickness of the carbon based counter electrode improves the performance of the DSSCs, but the large thickness (>5 μm) of the counter electrode creates resistance through the bulk of the counter electrode and high contact resistance of carbon with FTO can outweigh the reduction in charge transfer resistance which can lead to overall increase in series resistance [31–33]. In the present study, we report the fabrication of dye sensitized solar cell using sucrose derived carbon for making counter electrode and effect of the counter electrode thickness on the performance of DSSCs.

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2. Experimental details

2.1. Materials

Sucrose was used as carbon precursor (Merck, Germany), Polyvinylpyrrolidone PVP (Sigma Aldrich, K-32) was used as surfactant for carbon produced from carbonization of sucrose and ethanol was used as solvent (Changshu Yangyuan Chemical, China AR Grade) for preparation of carbon based counter electrode. Fluorine doped tin oxide (FTO) glass substrates (TEC8, sheet resistance $8-9 \Omega \square^{-1}$ Pilkington), TiO₂ Paste (Dyesol), [RuL₂(NCS)₂]: 2TBA (L = 2,2'-bipyridyl-4,4'-dicarboxylic acid; TBA = tetra-n-butylammonium) (known as N719 dye) (Dyesol) were used for fabrication of cell. Electrolyte was prepared by using 1-Methyl-3-propylimidazolium iodide [PMII] ($\geq 98\%$ Aldrich) (0.60 M), iodine (LR, Thomas Baker) [I₂](0.03 M), guanidinium thiocyanate (0.10 M) and 4-tert-butylpyridine (0.50 M) [TBP] (96% Aldrich).

2.2. Synthesis of carbon material and fabrication of counter electrode

For the fabrication of counter electrode for DSSC, carbon was produced from carbonization of sucrose at 1400 °C in flowing argon as reported in our previous work [34]. Flake like carbon was obtained after carbonization of sucrose at high temperature in flowing argon. This flake like carbon was crushed in mortar pestle to make it finer. To prepare carbon slurry, initially PVP was added to ethanol and stirred for half an hour to make a homogeneous solution. PVP works as a surfactant for carbon materials [34]. After this, fine carbon was added to the PVP solution and this mixture was kept on pot mill for 48 h in order to achieve deagglomeration and thus achieve a homogeneous slurry. The carbon to PVP weight ratio was 8:1. Counter electrode was made by coating the slurry on FTO-glass substrate three times by doctor blade technique to achieve thickness of the carbon layer in the range of 4–5 μm. Scotch tape (3 M) was used to mask part of the substrate and coat on the desired area. Then the coated substrate was kept in a furnace at 450 °C for 1 h in flowing argon in order to burn out the PVP. For comparison with the carbon based counter electrode a sputter deposited platinum counter electrode was also prepared.

2.3. Fabrication of DSSC

Titania paste (Dyesol) was used to fabricate the photoanodes. The paste was coated onto the cleaned FTO-glass substrates and sintering was carried out at 450 °C for 1 h. The paste was coated on the FTO substrate three times to build thickness and sintering was also carried out after each coating (three times) at the same temperature and same time. Then the electrodes were cooled to 80 °C and dipped into a 0.3 mM solution of N719 dye in ethanol. After 24 h, the electrodes were taken out of the dye solution, rinsed with ethanol and dried. An electrolyte used in the DSSCs was prepared by mixing 1-Methyl-3-propylimidazolium iodide [PMII] ($\geq 98\%$ Aldrich) (0.60 M), iodine (LR, Thomas Baker) [I₂](0.03 M), guanidinium thiocyanate (0.10 M) and 4-tert-butylpyridine (0.50 M) [TBP] (96% Aldrich) in the mixture of acetonitrile and valeronitrile (volume ratio: 85:15). The solution was stirred by magnetic stirring for 30 min. A spacer (Surlyn) was placed around the titania layer and heated to bond to the FTO substrate. Electrolyte was filled in the gap defined by the spacer and the platinum or carbon coated FTO substrate (counter electrode) was placed over it and the assembly was held together by binder clips. The active area of each cell was 0.25 cm².

2.4. Characterization

Carbon and platinum films were characterized by FEG-SEM (JEOL, JSM-7600F). Cyclic voltammetry (CV) of counter electrodes were performed at a scan rate of 50 mV/s from –0.6 to +1.2 V using a three electrode assembly where the carbon or platinum coated FTO-glass, platinum wire and Ag/AgCl served as the working electrode, counter electrode and reference electrode respectively. The electrolyte solution was composed of 5 mM LiI, 0.5 mM iodine and 0.1 M lithium perchlorate in acetonitrile. The EIS spectra of DSSCs were measured under AM 1.5G simulated solar illumination at 100 mW cm⁻², at a frequency range of 100 kHz–0.1 Hz. The applied bias voltage and AC amplitude were set at open circuit voltage (V_{OC}) at 0 mV and 5 mV respectively. EIS spectra of DSSCs were analyzed using equivalent circuit models with Zsimpwin software. Thickness of the TiO₂ film and platinum films was measured by profilometer (Dektak XT profilometer, Icon Analytical Equipment Pvt. Ltd.). Photo-current-voltage (I–V) characteristics were obtained using a Keithley model 2420 source measure unit. The irradiation source was a 150 W xenon lamp on a Newport solar simulator with AM 1.5 G.

3. Results and discussion

3.1. Morphology characterization

Carbon produced from carbonization of sucrose was characterized and reported in our previous work [34]. Carbon produced from carbonization of sucrose was crystalline in nature as confirmed by Raman spectroscopy and FEG-TEM and has been reported in our previous work [34]. FEG-SEM was used to characterize the surface morphology of the counter electrode after heat treatment at 450 °C (1 h) in flowing argon as shown in Fig. 1. Fig. 1(a) shows the thickness of the counter electrode measured by FEG-SEM and was found to be 4.76 μm. Fig. 1(b) shows the morphology of the film. The morphology of the carbon film seems to be rough and film appears porous in nature. Rough morphology and porous nature of the carbon films can provide large effective surface area, which leads to a large number of reduction sites. The sputter platinum film appears dense in nature as shown in Fig. 1 (c&d). The dense platinum film provides the limited contact area with the electrolyte for charge transfer from counter electrode to the electrolyte. The thickness of the platinum film was measured by a profilometer and was around 40 nm. The thickness of the TiO₂ film was also measured by a profilometer and found to be around 10 μm.

3.2. Electrochemical properties

Cyclic voltammetry (C–V) measurements of platinum (Pt) and carbon based counter electrode were carried out in an acetonitrile solution containing 5 mM LiI (Lithium iodide) and 0.5 mM I₂ (Iodine) using 0.1 M LiClO₄ (Lithium perchlorate) as supporting electrolyte and Ag/AgCl as reference electrode (Fig. 2). Fig. 2 shows the Cyclic Voltammograms of platinum and carbon CE's which were obtained at a scan rate of 50 mV s⁻¹. Two pairs of oxidation and reduction peaks were observed for both counter electrodes. The oxidation–reduction peaks on the left are directly related to the reduction reaction of triiodide ions ($I_3^- + 2e^- = 3I^-$) and thus characterize catalytic capability and performance of corresponding counter electrode. Larger oxidation–reduction current density of carbon counter electrode indicated a faster reduction of triiodide ions. The oxidation–reduction peaks on the right are attributed to the redox reaction of $3I_2 + 2e^- = 2I_3^-$, which has almost no effect on cell performance [35]. It is noticeable that the characteristics of oxidation and reduction peaks assigned to redox reaction

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