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Dye-Sensitized Solar Cell Based Carbon Nanotube as Counter Electrode

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Abstract. The counter electrode using Carbon nanotube (CNT) has been successfully fabricated by the doctor blade method and their performances were investigated. We found that increasing mass of the CNT powder in binder increases electrocatalytic activity which this beneficial to conversion efficiency of the Dye-sensitized solar cell (DSSC). The photovoltaic performance of the DSSCs with 0.01, 0.02 and 0.04 gr of the CNT obtained overall conversion efficiencies of 0.32%, 0.74% and 0.91%, respectively. The results suggest that the CNT counter electrode has potential as alternative to the Pt free counter electrode for DSSC.

Keywords: CNT, counter electrode, DSSC, photovoltaic performance, electrocatalytic

INTRODUCTION

Silicon (Si) based solar cell are commonly used as a photovoltaic device due to currently more efficient. However, Si-based solar cell is known to be a very expensive solar cell. Another type of solar cell Dye-sensitized solar cell (DSSC) is the third generation solar cell which reported by O'Regan and Grätzelin 1991 has advantages over Si-based solar cell[1]. Recently, the DSSC has attracted considerable attention of researchers due to its high conversion efficiency, simple production process, low production cost and environment friendly [2-3]. Basically, the DSSC consists of a conducting glass coated with nanocrystalline titanium dioxide (TiO_2) anode, a ruthenium based sensitizer, an electrolyte solution containing iodide/ triiodide (I^-/I_3^-) redox couple and a counter electrode [4-6]. The counter electrode is one of the most important components in DSSC which it plays a crucial role in collecting electrons from the external circuit into electrolyte and reduces I_3^- to I^-, simultaneously [7-8]. Generally, Platinum (Pt) is the most widely used as CE at present due to its high electric conductivity and excellent electrocatalytic activity for the I_3^- reduction[9-10]. However, owing to its relatively expensive, rarity and corrosion in corrosive electrolyte, Pt has to be replaced by other low cost materials with high conductivity and high electrocatalytic activity, such as carbon materials [11], metal oxides [12-13], alloys [14] and conducting polymers [15].Carbon materials such as graphene, carbon black, hard carbon spherules, activated carbon and graphite have been studied as counter electrode owing to their corrosion resistance, high electrocatalytic activity and low cost [16-17].Recently, carbon nanotube (CNT) has attracted attention to replace platinum due to its high ratio area, good electric conductivity, heat as well as corrosion resistance and high electrocatalytic activity for triiodide reduction [18-19]. In the present work, CNT films with different mass were

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deposited onto FTO glasses using the doctor blade method and their performance of the DSSCs were investigated using AM 1.5G solar illumination and Keithley 2440 Source Meter.

METHOD

Material

Fluorine-doped tin oxide (FTO) substrates (Dyesol, Australia) were used in this research which cut with area of 2.5 x 2.5 cm^2. TiO_2 paste (20 nm, Dyesol, Australia) was used as photoanoda layer material. Electrolyte which consists of iodine and triiodie I^-/I_3^-(HPE, Dyesol, Australia) was used as the transport mechanism for the redox mediator from the TiO_2 electrode to the counter electrode and will be reduced to iodide. Ruthenium dye N719 (Dyesol, Australia) solution was used as photoactive element of the photovoltaic device. The CNT powder which prepared using spray pyrolysis method as previous reported by Subagio, et al., 2009 [20] was used as counter electrode layer material. Sealants (Dyesol, Australia) were used for sealing DSSC devices for longer term applications. Ethanol (Merck, Jerman), terpineol (Sigma Aldrich, USA) and ethylcellulose (Sigma Aldrich, USA) were used without purification.

Preparation of CNT based counter electrode

The CNT counter electrodes with different mass of 0.01, 0.02 and 0.04 gr of CNT powder are named as CNT 0.01, CNT 0.02 and CNT 0.04, respectively. To prepare the CNT counter electrode by the doctor blade method, 0.2 gr ethylcellulose was dissolved in 2 ml ethanol which stirred for 5 minutes, followed by mixing 0.8 gr terpineol into the solution used as binder. The CNT powder was dispersed in the binder with stirred for 5 minutes. FTO glass substrates were washed with 70% ethanol and aquades several times to remove impurities. The CNT paste was deposited onto the FTO substrate by using the doctor blade method with a thickness equal to the thickness of scotch tape. After drying at 80^{o}C for 5 minutes, the CNT counter electrode annealed at 450^{o}C for 1 hour.

Preparation and Assembly of DSSC

The FTO glass substrates were washed with 70% ethanol and pure water several times. After that, the working electrodes for DSSCs were prepared by the doctor blade method of TiO_2 paste onto the FTO substrate then sintered at 325, 375, 350 and 500^{o}C for 5, 5, 15 and 15 minutes, respectively. After cooling down to 80^{o}C, the working electrodes were immersed into ruthenium dye solution for 24 hours at room temperature. The area active of the working electrode and the counter electrode was fixed at 1 x 1 cm^2.

The sealant was sandwiched between the two electrodes and secured the electrode assembly using two binder clips on each side. The electrolyte was injected through hole from the counter electrode by using a micro pipet. Finally, the holes were sealed using silicon glue to prevent electrolyte evaporation.

Characterization

Surface morphology of the CNT counter electrodes was investigated by scanning electron microscope (SEM, JEOL JSM-6360 LA, Japan). Photocurrent–voltage (I-V) characteristics of the DSSCs were performed with a Keithley 2440 Source Meter and performed under simulated AM 1.5 G solar illumination using 100 mW/cm^2 (Abet technology inc.).

RESULT AND DISCUSSION

Figure 1 shows low-magnification and high-magnification SEM images of the CNT counter electrodes with various masses of CNT on FTO glass. The CNT counter electrodes are composed with various diameters of the CNT on the order of 70 to 115 nm. Additionally, the CNTs are randomly oriented, agglomerated and woven into each other. The density of the CNT was increased owing to it has more CNT in binder which is beneficial to the electron transfer from the counter electrode to electrolyte interface [21].The one dimensional structure of the CNTs helps them in making a good electrical conductivity [22,23].

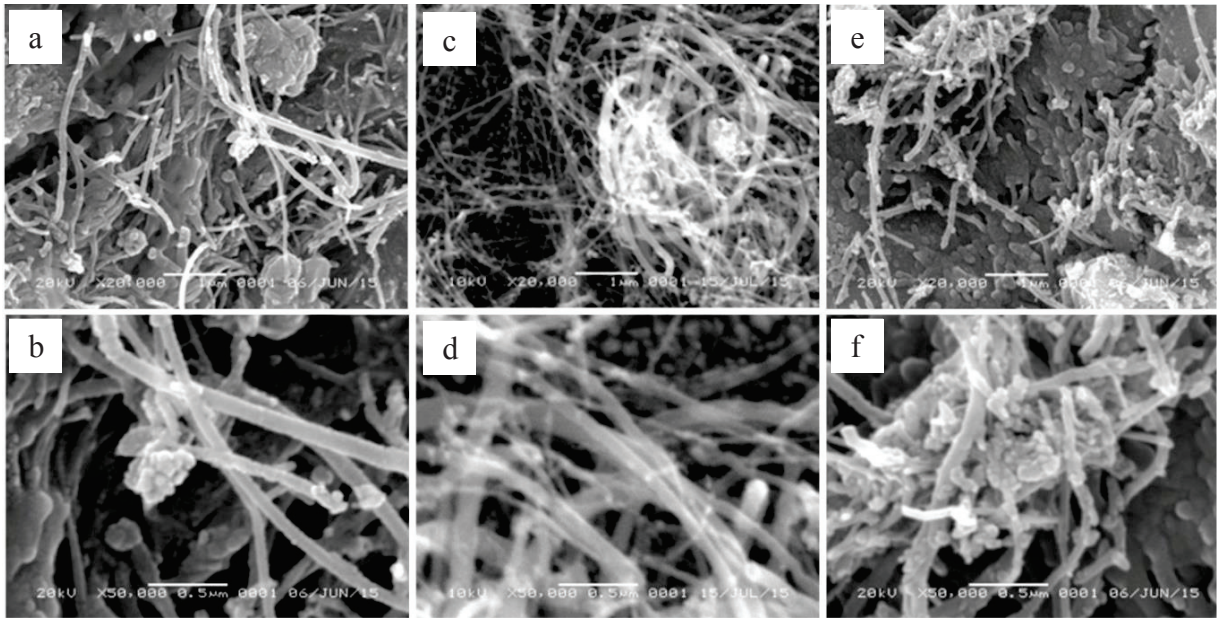

FIGURE 1.SEM images low-magnification (top) and high- magnification (bottom) of prepared CNT layers deposited on FTO glasses with various masses of the CNT (a,b) 0.01 (c,d) 0.02 and (e,f) 0.04 gr

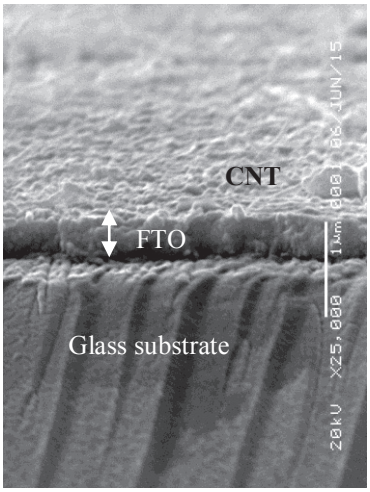

FIGURE 2. Cross-sectional SEM image of prepared CNT layers deposited on FTO glass

Figure 2 shows a representative cross-sectional SEM images of the CNT layer on FTO substrates with a thickness of about 0.5 µm. The characteristics of the counter electrode should be related to the electrocatalytic activity.

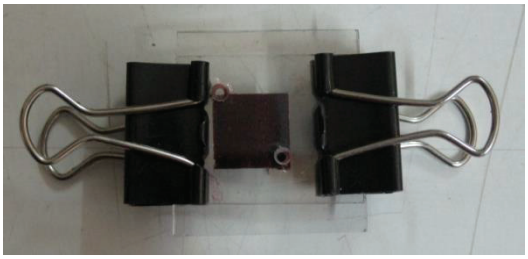

FIGURE 3. The DSSC prototype using CNT of 0.04 gr as counter electrode with the dimension of active area of 1 cm in length and 1 cm in width

Figure 3 shows the prototype of DSSC which used CNT of 0.04 gr as a counter electrode. The dimension of active area is 1 cm in length and 1 cm in width. Figure 4 shows the current density-voltage (J-V) curves of the DSSC fabricated with various masses of the CNT were performed under simulated AM 1.5 G solar illumination using 100 mW/cm^2.

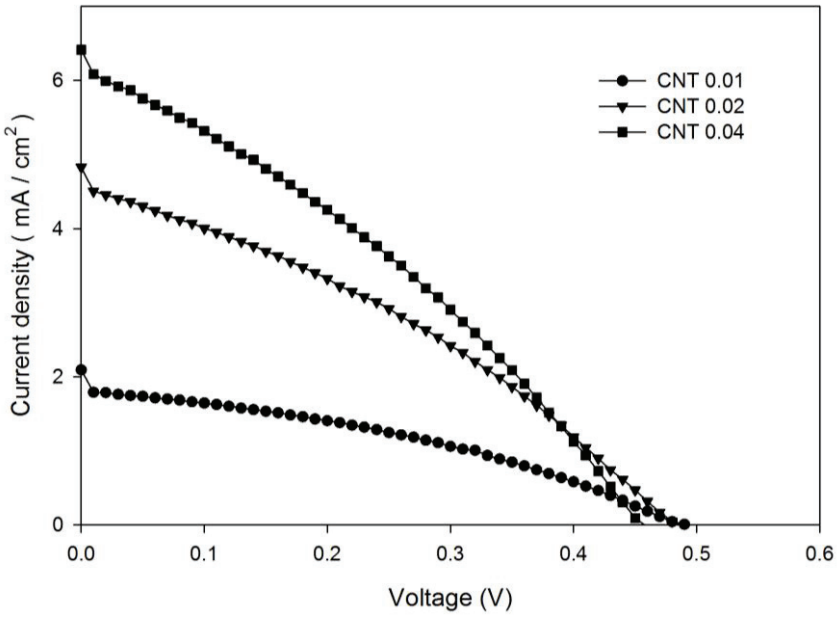

FIGURE 4. J-V curves of DSSCs with 0.01, 0.02 and 0.04 gr of the CNT counter electrodes

The fill factor (FF) can be calculated using the following equation :

$$FF = \frac{V_{\max} \times J_{\max}}{V_{oc} \times J_{sc}} \tag{1}$$

Following the fill factor, the next step is to calculate the efficiency of the DSSC using equation (2) :

$$\eta = \frac{FF \times J_{sc} \times V_{oc}}{P_{in}} \tag{2}$$

TABLE 1. Photovoltaic properties of DSSCs with various mass of CNT as counter electrode.

Sample name	J_{sc} (mA/cm^2)	V_{oc} (V)	FF (%)	η (%)
CNT 0.01	2.093	0.49	31	0.32
CNT 0.02	4.829	0.48	32	0.74
CNT 0.04	6.413	0.45	32	0.91

The photovoltaic properties, short circuit current density (J_{sc}), open circuit voltage (V_{oc}), FF and η are listed in Table 1. Figure 4 and Table 1 show that the DSSC with highest mass of the CNT has more efficiency than the other DSSCs. Photovoltaic performance of DSSCs with 0.01, 0.02 and 0.04 gr of CNT obtained overall conversion efficiencies (η) of 0.32%, 0.74% and 0.91%, respectively. When the mass of CNT counter electrodes increases cause to J_{sc}, FF and η increase, which should be related to electrocatalytic activity of different mass of the CNT counter electrodes [24, 25, 26].

CONCLUSION

In conclusion, counter electrodes with various masses of the CNT prepared by the doctor blade method have been investigated. By the optimization mass of CNT, efficiency of the DSSC reaches 0.91%. This value is lower than Pt counter electrode due to low FF and J_{sc}. However, considering low cost and high electrocatalytic activity the CNT counter electrode, it should be a competitive alternative to the Pt free counter electrode for DSSC.

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