

## Highly Efficient Dye-Sensitized Solar Cells based on Carbon Nanofibers Counter Electrodes

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**Abstract.** Carbon nanofibers (CNFs) exhibiting a large surface area and structural stability can provide high electrochemical performance in dye-sensitized solar cells (DSSCs). The effect of CNFs layer thickness on the performance of the DSSCs was researched by cyclic voltammetry (CV), and Tafel polarization measurements. The highest power-conversion efficiency (PCE) of 6.07% was achieved for the DSSC fabricated with CNFs CE at the optimized film thickness of 13  $\mu\text{m}$ , a value similar to that achieved with Pt CE (6.2%).

### Introduction

Dye-sensitized solar cells (DSSCs) have gained intense attention as one of hopeful substitute to traditional silicon-based cells ever since Grätzel's group first introduced it, because of their remarkable plasticity, low-cost, simple fabrication process, environmental friendliness, and relatively high power conversion efficiency [1, 2]. To date, based on new type cobalt electrolyte, the highest power-conversion efficiency (PCE) of DSSCs have reached 13%, achieved in Grätzel's group [3]. A typical DSSC is constructed with a dye-sensitized thin film of  $\text{TiO}_2$  as the photoanode, an electrolyte and a counter electrode (CE) [4, 5]. Although the platinum (Pt) is the most popularly selected as counter electrode in DSSCs due to its excellent electrocatalytic activity, superior electrical conductivity, efficient electron transport and high stability, Pt is high cost (one of the most expensive materials available) and easily corroded in the electrolyte solution hinder its widespread application [6-10]. Therefore, it is required to explore cost-effective functional electrode materials with high catalytic activity to be utilized as Pt alternatives for DSSCs counter electrodes.

Heretofore, several kinds of carbonaceous materials, such as carbon black, graphite, carbon nanotubes, and activated carbon, have been investigated as substitutes for expensive Pt [11-14]. Murakami et al. found that the PCE of DSSCs was greatly impact on the thickness of the carbon layer [15]. Carbon nanofibers (CNFs) are versatile material exhibiting excellent conductivities for electricity and heat, structural stability and immense specific surface area, which has been applied widely in electrochemical energy devices [16].

In view of these facts mentioned above, optimization of the performance of DSSCs based on cobalt electrolyte and CNFs with different thicknesses were performed, including a study of the electrochemical catalytic activity, with the purpose of exploring the effects of CNFs film thickness on the performance of the DSSCs. It is notable revealing that the thickness of 13  $\mu\text{m}$  was sufficient to achieve a high-performance CNFs CE.

## Experimental Studies

### Sample Preparation

Polyacrylonitrile (PAN, 2 g) was dissolved in DMF (18 g) and magnetically stirred for 12 h at room temperature. The resulting solution was electrospun into nanofibers by applying electrical potential, collecting distance, flow rate and humidity of 15 kV, 25 cm, 1 ml/h and 35%, respectively. The nanofiber felt was collected by a aluminium foil for 10 h. The as-spun PAN felt was preoxidized at 260 °C (air, 1 °C/min, 1 h) and carbonized at 1000 °C, and the CNFs were obtained.

The CEs were prepared by a spray-coating technique, the method as follow: CNFs (70 mg, 100 mg 120 mg) were added in isopropanol (7 ml, 10 ml, 12 ml) with ball-milling dispersed for 4 h and obtained suspension. After TiO<sub>2</sub> (35 mg 50 mg, 60mg) had been doppe in suspension, the mixed solution was ultrasonicated for 30 minutes. Then the prepared mixed solution was sprayed on FTO glass and sintered in a tube furnace under N<sub>2</sub> atmosphere at 500°C for 30 min, and the CNFs CE was prepared. The CNF film thicknesses of A, B, and C are 9, 13, and 18 μm, respectively.

The afforded TiO<sub>2</sub> photoanodes were further sensitized by immersing them into the YD2-o-C8 dye for 24 h. Then the DSSC was fabricated by sandwiching redox electrolyte between dye-sensitized TiO<sub>2</sub> photoanode and FTO supported CNFs CEs. The redox electrolyte composed of 0.25 M Co (II) tris (bipyridyl) tetracyanoborate, 0.05 M Co(III) tris (bipyridyl) tetracyanoborate, 0.5 M TBP and 0.1 M LiTFSI in acetonitrile.

### Characterization

The surface features of CNFs were characterized by using a scanning electron microscopy (SEM). The cyclic voltammetry (CV) and Tafel polarization measurements were carried out in an electrochemical workstation system. The current density–voltage (*J*–*V*) characteristics of the DSSCs were measured in simulated AM 1.5 illumination.

## Results and Discussion

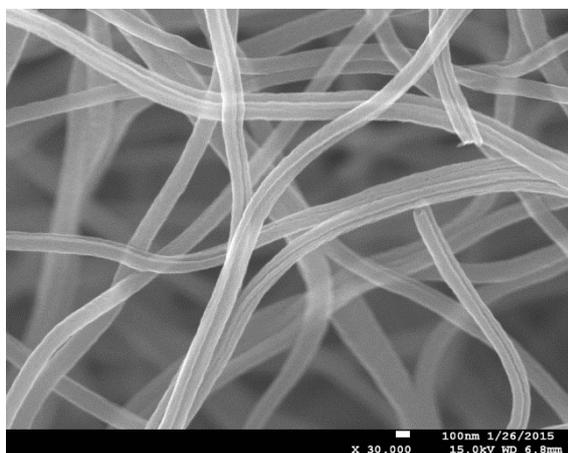


Fig. 1 SEM image of SCF

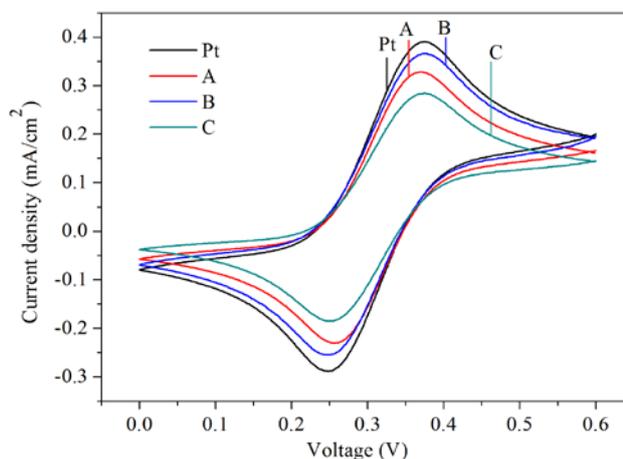


Fig. 2 CV images of four different CEs

The surface morphology of CNFs was examined by field-emission scanning electron microscope (SEM). Fig. 1 shows the SEM image of CNFs, showing that the nanofibers showed smooth surface with diameter of approximately 200-250 nm.

In the cyclic voltammogram (CV), as shown in Fig. 2, the peak positions of the CNFs CEs are similar to those of the Pt CE. The peak current densities with an order of B > A > C prove that the CEs could display the consistent catalytic activity in the same order. The larger cathodic peak current density of B (0.365 mA/cm<sup>2</sup>) is in close proximity to Pt (0.39 mA/cm<sup>2</sup>). In addition, the peak-to-peak separation (*E*<sub>pp</sub>) of A, B, C and Pt are extremely approximate. Overall, the CNF of film thicknesses as 13 μm showed superior catalytic activity.

Tafel polarization was carried out and showed in Fig. 3 by performing with the symmetrical cells to prove the interfacial charge-transfer capabilities at the CE/electrolyte interface. A similar slope was obtained for the B CE and Pt CE which is clearly higher than that of the A and C CEs, indicating that the catalytic activity of B CE closes to Pt CE, and higher than A and C CEs.

Fig. 4 shows the photocurrent density–voltage ( $J$ - $V$ ) curves of the DSSCs with Pt and CNF layers of different thicknesses as CEs with detailed photovoltaic parameters listed in Table 1. The DSSC using B as the CE exhibited a high PCE of 6.07%, reaching the photovoltaic performance of the DSSC with a Pt CE (6.2%). The result demonstrates that CNFs show high catalytic activity in DSSC. When the CNF layer was thicker than the optimization film thicknesses of 13  $\mu\text{m}$ , the PCE began to decrease due to the fact that too thick film may crack slightly because of CNFs film body stress.

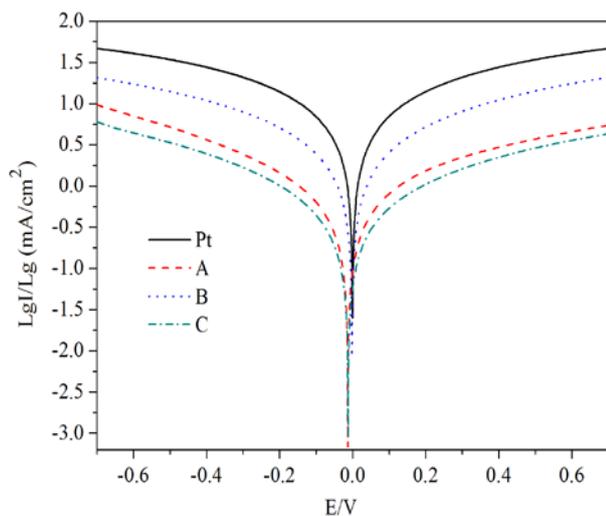


Fig. 3 Tafel curves of four different CEs

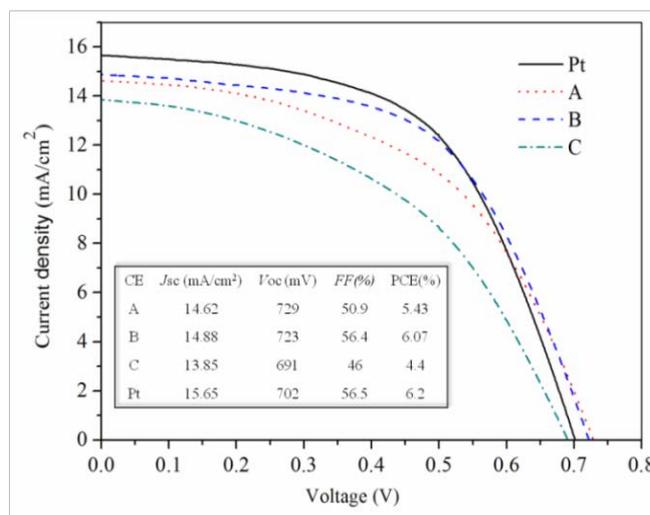


Fig 4.  $J$ - $V$  curves of the DSSCs using different CEs

## Conclusions

We brought in a new type cobalt electrolyte and researched the influence of the thickness of the CNF CE about the performance based on the DSSC. As a result, we found that the cell obtained a high PCE of 6.07% when the film thickness was 13  $\mu\text{m}$ . Furthermore, this study has revealed CNF to be an efficiently catalyst that can be a substitutes for expensive Pt. CNFs exhibit remarkable performance as a CE for DSSCs with the advantages of large surface area and low cost.

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