PHOTOVOLTAIC PERFORMANCE OF DYE-SENSITIZED SOLAR CELL INCORPORATED WIRE ELECTRODE

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1 Introduction

As the remainder of petroleum decreased, the interest about alternative energy resources has increased. Among the alternative candidates, solar cells are in the limelight because these offer inexhaustible resources and low environmental impact [1]. Nowadays, dye-sensitized solar cell (DSSC) is concerned as a third generation photovoltaic cell to replace inorganic solid-state solar cells thanks to their low cost, high conversion efficiency and simple fabrication process [2,3]. However, application areas of conventional DSSCs are limited due to the rigidness of the transparent conducting oxide (TCO) coated glass substrates. To overcome this drawback, flexible DSSCs based on polymer substrates become an object of attention but their efficiencies are lower than typical DSSCs due to low thermal resistance of polymer substrates. On the other hand, Fibrous flexible DSSCs based on metal wires are able to achieve both high efficiency and flexibility thanks to good interconnection of TiO_2 nanoparticles through the sintering process at high temperature. Recently, several studies have reported fibrous flexible DSSCs to extend their application areas [4,5].

In this study, we fabricated the fibrous flexible DSSCs having different TiO_2 film thicknesses and characterized their photovoltaic properties. In addition, we fabricated DSSCs using Zylon® wrapped around metal wire. It is appropriate material to investigate the potential of application to smart textiles because it possesses outstanding mechanical properties, chemical stability, and superior thermal resistance [6].

2 Experimental

2.1 Preparation of metal electrodes

Two titanium (Ti) wires (Sigma-Aldrich, Ø = 127 μm) were twisted for the working electrode (Ø = 254 μm) in order to improve the adsorption of dye and the handling of wires during cell fabrication process. The twisted Ti wires were washed with acetone and uniformly coated with a commercial TiO_2 paste (13nm anatase particles, Solaronix) using a nano dip coater (MD-0408-S2, SDI Co., Ltd.). The thickness of the TiO_2 film was controlled by the number of 10 min thermal treatment at 120 ℃. The TiO_2 coated Ti wires were sintered in a furnace at 450 ℃ for 30 min and then immersed in an ethanol solution containing 0.3 mM of N719 dye for 24 h. A platinum (Pt) wire (Sigma-Aldrich, Ø = 127 μm) having a twisted structure was used as the counter electrode (Ø = 254 μm).

2.2 Solar cell assembly

The dye-adsorbed TiO_2 film coated Ti wires and the Pt wires were inserted to poly vinyl chloride (PVC) tube which has a inner diameter of 3 mm. Polymer tubes were sealed with parafilm and epoxy resin and then filled with an electrolyte composed of 0.5 M LiI, 0.05 M I_2 and 0.5 M 4-tertbutylpyridine in acetonitrile. A schematic of the fibrous DSSC is presented in Fig. 1. The total length and active area of the cell was 2 cm and 0.0254 cm^2, respectively.

2.3 Application of Zylon® in working electrodes

We wrapped Ti wire around Zylon® (Ti/Zylon®) and then TiO_2 paste was coated on it by dip coater. To examine the possibility of Zylon® as an electrode substrate, we sintered TiO_2 coated Ti/Zylon® at 450 ℃. The TiO_2 coated Ti/Zylon® was applied as two types. The first type was inserted into the PVC tube and the second one was not. A schematic of the DSSC used Zylon® as an electrode is presented in Fig. 2.

2.4 Characterization

Surface morphology of the TiO_2 coated Ti wire and the thickness of the TiO_2 film were observed by using scanning electron microscopy (SEM). The short-circuit current density (J_{sc}) and open-circuit voltage (V_{oc}) were measured using a solar cell QE measurement system (K3000(IV), McScience) under AM 1.5 illumination 100 mW/cm^2.

3 Results and discussion

3.1 The effects of thickness of TiO_2 film

As the number of thermal treatment increased, the thickness of the TiO_2 film increased. The thicknesses of the TiO_2 films correspond to the number of thermal treatment were measured about 0.8 µm (0 trmts), 1.3 µm (2 trmts), 2.5 µm (7 trmts), 3.6 µm (11 trmts), 6.8 µm (20 trmts), and 9.5 µm (31 trmts). As shown in Fig. 3, some cracks were formed around the intersection between the two Ti wires due to the twisting stress and grew gradually with increase of thickness of TiO_2 layer. The I-V curves of DSSCs fabricated with different thicknesses of TiO_2 film are shown in Fig. 4 and their photovoltaic characteristics are shown in Fig. 5. The V_{oc} decreased with increase in TiO_2 film thickness. As the thickness of TiO_2 film increased, charge recombination between the electrons injected into the conduction band of TiO_2 and the triiodide (I_3^-) increased. V_{oc} is determined by energy difference between conduction band of TiO_2 and redox potential of the electrolyte. Thus, decline of conduction band of TiO_2 due to the charge recombination reduces V_{oc}. The J_{sc} increased as TiO_2 film thickness increased due to the increased dye adsorption. However, when the thickness of the TiO_2 film further increased, the J_{sc} decreased significantly because charge recombination became dominant factor. The fill factor (FF) decreased with increase of TiO_2 film thickness and the conversion efficiency (η) is changed remarkably according to the thickness of the TiO_2 film. The photovoltaic parameters of DSSCs are summarized in Table 1. The fibrous flexible DSSC with 6.8 µm TiO_2 film thickness showed best performance, giving a J_{sc} of 3.38 mA/cm^2, a V_{oc} of 0.63 V and a FF of 0.69.

3.2 Application of Zylon®

From Fig. 6, we can see the possibility of application of Zylon® as an electrode. The first type showed better photovoltaic performance than second one. The second type has lower stability and efficiency than first one because liquid electrolyte evaporated easily.

4 Conclusions

Fibrous flexible DSSCs based on metal wires were fabricated to extend application areas. In order to determine the optimal TiO_2 thickness of fiber-type cell, thickness of TiO_2 film is controlled by number of thermal treatment. As the thickness of TiO_2 film increased from 0.8 µm to 6.8 µm, efficiency of DSSC increased from 0.45% to 1.48%. However, cell efficiency decreased dramatically beyond the TiO_2 film thickness of 9.5 µm. Application of Zylon® to fibrous flexible DSSCs was also studied. Although the efficiency of cell applied Zylon® was still low, possibility of Zylon® as an electrode could be verified. According to the case of the second type, Zylon® applied cell should be sealed or change the type of electrolyte to improve cell stability.

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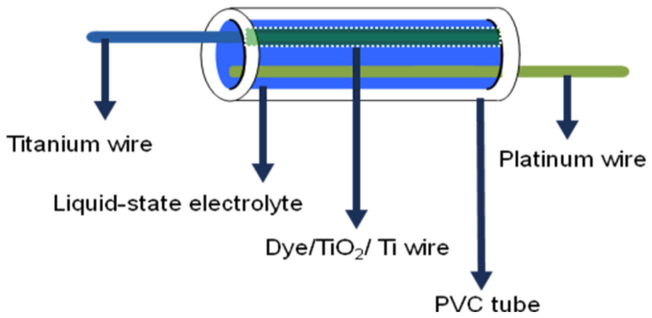

Fig. 1 A schematic of the fibrous flexible DSSC based on metal wire

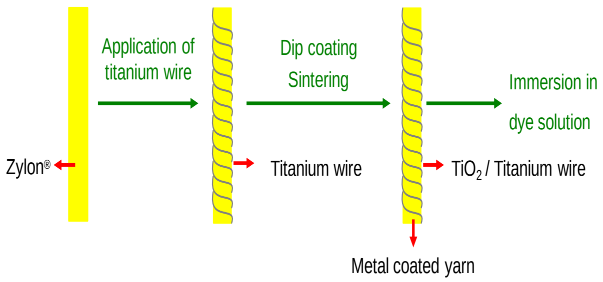

Fig. 2 A schematic of the cell applied Zylon® as an electrode

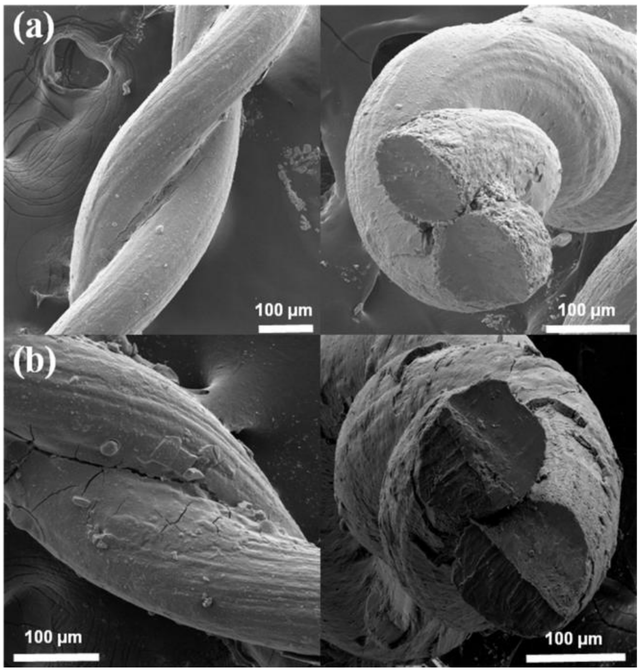

Fig. 3 SEM images of Ti wire coated with various TiO_2 film thicknesses; (a) TiO_2 layer thickness - 0.8 μm and (b) TiO_2 layer thickness - 9.5 μm.

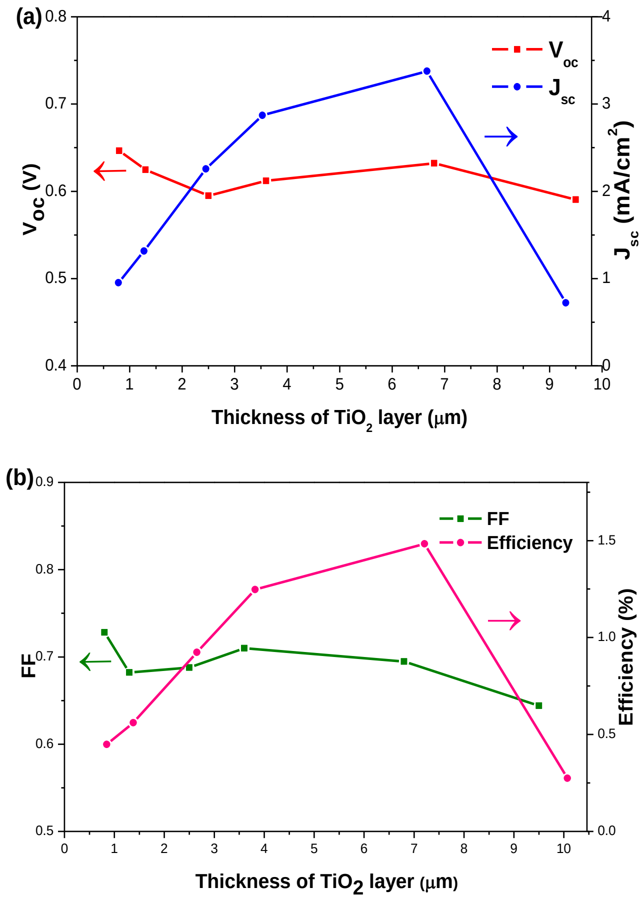

Fig. 5 Photovoltaic characteristics of fibrous DSSCs fabricated with various thickness of TiO_2 film; (a) V_{oc} and J_{sc} and (b) FF and Efficiency

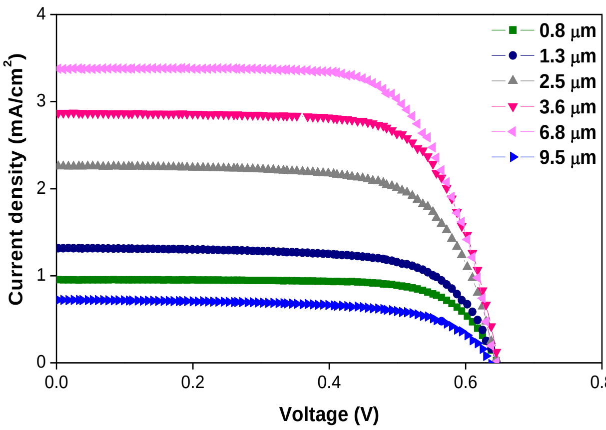

Fig. 4 I-V curves of fibrous DSSCs fabricated with various thickness of TiO_2 film

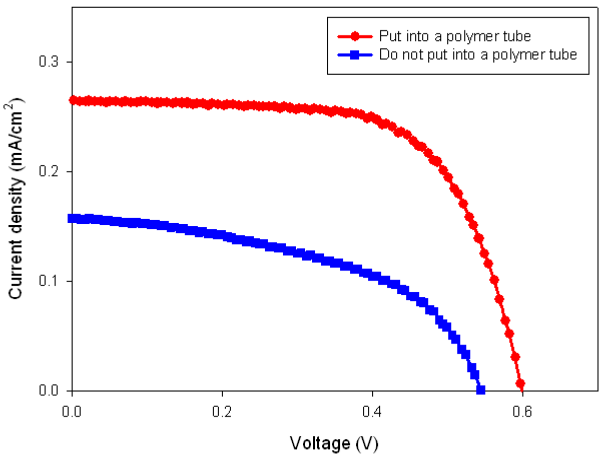

Fig. 6 I-V curves of the DSSCs fabricated with Zylon®

Table 1. Photovoltaic parameters of fibrous DSSSs with various thicknesses of TiO_2

TiO_2 layer Thickness (μm)	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	η (%)
0.8	0.95	0.65	0.73	0.45
1.3	1.32	0.62	0.68	0.56
2.5	2.26	0.59	0.69	0.92
3.6	2.87	0.61	0.71	1.25
6.8	3.37	0.63	0.69	1.48
9.5	0.72	0.59	0.64	0.27

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