Design and Analysis of Arrayed Flexible Dye-sensitized Solar Cell

Jui-En Hu [1], Po-Hao Shih[1], Shu-Huei Huang[2], Jung-Chuan Chou[1,*],
Shu-Ying Yang [3], Yi-Hung Liao[4]
[1] Graduate School of Electronic and Optoelectronic Engineering, National Yunlin University of Science and Technology, Yunlin
*e-mail: choujc@yuntech.edu.tw
e-mail: M10013305@yuntech.edu.tw, g9918734@yuntech.edu.tw
[2] Department of Electronic Engineering, National Yunlin University of Science and Technology, Yunlin
e-mail: u9813111@yuntech.edu.tw
[3] Department of Information Management, Fortune Institute of Technology, Kaohsiung
e-mail: allison@center.fotech.edu.tw
[4] Department of Information Management, TransWorld University, Yunlin
e-mail: liaoih@twu.edu.tw
NSC Project：NSC 100-2221-E-268-004, NSC 101-2221-E-224-046

Abstract

In this article, arrayed flexible dye-sensitized solar cell (FDSSC) modules are designed as the parallel grid, parallel-interconnect and sandwich structure. The active area of single strip-shaped TiO_2 layer of working electrode is 5 × 1 cm^2 and the total active area of two-strips shaped TiO_2 layers are 2 × 5 cm^2. Arrayed flexible dye-sensitized solar cell module was investigated by electrochemical impedance spectroscopy (EIS), which analyzed the redox reaction at the hereto-junction in FDSSC.

In this study, the parameters of open circuit voltage (V_{oc}), short-circuit current density (J_{sc}) and conversion efficiency (η) of arrayed flexible dye-sensitized solar cell, which are 0.64 V, 0.64 × 10^{-2} mA/cm^2 and 2.17 × 10^{-1} %, respectively.

Keywords arrayed flexible dye-sensitized solar cell, parallel-interconnect, working electrode, electrochemical impedance spectroscopy.

1. Introduction

Solar cells are very effective solution for solving the problems of the depletion of fossil fuels and the emission of greenhouse gases [1]. Various solar cells, such as dye-sensitized solar cells (DSSCs) [1], a-Si thin film solar cells [2], organic solar cells [3], and quantum dot solar cells [4] have been researched. Compared with silicon solar cell, glass-based DSSC has been extensively studied due to its low cost, easy fabrication and high transmittance [5, 6].

The DSSC has been developed by Grätzel in 1991 as a substitute for the Si crystalline solar cell, since it has a theoretical efficiency of 33% and is more effective than the latter under low intensities of illumination [7-9]. A parallel connected DSSC modules of 10×10 cm^2 area has been demonstrated by Späth et al. [10], they utilized a polymer-based hot melt foil to protect current collecting silver grid.

The cell size and conductivity of substrate were influenced by the internal resistance in dye-sensitized solar cell. The fill factor and the conversion efficiency of dye-sensitized solar cell were influenced by above mention, too.

For above reason, the small size cells are normally used to obtain high conversion efficiency on non-industrial study, but the conversion efficiency of 0.3% was very low when 100 mm × 100 mm large cell module was fabricated with a 10 Ω/□ fluorine doped SnO_2 (FTO) substrate normally used for mini size cells [11].

For large sizes of the DSSCs, three different modules designs have been considered: the parallel grids module, series interconnect Z and W modules designs, monolithic series interconnect [12, 13].

Every design of arrayed working electrode has its superiority and defects, were proved in the past researches. The first parallel module design was tested in 1995, utilized conductive fingers protected by polymer or ceramic glazes to collect current as a conductive current collector layer in a 100 mm × 100 mm glass substrate module, the pinhole and leakage at the interface overcoated with the substrate, this design of dye-sensitized solar cell module has been suspended until 2001. Although the parallel modules need to be connected to realize the designed voltage, and high current in one module will lead to low fill factor, however, high active area, high short-circuit current density and high efficiency are the advantages of this design [12].

In this study, the working electrodes of arrayed flexible dye-sensitized solar cell module were connected with parallel type, which can enhance the short-circuit current density and conversion efficiency of arrayed flexible dye-sensitized solar cell module.

2. Experimental

2.1 Preparation of Arrayed Flexible Dye-sensitized Solar Cell

2.1.1 Materials

Titanium dioxide (TiO_2) powder and Ruthenium-535 (N3) were purchased from UniRegion Bio-Tech, Taiwan. The ethanol was purchased from Katayama Chemical, Japan. The Triton X-100 was purchased from PRS Panreac, Spain. The Acetylacetone (AcAc), lithium iodide (LiI) and 4-Tert-Butylpyridine (TBP) were purchased from Sigma-Aldrich, United States. The iodine (I_2) was purchased from Riedel-deHaen, United States. The 1-propyl-2,3-dimethylimidazolium iodide (DMPII) was purchased from Tokyo Chemical, Japan.

2.1.2 Preparation of solvent, paste and fabrication of DSSC

The TiO_2 paste consists of 3g TiO_2 powder (P25), 3.5 mL deionized (D. I.) water, 0.1 mL acetylacetone and 0.3 mL Triton X-100 [14, 15]. The TiO_2 working electrodes with the active area of 5 cm^2, which were designed as parallel types of strip-shaped TiO_2 thin films, were fabricated on ITO-PET substrates [16] by screen-printing technique, as shown in Fig. 1.

The working electrode was baked at 100 °C for 10 minutes, and then immersed in an absolute ethanol solution of 3×10^{-4} M N3 dye at 75 °C for 1 hour [17]. Platinum was fabricated on ITO-PET substrate by sputtering for 90 seconds and is generally regarded as the counter electrode [18]. The liquid-state electrolyte consists of 0.6 M DMPII, 0.5 M LiI, 0.05 M I_2, and 0.5 M TBP in 15 mL MPN. Finally, FDSSCs were sealed by Surlyn.

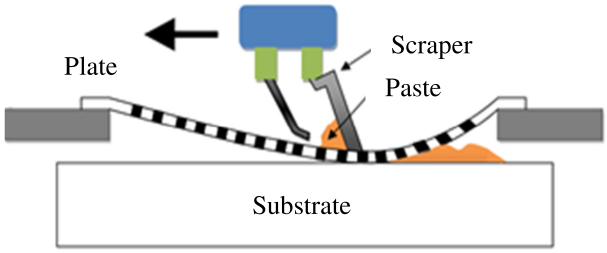

Fig. 1 Fabricated TiO_2 thin film of working electrode by screen printing technique.

2.1.3 Design and measurement of arrayed flexible dye-sensitized solar cell

First, the 2 cm × 5 cm two strips-shaped TiO_2 thin films were fabricated on substrate with parallel types. The FDSSC is based on a sandwich structure [19], which consists of working electrode, electrolyte and counter electrode, as shown in Fig. 2. The novel structure of parallel connects for arrayed flexible dye-sensitized solar cell is designed as shown in Fig. 3 and the external circuit direction is shown in Fig. 4.

The short-circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and conversion efficiency (η) of FDSSC were measured by Keithley 2400 digital source meter under one sun illumination (AM 1.5G, 100mW/cm^2). Electrochemical impedance spectroscopy (EIS) is performed with a frequency response analyzer (BioLogic SP-150, France). The frequency range was scanned from 50 mHz to 1 MHz. The negative applied bias voltage was 0.7 V, and ac voltage was set 10 mV as open-circuit voltage of the DSSC, respectively [20, 21].

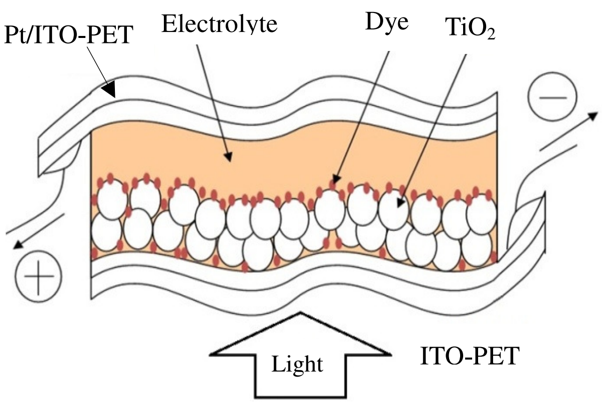

Fig. 2 Schematic diagram of flexible dye-sensitized solar cell.

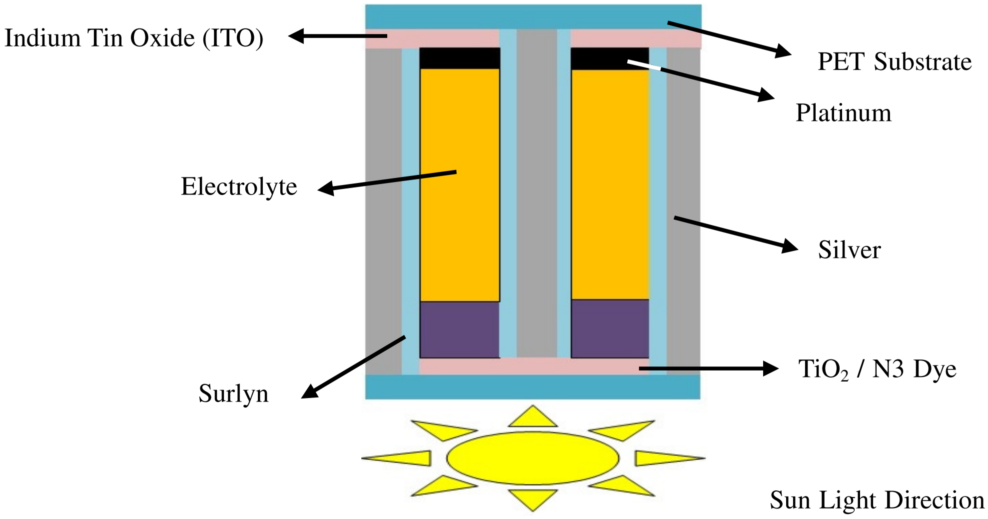

Fig. 3 Schematic diagram of novel arrayed structure in arrayed flexible dye-sensitized solar cell.

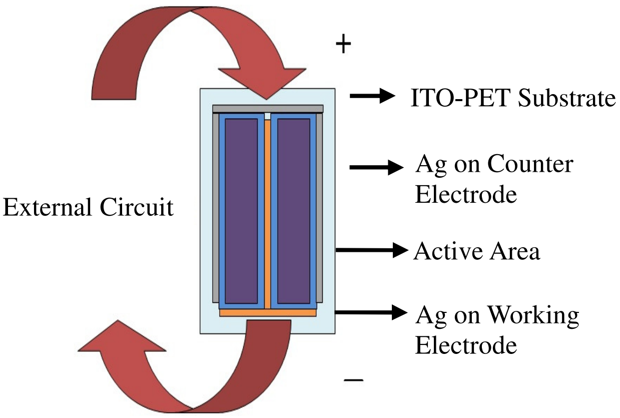

Fig. 4 Schematic diagram of external circuit direction for novel arrayed flexible dye-sensitized solar cell.

3. Results and discussion

Figure 5 shows the J-V curves of working electrode which were single strip-shaped TiO_2 layer and two strips-shaped TiO_2 layers of arrayed flexible dye-sensitized solar cells, and the measured parameters are shown in Table 1. And the Nyquist plot shows the transmission resistance in arrayed flexible dye-sensitized solar cell is very low, as shown in Fig. 6.

According to the experiment, compared with the single strip-shaped TiO_2 layer and two strips-shaped TiO_2 layers of flexible dye-sensitized solar cells, the important point of improving method for arrayed flexible dye-sensitized solar cells means the electrons are generated from TiO_2 adsorption layer and transmit from working electrode (WE) to counter electrode (CE) along the current collector conductive layer, the current collector conductive layer which is fabricated by silver paste.

The conductive layer of the silver current collector is a short cut for electrons to transmit and reduces the electron transmission losses for two strips-shaped TiO_2 layers, so the silver current collector would cause the short-circuit current density and conversion efficiency higher.

Therefore, the electrons transmitted in arrayed flexible dye-sensitized solar cell could be improved by fabricating the silver current collector. The impedance of TiO_2/electrolyte in FDSSC is about 9-24 Ω. Thus, the smaller impedance can improve the electron transmission for FDSSC. The single strip-shaped TiO_2 layer of working electrode which measured the parameters short-circuit current density and conversion efficiency were 0.47×10^{-3} mA/cm^2 and 4.56×10^{-2} %. And the two strips-shaped TiO_2 layers of working electrode which measured the parameters short-circuit current density and conversion efficiency were 0.64×10^{-3} mA/cm^2 and 2.17×10^{-1} %.

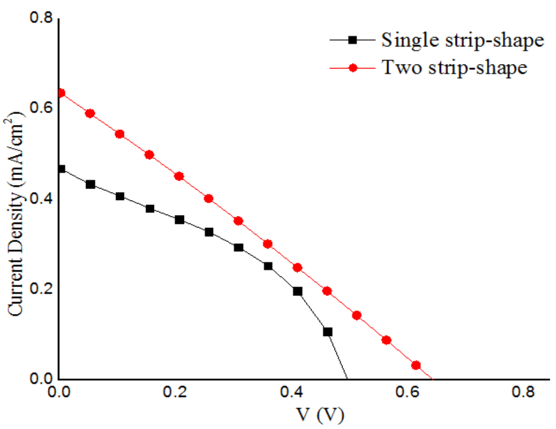

Fig. 5 J-V curves of working electrode which were single and two strips-shaped TiO_2 layers of arrayed flexible dye-sensitized solar cells.

Table 1 Photovoltaic parameters of the single strip-shaped TiO_2 layer and two strips-shaped TiO_2 layers of arrayed flexible dye-sensitized solar cells.

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	η (%)
Single	0.50	0.47×10^{-3}	39.14	4.56×10^{-2}
Two	0.64	0.64×10^{-2}	26.45	2.17×10^{-1}

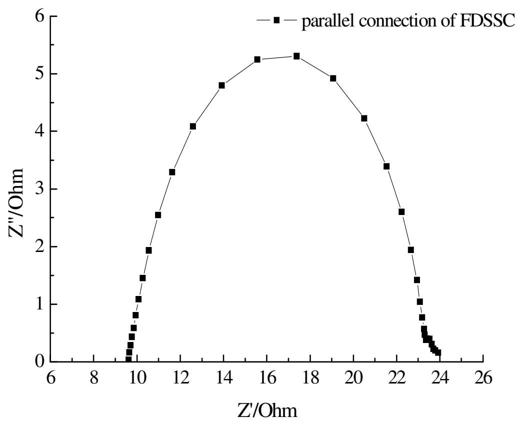

Fig. 6 Experimental result of two strips-shaped TiO_2 layers of arrayed flexible dye-sensitized solar cell.

4. Conclusions

In this article, the parallel connected type of arrayed flexible dye-sensitized solar cell was investigated to provide an improved method for enhancing the current density and conversion efficiency. And this experiment has other method to enhance the parameters of arrayed flexible dye-sensitized solar cell, the silver current collector which is a short cut for electrons to transmit, it also can reduce the electron transmission losses for two strips-shaped TiO_2 layers, the silver current collector would cause the better characteristic parameters of arrayed flexible dye-sensitized solar cell.

According to this experiment, the two strips-shaped TiO_2 layers of working electrode has the better parameters, where the short circuit current density (J_{sc}) and conversion efficiency (η) can reach to 0.64×10^{-3} mA/cm^2 and 2.17×10^{-1} %, respectively.

5. Acknowledgment

This study is supported by National Science Council, the Republic of China, under the contracts NSC 100-2221-E-268-004 and NSC 101-2221-E-224-046.

6. References

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陣列型可撓式染料敏化太陽能電池之設計與分析

胡睿恩[1]、施柏豪[1]、黃錦惠[2]、周榮泉[1,*]、楊淑英[2]、廖義宏[3]
[1] 國立雲林科技大學電子工程系暨電子與光電工程研究所
[*]e-mail: choujc@yuntech.edu.tw
e-mail: M10013305@yuntech.edu.tw,
g9918734@yuntech.edu.tw,
[2] 國立雲林科技大學電子工程系
e-mail: u9813111@yuntech.edu.tw
[3] 和春技術學院資訊管理系
e-mail: allison@center.fotech.edu.tw
[4] 環球科技大學資訊管理系
e-mail: liaoih@twu.edu.tw

摘要

本論文所使用可撓式染料敏化太陽能電池(Flexible Dye-sensitized Solar Cell, FDSSC)其設計主要係以並聯陣列排列、並聯連接及三明治結構所組成。其工作電極之單一片二氧化鈦層其反應面積為 5×1 cm^2，而二片並聯連接之二氧化鈦層總反應面積為 2x5 cm^2。本論文使用阻抗分析儀分析可撓式染料敏化太陽能電池於異質界面之氧化還原反應。

本論文之陣列型可撓式染料敏化太陽能電池所量測得開路電壓、短路電流及光電轉換效率分別為 0.64 V、0.64×10^{-2} mA/cm^2 及 2.17×10^{-1} %

關鍵字：陣列型可撓式染料敏化太陽能電池、並聯連接、工作電極、電化學阻抗分析儀