

Reduction of Collection Efficiency of Charge Carriers with Increasing Cell Size in Dye-Sensitized Solar Cell

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ABSTRACT

In the last few years, several articles have been devoted to the study of the flexible dye-sensitized solar cell (DSSC) in stainless steel substrate, but few of them discuss the performance of 1cm x 1cm photoelectrode permuted differently on different size stainless steel substrate. The size of stainless steel changes with the photoelectrode permutation, and is augmented on a scale from 2cm x 2cm, 2cm x 4cm, to 4cm x 4cm while the figures of short circuit current density (J_{sc}) and power conversion efficiency (η) show little discrepancy, the figures of open circuit voltage (V_{oc}) and the fill factor (FF) reduce when the size of the substrate is enlarged. Such a reduction is caused by the suppression of J_{sc} . Besides, put on 4cm x 4cm substrate, the performance of 4 pieces 1cm x 1cm photoelectrodes is better than one piece of 2cm x 2cm photoelectrode. With this result, we intend to find an efficient way in the manufacturing process for large-area.

Keywords: DSSC, fill factor (FF), short circuit current density (J_{sc}), open circuit voltage (V_{oc}), power conversion efficiency (η), stainless steel

1 INTRODUCTION

Since the end of 20th century, different kinds of energy, such as coal, oil, natural gas, have been consumed considerably. And these kinds of energy will also bring about serious environment pollution. Therefore, many countries start to pay attention to the development of renewable energy. Solar cells, for instance, are utilized to transform light into electricity by photovoltaic effect [1–3]. With solar cells, some energy loss caused by complicated procedures of energy conversion can be avoided. Nowadays, solar cells are divided into crystalline silicon solar cells, multicrystalline silicon solar cells, dye-sensitized nanostructured solar cells and organic solar cells. The first two kinds of solar cells are characterized by high efficiency. However, the application is limited by the abundant but high-priced silicon. The last two kinds of solar cells are still at the development stage. Although organic semiconductor thin film solar cells are flexible and controllable, their efficiency is still quite low.

The dye-sensitized solar cell (DSSC) has attracted much scientific attention in recent years because of its low cost, relatively high photoelectric conversion efficiency and its facile fabrication process [1, 4]. However, it is difficult for DSSC to enter the market since commercial silicon solar cells have achieved low costs due to the scale in production and would be the long-term market leader. Thus, DSSC assembled with a flexible electrode is competitive and expected to facilitate market entry, both for use in domestic devices as well as in architecture or decorative applications [5, 6]. Considerable efforts have focused on the flexible substrate including conducting plastic substrates [7–9], stainless steel [10, 11], Ti substrate [12–14], etc.

Flexible DSSC was initially proposed by Pichot et al. [15], though it was not until 2005 that the stainless steel was proposed as the substrate for flexible DSSC [16]. Although similar studies were presented subsequently, it was not until 2009 that the substitution of stainless steel sheet by titanium (Ti) sheet was proposed to achieve higher photoelectric conversion efficiency [17]. The most important advantage of the StSt-based TiO_2 film electrode over plastic-based electrodes lies in its high-temperature sinterability. Both ITO- and SiO_x -sputtered StSt were chosen as substrates for flexible DSSCs, because it has previously been ascertained that the insertion of an insulating SiO_x layer improves the photovoltaic properties over DSSCs without a SiO_x layer [18]. The power conversion efficiency (η) of the DSSC with a StSt/ SiO_x /ITO/ TiO_2 electrode was improved by 17 and 30%, compared to those based on StSt/ITO/ TiO_2 and StSt/ TiO_2 electrodes, respectively [19].

This paper is intended as an investigation of available method for large-area. When the flexible dye-sensitized solar cell (DSSC) in stainless steel substrate was up to 4cm x 4cm, change the photoelectrode size as the same total area in stainless steel substrate. The fill factor (FF) showed little change and the power conversion efficiency was increased significantly.

2 EXPERIMENTAL

In this paper was used four different kinds of flexible dye-sensitized solar cells (DSSC) in stainless steel devices and used the performance of 1cm x 1cm photoelectrode in 2cm x 2cm stainless steel substrate to discuss others. Those devices had the same conditions of manufacturing process.

Figure 1 shows the different type of flexible dye-sensitized solar cells (DSSC) in stainless steel devices. A is 1cm x 1cm x 1pcs photoelectrode in 2cm x 2cm stainless steel substrate, B is 1cm x 1cm x 2pcs photoelectrode in 2cm x 4cm stainless steel substrate, C is 1cm x 1cm x 4pcs photoelectrode in 4cm x 4cm stainless steel substrate, and D is 2cm x 2cm x 1pcs photoelectrode in 4cm x 4cm in stainless steel substrate.

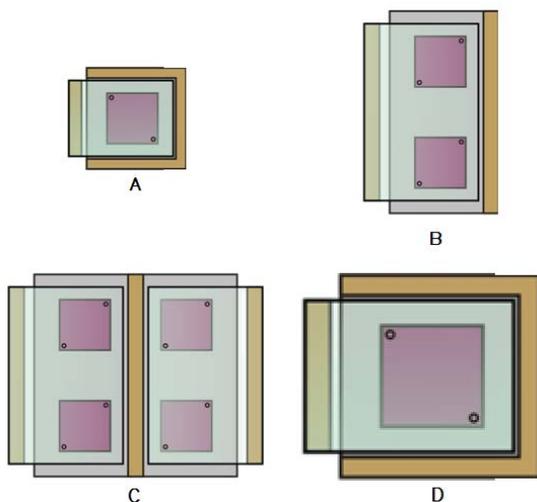


Figure 1: The different type of flexible dye-sensitized solar cell (DSSC). A is 1cm x 1cm x 1pcs photoelectrode in 2cm x 2cm stainless steel substrate, B is 1cm x 1cm x 2pcs photoelectrode in 2cm x 4cm stainless steel substrate, C is 1cm x 1cm x 4pcs photoelectrode in 4cm x 4cm stainless steel substrate, and D is 2cm x 2cm x 1pcs photoelectrode in 4cm x 4cm in stainless steel substrate.

2.1 Fabrication of photovoltaic devices

16 μm nanocrystalline TiO_2 photoelectrodes were prepared from titania paste (Ti-Nanoxide T series, Solaronix SA). The paste was applied to the transparent conducting oxide by 'doctorblading' techniques and annealed at 450 $^\circ\text{C}$ for 30 min in air. The thickness of the TiO_2 films was measured with an Alpha-Step 300 profiler. Once the TiO_2 electrodes had been cooled to around 100 $^\circ\text{C}$, they were dipped in a 0.3 mM solution of N719 in tert-butanol-AN (1 : 1, v/v). The TiO_2 electrodes were immersed in the dye solutions and then kept at 25 $^\circ\text{C}$ for more than 12 h to allow the dye to adsorb on the TiO_2 surface, and rinsed with the same solvents. The dye-loaded TiO_2 film (as the working electrode) and Pt-coated TCO (as the counter electrode) were separated by a hot-melt Surlyn sheet (60 mm) and sealed together by pressing them under heat. The electrolytes was heated to 80 $^\circ\text{C}$ for a clear solution and introduced into the gap between the working and the counter electrodes from the two holes predrilled on the back of the counter electrode. Finally, the two holes

were sealed with a Surlyn film covering a thin glass slide under heat. The electrolyte, 0.6 M [PMI][I] + 0.1 M LiI + 0.03 M I_2 + 0.5 M TBP in methoxypropionitrile, was used in this work.

2.2 Photovoltaic measurements

The current-voltage (I - V) characteristics in the dark and under illumination were measured with a Keithley 2400 sourcemeter. The photocurrent was measured in a nitrogen-filled glove box under a solar simulator (Oriel 96000 150W) with AM 1.5G filtered illumination (100 mW cm^{-2}). The spectra-mismatch factor of the simulated solar irradiation was corrected using a Schott visible-color glass-filtered (KG5 color filter) Si diode (Hamamatsu S1133). [20]

3 RESULTS AND DISCUSSION

Under illumination of 100 mW cm^{-2} , the photovoltaic performances of DSSCs based on photoelectrode permutation 1cm x 1cm x 1pcs, 1cm x 1cm x 2pcs, 1cm x 1cm x 4pcs, and 2cm x 2cm x 1pcs are shown in Table 1, and its graph it presented in Fig. 2. Fig. 2 shows the photocurrent density vs. voltage response of four cells made with 16 μm layers of TiO_2 . In this case, device A shows a higher light-to-electricity conversion efficiency (η 4.51%) than device B (η 4.30%), C (η 3.79%) and D (η 3.47%). This result is probably caused by a series connection of the same DSSC in stainless steel substrate. Similar observations have also been made by Yamaguchi et al.[21]. Fig. 3 shows the different type device of flexible dye-sensitized solar cells (DSSC).

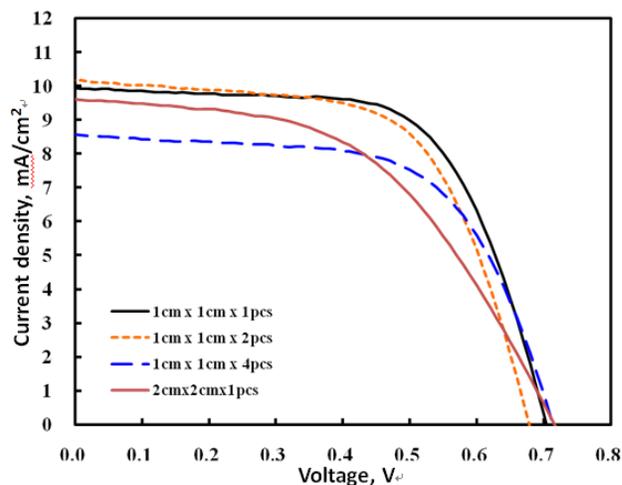


Figure 2: The J-V curve of different type of flexible dye-sensitized solar cell (DSSC) in stainless steel substrate.

| | (A) 1cmx1cm | (B) 1cmx1cm 2pcs | (C) 1cmx1cm 4pcs | (D) 2cmx2cm 1pcs |
|--------------------------------|----------------|------------------------|------------------------|------------------------|
| J_{sc} (mA/cm ²) | 9.94 | 10.17 | 8.57 | 9.61 |
| V_{oc} (V) | 0.70 | 0.68 | 0.71 | 0.72 |
| FF | 0.64 | 0.62 | 0.62 | 0.50 |
| Eta(%) | 4.51 | 4.30 | 3.79 | 3.47 |

Table 1: The performance of different type of flexible dye-sensitized solar cell (DSSC) in stainless steel substrate.

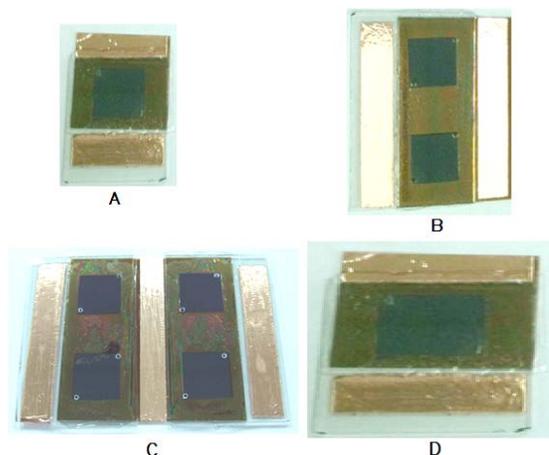


Figure 3: The different type of flexible dye-sensitized solar cell (DSSC). A is 1cm x 1cm x 1pcs photoelectrode in 2cm x 2cm stainless steel substrate, B is 1cm x 1cm x 2pcs photoelectrode in 2cm x 4cm stainless steel substrate, C is 1cm x 1cm x 4pcs photoelectrode in 4cm x 4cm stainless steel substrate, and D is 2cm x 2cm x 1pcs photoelectrode in 4cm x 4cm in stainless steel substrate.

Compared device A with device D, exhibits excellent photocurrent density (9.61 mA cm^{-2}), V_{oc} (0.72 V), but lower efficiency of power conversion by 23%. Hence, it can be assumed that the high internal resistance of device D will cause the Fill Factor (FF) to decrease and that the increase of activated area and length of electron pathway will cause the resistance value of device D to enhance.

Compared with device A (1cm^2 activated area), B (2cm^2 activated area) and C (4cm^2 activated area), exhibits lower J_{sc} (8.57 mA cm^{-2}), because device C has higher stainless steel resistance. The variation of V_{oc} for these devices is within $0.7\text{V} \pm 3\%$. This resistance value was responsible for the lower J_{sc} and η .

The activated area for device C and D is the same (4cm^2 activated area). However, device C shows lower J_{sc} (8.57 mA cm^{-2}) but higher FF (0.62). This phenomenon results from the too high inner resistance of activated area which will cause FF to decrease. (as shown in Fig. 4.) The influence of parallel resistance R_p on the J - V characteristic is ignorable in device C, so we just discussed the influence of series connection in this case. [21]

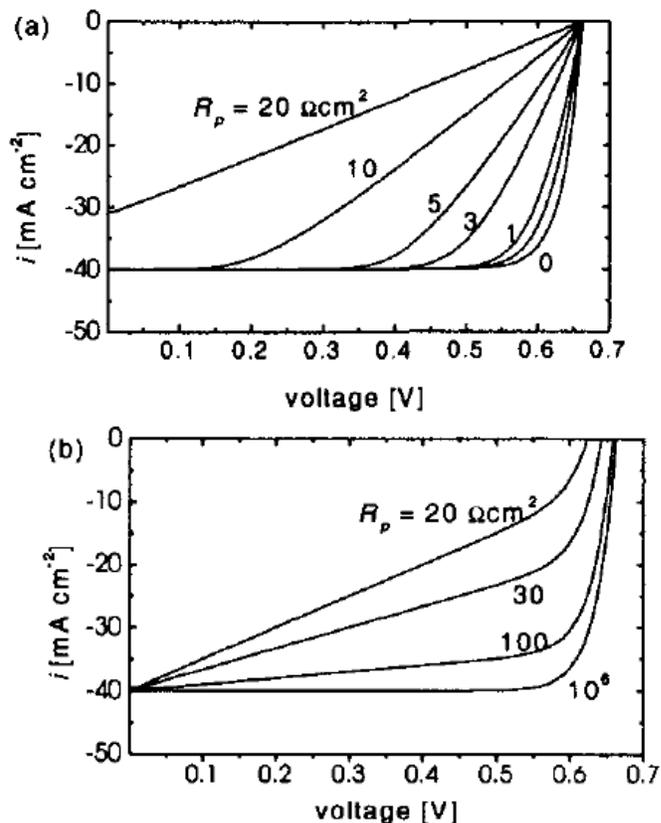


Figure 4: Influence of series resistance R_s and parallel resistance R_p on the J - V characteristic: (a) illuminated, R_s varied; (b) illuminated, R_p varied [21]

4 CONCLUSION

In conclusion, we find an efficient method to enlarge the flexible dye-sensitized solar cell (DSSC) in stainless steel devices. To compare device C with device D, we discover that in the manufacturing process for large-area, the performance for dispersed same-sized photoelectrode is better than that for gathered same-size photoelectrode.

5 REFERENCES

- [1] B. O'Regan, M. Grätzel, Nature 353 (1991) 737–740.
- [2] M. Grätzel, Nature 414 (2001) 338–344.
- [3] A. Hagfeldt, M. Grätzel, Chem. Rev. 95 (1995) 49–68.
- [4] M. Grätzel, J. Photochem. Photobiol. A, Chem. **164**,3 (2004)
- [5] M. Grätzel, Prog. Photovolt. Res. Appl. **14**, 429 (2006)
- [6] K.L. Chopra, P.D. Paulson, V. Dutta, Prog. Photovolt. Res. Appl. **12**, 69 (2004)
- [7] M. Dürr, A. Schmid, M. Obermaier, S. Rosselli, A. Yasuda, G. Nelles, Nat. Mater. **4**, 607 (2005)
- [8] C.G. Wu, M. Ikegami, K. Miyoshi, T. Miyasaka, K.C. Ho, J. Mater. Chem. **19**, 5009 (2009)
- [9] M. Ikegami, J. Suzuki, K. Teshima, M. Kawaraya, T.

- Miyasaka, *Sol. Energy Mater. Sol. Cells* **93**, 836 (2009)
- [10] Y. Jun, J. Kim, M.G. Kang, *Sol. Energy Mater. Sol. Cells* **91**, 779 (2007)
- [11] M.G. Kang, N.G. Park, K.S. Ryu, S.H. Chang, K.J. Kim, *Sol. Energy Mater. Sol. Cells* **90**, 574 (2006)
- [12] K. Onoda, S. Ngamsinlapasathian, T. Fujieda, S. Yoshikawa, *Sol. Energy Mater. Sol. Cells* **91**, 1176 (2007)
- [13] H. Wang, Y. Liu, H. Huang, M.Y. Zhong, H. Shen, Y.H. Wang, H.X. Yang, *Appl. Surf. Sci.* **255**, 9020 (2009)
- [14] W.W. Tan, X. Yin, X.M. Zhou, J.B. Zhang, X.R. Xiao, Y. Lin, *Electrochim. Acta* **54**, 4467 (2009)
- [15] M. Grätzel, *Curr. Opin. Colloid Interface Sci.* **4**, 314 (1999)
- [16] T. Oekermann, D. Zhang, T. Yoshida, H. Minoura, J. *Phys. Chem. B* **108**, 2227 (2004)
- [17] J. van de Lagemaat, A.J. Frank, *J. Phys. Chem. B* **105**, 11194 (2001)
- [18] G.K. Mor, O.K. Varghese, M. Paulose, K. Shankar, C.A. Grimes, *Sol. Energy Mater. Sol. Cells* **90**, 2011 (2006)
- [15] F. Pichot, J.R. Pitts, B.A. Gregg, *Langmuir* **16** (2000) 5626–5630.
- [16] M.G. Kang, N.-G. Park, K.S. Ryu, S.H. Chang, K.-J. Kim, *Sol. Energy Mater. Sol. Cells* **90** (2006) 574–581.
- [17] W. Tan, X. Yin, X. Zhou, J. Zhang, X. Xiao, Y. Lin, *Electrochim. Acta* **54** (2009) 4467–4472.
- [18] M. Durr, A. Schmid, M. Obermaier, S. Rosselli, A. Yasuda, and G. Nelles, *Nat. Mater.*, **4**, 607 (2005).
- [19] Jong Hyeok Park,^a Yongseok Jun,^b Ho-Gyeong Yun,^b Seung-Yup Lee,^b and Man Gu Kang^{b,z}, *J. Electrochem. Soc.*, **155** F145-F149 (2008)
- [20] V. Shrotriya, G. Li, Y. Yao, T. Moriarty, K. Emery and Y. Yang, *Adv. Funct. Mater.*, 2006, **16**, 2016.
- [21] M. Yamaguchi, The past and present, in: M. D. Archer, R. Hill (Eds.), *Clean electricity from photovoltaics*, London: Imperial College Press, 2001, p. 60.