Analysis of Different Thicknesses of Electrolyte Applied in Flexible Dye-sensitized Solar Cells

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***Abstract*—In this study, the different electrolyte thicknesses were investigated with various quantities of space layers, which were applied in the flexible dye-sensitized solar cells. The different materials of space layers were Surlyn film and Teflon tape. The thicknesses of Surlyn and Teflon tape were 60 µm, and 46.72 µm, respectively. The thickness of TiO_2 layer is 8.25 µm. According to the experiment for different thicknesses and layers of Surlyn and Teflon tapes, and then the thickness of space layer subtracts the thickness of TiO_2 layer will get the thickness of electrolyte, so the flexible dye-sensitized solar cells will have different thicknesses of electrolyte. The active area of flexible dye-sensitized solar cell was 0.8 cm × 0.8 cm, and the area of space layer of flexible dye-sensitized solar cell was 1.2 cm × 1.2 cm without hollow area 0.8 cm × 0.8 cm. According to the experimental results, the Surlyn of 3 layers has the best characteristic parameters and conversion efficiency, the open circuit voltage is 0.72 V, where the short circuit current density is 1.88 mA/cm^2, and the conversion efficiency is 0.45 %.**

***Index Terms*—Electrolyte thicknesses, space layers, flexible dye-sensitized solar cells, Surlyn film, Teflon tape**

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I. 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].

Recently, dye-sensitized solar cells (DSSCs) have been widely investigated due to their potential as environment-friendly and low-cost photovoltaic cells [6, 7]. Compared with silicon solar cell, glass-based DSSC has been extensively studied due to its potential for manufacturing low cost solar cells and over 11% conversion efficiency [5].

DSSC is one of photoelectrochemical solar cells, which is composed of a dye-modified wide band semiconductor electrode, a counter electrode, and an electrolyte containing a redox couple (I^-/I_3^-). The dyes, which are adsorbed and modified the surface of wide band semiconductor electrode, are excited from base states (S^0) to excited states (S^*) after light absorption. The injection of electrons occurs from the dye excited state into the TiO_2 conduction band, and then, the electrons transport and are collected on the ITO conducting substrate. Finally, the electron flows through the external circuit [8].

In the case of solar ultraviolet rays, only 2–3% sunlight in the UV spectrum can be utilized by DSSC [9]. To overcome this limitation, a dye-sensitizer, which need to absorb visible light between 500 nm and 600 nm as far as possible, transfers charges and injects electrons into the TiO_2 conduction band. Theoretically, the conversion efficiency of DSSC can be increased to 33% with less environmental damage. In general, the production cost is much less in DSSC (~30%) than in traditional silicon solar cell [10-12]. Therefore, it is a tendency towards DSSC development in the future.

In this connection of electrolyte, Grätzel et al. [13] have reported about 8% efficiency for the dye-sensitized solar cells consisting of ionic liquids [14]. However, our purpose is to clarify the influence of different thicknesses of space layers applied in flexible dye-sensitized solar cells, and discuss the

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important issues for increasing the efficiencies of the flexible dye-sensitized solar cells.

Usually each cell has an electrolyte layer separated from a TiO_2 layer called ''bulk electrolyte layer'', and this should have an effect for the dye-sensitized solar cell performances. However, the bulk electrolyte layers have not been taken into account sufficiently in simulation models to date [14].

In this study, the reduction-oxidation reaction of electrolyte of flexible dye-sensitized solar cell was influenced by different amounts of electrolyte. The thicknesses of space layers were used to control the amount of electrolyte, which can improve the reduction-oxidation reaction of flexible dye-sensitized solar cells, enhance the short-circuit current density and conversion efficiency.

II. Experimental

A. Chemicals and 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. The Surlyn layer (Meltonix 1170-60 Series) was purchased from Solaronix, Switzerland.

B. Preparation of Solvent, Paste and Fabrication of Flexible Dye-sensitized Solar Cell

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 [15, 16]. The TiO_2 working electrodes with an active area of 0.64 cm^2, which were designed as parallel types of strip-shaped TiO_2 thin films, and fabricated on ITO-PET substrates [17] by screen-printing technique, as shown in Fig. 1.

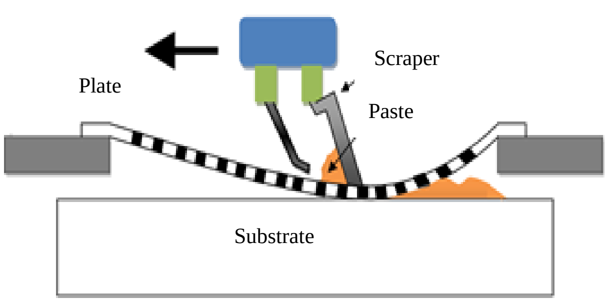

Figure 1. Fabricated TiO_2 thin film of working electrode by screen printing technique.

The working electrode was baked at 100 ℃ for 10 minutes, and then immersed in an absolute ethanol solution of 3×10^{-4} M N3 dye at 75 ℃ for 1 hour. Platinum was fabricated on ITO-PET substrate by sputtering for 90 seconds and was generally regarded as the counter electrode. 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 [18]. Finally, FDSSCs were sealed by Surlyn.

C. Design and Measurement of Arrayed Flexible Dye-sensitized Solar Cell

First, the 0.8 cm × 0.8 cm active area of TiO_2 thin films were fabricated on substrate by screen printing technique. The FDSSC is based on a sandwich structure [19], which consists of working electrode, electrolyte and counter electrode, as shown in Fig. 2. Fig. 3 shows the schematic diagram of space layer of flexible dye-sensitized solar cell. The thicknesses of electrolyte were changed by different materials and space layers quantities.

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). And the thickness of Surlyn, Teflon tape, and TiO_2 thin film were measured by Stylus Surface Profiling System.

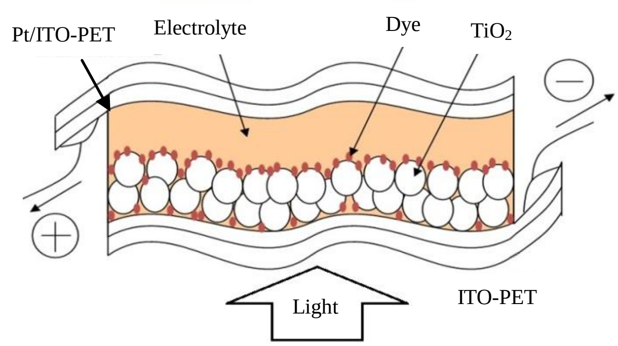

Figure 2. Schematic diagram of flexible dye-sensitized solar cell.

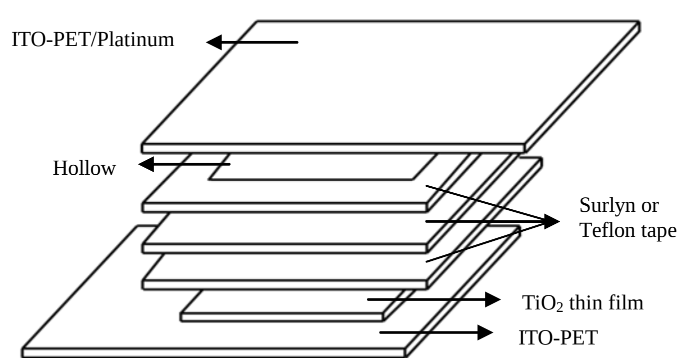

Figure 3. Schematic diagram of space layer of flexible dye sensitized solar cell.

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III. Results and Discussion

The thickness of space layer of flexible dye-sensitized solar cell was an important part for reduction-oxidation reaction of electrolyte. When the space layer is too thin, the TiO_2 thin film will touch the counter electrode and produces the leakage current, but has short distance of electron transmission. When the space layer is too thick, the excessive amount of electrolyte will produce higher resistance and longer electron transmission. Fig. 4 shows the schematic diagram of different thicknesses of electrolyte. Fig. 4(a) shows the regular FDSSC which has one space layer, and Fig. 4(b) shows the FDSSC which has thicker space, and the extra space region is called "region 2".

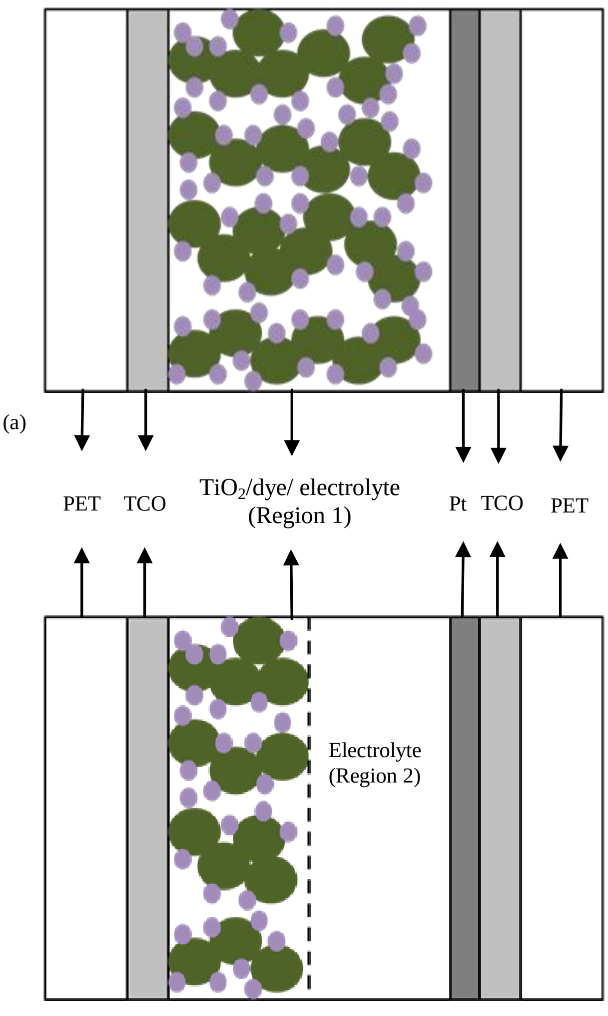

Figure 4. Simulation models for FDSSCs. (a) Cell a: model employed by Ferber et al. [20], (b) Cell b: model proposed in this work [14].

Fig. 5 shows the short circuit current density - open circuit voltage (J-V) curves of flexible dye-sensitized solar cells with different space layers for Teflon tape. The one layer thickness applied in Teflon tape were 46.72 μm. The space layer thickness subtracts the thickness of TiO_2 thin film will get the real thickness of electrolyte to investigate the different thicknesses of space layers. After the FDSSC was sealed by heat pressure sealing machine, the thicknesses of one, two and three space layers of electrolyte applied in Teflon tape were 38.47 μm, 85.19 μm and 131.91 μm, respectively. According to Fig. 5, the one layer of Teflon tape touches the counter electrode which has no trend of fill factor, and the 3 layers of Teflon tape has better open circuit voltage and short circuit current density.

Fig. 6 shows the J-V curves of flexible dye sensitized solar cells with different space layers for Surlyn. The thicknesses of one, two and three space layers of electrolyte applied in Surlyn were 51.75 μm, 111.75 μm and 171.75 μm, respectively. According to Fig. 6, the one layer of Surlyn has less reduction-oxidation reaction, because the electrolyte is too less to reaction, and the 3 layers of Surlyn has enough electrolyte to enhance reduction-oxidation reaction, which can enhance open circuit voltage and short circuit current density, obviously. The values of characteristic parameters and thicknesses of space layers are listed in Table 1.

According to Table 1, the experimental results of the thickness of thicker space has larger amount of electrolyte in flexible dye-sensitized solar cell. Although the distance of electron transmission become longer, the FDSSC has better reduction-oxidation reaction to enhance short circuit current density and conversion efficiency for flexible dye-sensitized solar cell. This results proves that the reduction-oxidation reaction is more important than the distance of electron transmission between working electrode and counter electrode.

When the thicknesses of space were increased, the fill factor was lower but the short circuit current density and conversion efficiency were higher. When the thickness of electrolyte was thicker, the inner resistance of flexible dye-sensitized solar cell was higher, so the fill factor was lower. But the couple of reduction-oxidation reaction increased which increase the short circuit current density, and then the conversion efficiency was higher.

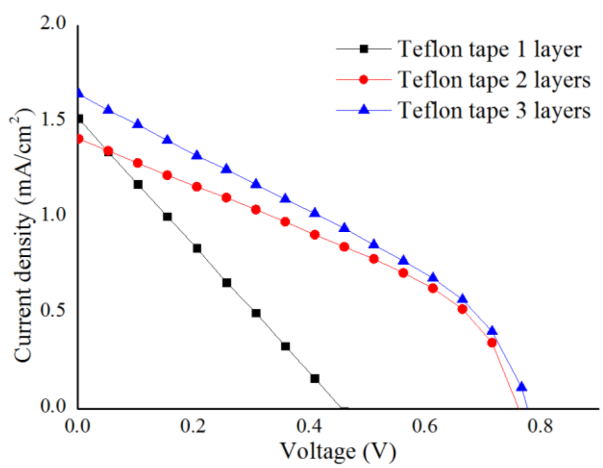

Figure 5. Dependence of J-V curves to the spacer thickness of Teflon tape.

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TABLE I. DIFFERENT SPACE THICKNESSES OF TEFLON TAPE AND SURLYN APPLIED IN FLEXIBLE DYE-SENSITIZED SOLAR CELLS.

Materials		Electrolyte thickness (μm)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	η (%)
Teflon tape	1 layer	38.47	0.46	1.52	24.82	0.17
Teflon tape	2 layers	85.19	0.76	1.41	37.24	0.40
Teflon tape	3 layers	131.91	0.78	1.65	34.19	**0.44**
Surlyn	1 layer	51.75	0.62	0.79	39.54	0.19
Surlyn	2 layers	111.75	0.71	1.57	35.83	0.40
Surlyn	3 layers	171.75	0.72	1.88	32.86	**0.45**

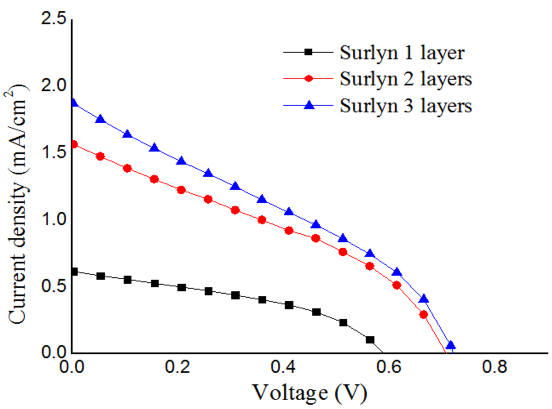

Figure 6. Dependence of J-V curves to the spacer thickness of Surlyn.

Fig. 7 shows the stability of different Surlyn layers of flexible dye-sensitized solar cells for different measurement times. According to the experimental results, the Surlyn of 1 layer has lower conversion efficiency than others, because the electrolyte layer is too thin to produce reduction-oxidation reaction. Although the Surlyn of 3 layers has the highest characteristic parameters than others, but the characteristic parameters just is enhanced a little and the cost is too high. According to the above considerations, the optimal quantities of Surlyn are 2 layers.

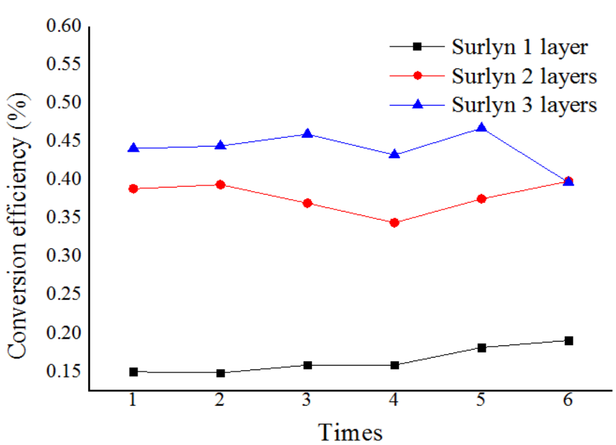

Figure 7. Stability of different Surlyn layers for different measured times.

IV. CONCLUSION

In this study, the different thicknesses of space layers of flexible dye-sensitized solar cells were investigated to provide an improved method to enhance the reduction-oxidation reaction, which can enhance the short circuit current density (J_{sc}) and conversion efficiency (η), although the cell has a smaller inner resistance.

The different types and amounts of space layers were utilized to investigate the optimal thicknesses of electrolyte layer. Both of Teflon tape and Surlyn, the short circuit current density and conversion efficiency were higher from 1 layer to 3 layers. According to experiment results, the optimal condition is Surlyn of 3 layers (171.75 μm), and the open circuit voltage, short circuit current density and conversion efficiency can reach to 0.72 V, 1.88 mA/cm^2 and 0.45 %, respectively.

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