Optimization of active cell area on the dye-sensitized solar cell efficiency

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Abstract. This study is aimed to obtain optimal active area producing high efficiency of DSSC module. The DSSC structure is constructed of TiO$_2$ as working electrode, dye as photosensitizer, platinum as counter electrode, and electrolyte as electron transfer media. TiO$_2$ paste was deposited on Fluorine-doped Tin Oxide (FTO) by screen printing method. Meanwhile, platinum was also coated on FTO via brush painting method. Keithley I-V meter was performed to characterize DSSC electrical property. The active area of each cell was varied of 4.5 cm$^2$, 9 cm$^2$, and 13.5 cm$^2$. Each cell was assembled into a module using an external series connection of Z type. The module was consisted of 12 cells, 6 cells, and 4 cells with module active area of 54 cm$^2$. The optimal active area of DSSC cell is 4.5 cm$^2$ resulting 0.4149% efficiency. In addition, the highest efficiency of DSSC module is 0.2234% acquired by 6 cells assembling.

1. Introduction

DSSC is the third generation of solar cell which converts light into electrical energy. It exploits a dye as a photon absorber in the converting process [1-3]. The DSSC structure consists of FTO glass that serves as the working electrode and the counter electrode. The working electrode consists of deposited TiO2 and dye, while the other one is coated Platinum. Between the two electrodes is given electrolyte [4-7].

Initially, DSSC was fabricated with a small active area size of about 1 cm$^2$ [8]. As the research grows rapidly, the researchers have developed DSSC cells into larger sizes. Various studies have combined several cells into a single module with varying circuit connections. The module can be applied as solar window [8-10].

Ramasamy et al., 2007 has studied the design of monolithic type of DSSC module with efficiency of 1.02%, while the parallel connection type with 5 cells combination yielded power conversion efficiency of 5.45% [11]. Lee et al., 2008 compared the two types of DSSC modules with various counter electrodes. The module using Pt electrode had efficiency of 5.26%, while using carbon electrode generated 4.23% [12]. Pranoto has manufactured DSSC module varying the connection type. It was monolithic, Z type and W type connection. The research yielded that the highest efficiency was 0.77% from Z type connection [13]. Hastuti et al., 2016 examined circuit types such as monolithic, external Z type series, internal Z type series, and parallel external connections. The best DSSC module efficiency that on an external series connection of Z type was 0.078% [14].
In order to be applied as a solar window, the DSSC module must be built into a large active area. However, it is difficult on the fabrication process. Alternatively, the DSSC module can be created by combining several cells into a module. The active area has effect on the efficiency of DSSC. Therefore, it is necessary to study the optimal active area of the cell and the DSSC module. The size of the cells active area is varied by 4.5 cm$^2$, 9 cm$^2$, 13.5 cm$^2$. Each cell is arranged using series external circuit to be a module.

2. Methods
In this research, the materials involved FTO glass substrate with resistance of 7 $\Omega$ / sq. Transparent TiO$_2$ Paste dyesol was functioned as the working electrode. Dye Ruthenium N719 dyesol was worked as photosensitizer. Platinum dyesol used as the counter electrode. EL-HPE dyesol electrolyte solution was performed as electron transfer medium. Silver paste was played as contact between cells. The FTO glass substrate was cut into various size of active area. They were 4.5 cm$^2$, 9 cm$^2$, and 13.5 cm$^2$ symbolized by A, B, and C, respectively. Because the module size must be 54 cm$^2$, there must be 12, 6, 4 combined cells to be a module for A, B, and C cell active area respectively. The substrate was washed via ultrasonic cleaner. The TiO$_2$ paste was deposited on FTO glass by screen printing method. It was dried by hotplate at temperature of 130°C for 10 min and then annealed in furnace at temperature of 500°C for 10 min. The working electrode was immersed in Ruthenium dye N-719 for 24 h. The platinum was coated by brush painting method on the counter electrode, and heated at temperature of 250°C for 10 min. The working electrode and the counter electrode were arranged like sandwiches. The electrolyte was injected into DSSC cells. The silver paste was applied as the intercellular contact. The DSSC sandwiches or cells were tested by Keithley I-V Meter. The cells then were assembled to be a module with external series circuit. The module was also characterized via Keithley I-V Meter. The characterization using Keithley I-V Meter was proposed to observe the DSSC electrical property.

3. Results and Discussion
The DSSC prototypes of each cell are shown by Figure 1. Each cell is connected to a unitary module by using the series external connection as in Figure 2. The DSSC module is made by connecting 12 cells (Figure 2a), 6 cells (Figure 2b), 4 cells (Figure 2c). All three modules have the same total active area of 54 cm$^2$.

Several parameters that affect the efficiency of DSSC include short circuit current ($I_{sc}$), open circuit voltage ($V_{oc}$), and fill factor ($FF$). $I_{sc}$ is a current when the output voltage is zero. $V_{oc}$ is the voltage in
the open circuit which has zero current because there is no current flowing [15]. $FF$ is the ratio of the output power of the solar cell to the actual power. It can be calculated by Eq. 1 [11]

$$Fill \ Factor = \frac{V_{m}I_{m}}{V_{oc}I_{sc}}$$ (1)

$V_{m}$ and $I_{m}$ are the voltage and the current at maximum power, respectively. The efficiency of DSSC is calculated using Eq. 2. $P_{in}$ is the incident solar radiation, expressed in Watt [11].

$$Efficiency = \frac{V_{oc}I_{sc}}{P_{in}} \times FF \times 100 \%$$ (2)

Figure 3 presents that the voltage of each cell has output voltage and currents. Table 1 demonstrates $I$-$V$ characteristic of each cell. The increasing of $I_{sc}$ occurs when the active area is larger. The larger active area leads the more photon absorbed in the dye which means more excited electrons produced. It makes the more current generated [16]. However, $V_{oc}$ has the similar voltage. Efficiency decreases as the larger active area. The optimal active area of DSSC cell is 4.5 cm$^2$ resulting efficiency of 0.4149%.

![Figure 3. $I$-$V$ curve of cell](image)

| Samples         | $I_{sc}$ (A) | $I_{max}$ (A) | $V_{sc}$ (V) | $V_{max}$ (V) | $FF$  | $P_{max}$ (W) | $P_{in}$ (W) | $\eta$ (%) |
|-----------------|--------------|---------------|--------------|--------------|-------|---------------|--------------|-------------|
| Cell A (4.5 cm$^2$) | 0.0086       | 0.0050        | 0.6556       | 0.3702       | 0.3320| 0.0019        | 0.45         | 0.4149      |
| Cell B (9 cm$^2$)  | 0.0124       | 0.0078        | 0.6846       | 0.3401       | 0.3139| 0.0027        | 0.9          | 0.2955      |
| Cell C (13.5 cm$^2$)| 0.0133       | 0.0076        | 0.6498       | 0.3501       | 0.3089| 0.0027        | 1.35         | 0.1973      |
International Conference on Science and Applied Science 2017
IOP Publishing
IOP Conf. Series: Journal of Physics: Conf. Series 909 (2017) 012008
doi:10.1088/1742-6596/909/1/012008

Figure 4. I-V curve of module

Table 2. I-V Characteristics of module

| Samples                  |  $I_{sc}$ (A) |  $I_{max}$ (A) |  $V_{oc}$ (V) |  $V_{max}$ (V) | FF   |  $P_{max}$ (W) |  $P_{in}$ (W) | η (%)    |
|-------------------------|--------------|---------------|--------------|--------------|------|----------------|--------------|--------|
| Module 1 (12 cells)     | 0.0009       | 0.0004        | 4.0114       | 2.7465       | 0.2870 | 0.0010         | 5.4          | 0.0193  |
| Module 2 (6 cells)      | 0.0119       | 0.0066        | 3.6407       | 1.8401       | 0.2772 | 0.0121         | 5.4          | 0.2234  |
| Module 3 (4 cells)      | 0.0181       | 0.0089        | 2.3105       | 1.3204       | 0.2818 | 0.0117         | 5.4          | 0.2176  |

Table 3. Resistance of module

| Samples                  | Resistance (kΩ) |
|-------------------------|-----------------|
| Module 1 (12 cells)     | 258.67          |
| Module 2 (6 cells)      | 120.88          |
| Module 3 (4 cells)      | 114.97          |

In the series circuit produces a greater voltage as a result of the more cell assembled presented by Figure 4 [14]. The DSSC module has a series resistance which affect the efficiency of DSSC. Series resistance ($R_s$) is caused by the resistance between the metal contact and the cells [17]. It is denoted that module 1 has the lowest efficiency because of the highest $R_s$. However, in the module 2 and module 3, it does not influence significantly. This is due to the larger active area the higher the resistance. The highest efficiency of DSSC module is 0.2234% acquired by 6 cells assembling.

4. Conclusion
Based on the cell variation of the active area, it is obtained that the optimal active area of DSSC cell is 4.5 cm$^2$ resulting 0.4149% efficiency. The highest efficiency of DSSC module is 0.2234% acquired by 6 cells assembling.

Acknowledgment
Ministry of Research, Technology and Higher Education Directorate General of Learning and Student Affairs which has funded PKM-PE

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