Influence of electrode spacing on the efficiency of dye-sensitized solar cell

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Abstract. This study reported the fabrication of Dye-Sensitized Solar Cell (DSSC) with optimization of electrode spacing. Optimization of electrodes in DSSC will affect the amount of electrolyte solution provided. The DSSC fabrication in this study consisted of coating the TiO$_2$ semiconductor as the working electrode, Platinum as the catalyst on the counter electrode, the Dye Ruthenium Complex as a photosensitizer, and the electrolyte solution as the electron transport media. The spacer between the working electrode and the counter electrode was varied by five variations with the thickness of 38 μm, 76 μm, 114 μm, 152 μm, and 190 μm. The DSSC was characterized using Keithley I-V Meter to know the efficiency of DSSC. The characterization showed that the best DSSC efficiency was at 76 μm electrode spacing.

1. Introduction
Dye-Sensitized Solar Cell (DSSC) is the third generation of solar cells which synthetic or organic dye are sensitized inside [1-2]. The advantages of DSSC are the low-cost production but the efficiency resulted is still relatively small so many research is done to improve it [3-6]. DSSC consists of several components that include Transparent Conductive Oxide (TCO) substrate as a working electrode and a counter electrode. A semiconductor layer is coated on the conductive side of the TCO glass as working electrode and the catalyst is coated on the TCO glass as counter electrode, dye as a photosensitizer and electrolyte solution as electron transport media (via redox reactions) [7-10]. Since 1991, the efficiency of DSSC obtained has increased from 7.1% to 13% [11].

Several studies have been reported to improve the efficiency and lifetime of DSSC, the optimization of electrolyte solution for example. Grätzel research group reported that one of the difficulties to keep the lifetime of a solar cell is the decomposition of sealing and electrolytes [12]. Electrolyte optimization can be investigated by varying the type or composition of the electrolyte. El-Shater et al. (2015) reported the effect of spacer thickness on the efficiency of DSSC. They used 10 μm, 20 μm, 30 μm, 40 μm, and 50 μm spacer thickness variations. The efficiency resulted was 2.47% at 10 μm spacer and it increased to 7.21% at 40 μm and then it decreased to 5.92% at 50 μm [13]. Taleb et al. (2015) reported a study to improve the DSSC performance by using 25 μm, the polymer spacer between the working electrode and counter electrode and it was filled by iodide/tri iodide (I$^-$/I$_3^-$) liquid electrolytes. The efficiency resulted was 4.3% [14].

Optimization of electrode spacing in DSSC affected the amount of electrolyte solution provided. Electrolyte filled the space between the working electrode, and the counter electrode should be optimal
if it is excessive, it caused the dye degradation and counter electrode corrosion. On the contrary, less electrolyte was easier to dry and resulted in the lower performance of DSSC.

2. Methods
Substrates used for working and counter electrodes were fluoride-doped tin oxide (FTO) glass. TiO$_2$ transparent paste was used for semiconductor layer on working electrode. Platinum was used for a catalyst layer on the counter electrode. Ruthenium Complex Dye was synthetic dye which used for photosensitizer. Electrolyte solution was used for electron transport media and 38 µm spacer.

Working electrode preparation using TiO$_2$ paste was mixed with ethanol in ratio 1 gram: 1 ml and it was coated on conductive side of FTO glass in 0.5 cm$^2$ active area by screen printing method. TiO$_2$ films were dried on the hotplate at 130 °C for 10 minutes. It was annealed in a furnace at 500 °C for 10 minutes. Working electrode was soaked in Ruthenium Complex Dye for 24 hours.

Counter electrode preparation using platinum liquid was coated by brush painting method. Counter electrode coated was dried on the hotplate at 250 °C for 10 minutes. The electrolyte solution was made by using potassium iodide (KI), poly ethylene glycol (PEG) 400, and iodine (I$_2$). The first solution was made by the mixture of 10 ml PEG and 0.8 gram KI. It was mixed with the second solution made by the mixture from 0.127 gram I$_2$ and 10 ml PEG. The electrolyte solution was stirred for 30 minutes to get the homogenous solution [16].

DSSC consisted of the working and counter electrode was assembled by 38 µm, 76 µm, 114 µm, 152 µm, and 190 µm spacers into sandwich type and it was filled by the electrolyte solution. The DSSC was characterized using Keithley I-V Meter measurement with Xenon 1000 W/m$^2$ illumination.

3. Result and Discussion
Figure 1 shows $I$-$V$ curves for DSSC with spacer variations.

![Figure 1. I-V curves for DSSC with spacer variations](image.png)
Table 1. The parameters of DSSC with spacer variations

| Electrode spacing (µm) | $V_{oc}$ (V) | $I_{sc}$ (A) (10^-2) | $V_{max}$ (V) | $I_{max}$ (A) (10^-5) | $P_{max}$ (Watt) (10^-5) | FF | η (%) (10^-2) |
|------------------------|--------------|----------------------|-------------|----------------------|----------------------|------|----------------|
| 38                     | 0.44         | 6.37                 | 0.20        | 3.93                 | 0.80                 | 0.28 | 1.61           |
| 76                     | 0.40         | 10.00                | 0.23        | 4.91                 | 0.11                 | 0.29 | 2.31           |
| 114                    | 0.35         | 7.94                 | 0.19        | 4.87                 | 0.92                 | 0.32 | 1.85           |
| 152                    | 0.29         | 1.60                 | 0.17        | 1.00                 | 0.17                 | 0.37 | 0.34           |
| 190                    | 0.14         | 2.61                 | 0.13        | 0.09                 | 0.01                 | 0.33 | 0.02           |

Based on Table 1, the highest efficiency of DSSC was at 76 µm spacer, and it decreased at 114 µm until 190 µm. The thicker the spacer, the more the electrolyte was added, and it influenced the efficiency of DSSC. Electrolyte solution consisted of a redox pair served as a substitute for excited electrons of the dye. The redox pair on the electrolyte consisted of I\(^{-}\) and I\(^{3-}\). Tri iodide was formed on the TiO\(_2\) surface while the redox reaction diffused to the catalyst. The redox reaction was accelerated by a catalyst deposited on the counter electrode [17]. Tri iodide reduced back to iodide by electrons arrived from the external circuit [18-19].

The less electrolyte in DSSC would lead to dry and its amount was probably not equal to number of excited electron so it was not able to fill the electron hole in dye as 38 µm spacer which had the lower efficiency. The excessive electrolyte caused the dye degradation and counter electrode corrosion with decreasing DSSC performance [2, 20]. Dye degradation caused its function to be not optimal to inject electrons into the TiO\(_2\) semiconductor layer [21]. The optimal electrode spacing was at 76 µm with the efficiency of 0.0231 %. It can be seen from the value of $V_{max}$ and $I_{max}$ produced are higher than the others that are 0.23 Volt and (4.91 x 10^-5) Ampere.

4. Conclusion

It reported the influence of electrode spacing on the efficiency of the dye-sensitized solar cell by varied the spacers. The highest efficiency of DSSC was at 76 µm spacer, and it decreased at 114 µm until 190 µm. It explained that the optimal spacer for this DSSC was 76 µm.

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