

# Enhancing Power Conversion Efficiency of Dye-Sensitised Solar Cell (DSSC) by Optimising Photoelectrode Thickness Layer

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**Abstract.** The photoelectrode element in DSSC plays a vital role as a substrate to hold dye and transport the electron to the conductive base in DSSC. A conventional photoelectrode consists of nanoparticle metal oxide semiconductor layered on the conductive side of transparent electrode. Photovoltaic (PV) parameters such as open-circuit voltage ( $V_{OC}$ ), short-circuit current density ( $J_{SC}$ ), maximum power point ( $P_{max}$ ), fill-factor (FF) and the power conversion efficiency (PCE) of the solar cell are determined through this experiment. In this project, the thickness of (TiO<sub>2</sub>) and Zinc Oxide (ZnO) are fabricated to 5  $\mu\text{m}$ , 10  $\mu\text{m}$ , 15  $\mu\text{m}$  and 30  $\mu\text{m}$  by doctor blading method to allow an efficient electron transport from N719 dye to photoelectrode. It was found that at 15  $\mu\text{m}$ , the PCE achieved by TiO<sub>2</sub> is highest at 1.303 % with  $J_{SC}$  of 5.842 mA/cm<sup>2</sup> which indicate about 57 % enhancement compared to TiO<sub>2</sub> at 5  $\mu\text{m}$  which generate PCE at 0.83 % and  $J_{SC}$  of 3.798 mA/cm<sup>2</sup>. Besides, at the thickness of 15  $\mu\text{m}$ , the efficiency achieved by ZnO is highest at 1.296 % with  $J_{SC}$  of 6.215 mA/cm<sup>2</sup> which indicate about 75 % enhancement compared to ZnO at 5  $\mu\text{m}$  which generate PCE at 0.741 % and  $J_{SC}$  of 3.505 mA/cm<sup>2</sup>. Lastly, the performance of TiO<sub>2</sub> as photoelectrode is more efficient compared to ZnO as the PCE achieved by TiO<sub>2</sub> at 5  $\mu\text{m}$ , 10  $\mu\text{m}$ , 15  $\mu\text{m}$  and 30  $\mu\text{m}$  are higher compared to PCE achieved by ZnO.

**Introduction.** Dye-Sensitized Solar Cell (DSSC) is introduced as low-cost devices with simple fabrication procedure, non-toxicity, generate higher PCE under low-light condition [1]. DSSC mainly composed of photoelectrode, photosensitiser, counter-electrode and electrolyte. In general, photoelectrode is layer with semiconductor oxides of Titanium Dioxides (TiO<sub>2</sub>) or Zinc Oxides (ZnO). The photoelectrode work as a substrate to allow photoexcited electrons transport from dye molecules to the conducting Fluorine doped Tin Oxide (FTO) electrode. Optimum photoelectrode thickness is important to allow efficient electron transport, thus it will result in higher  $J_{sc}$  and PCE

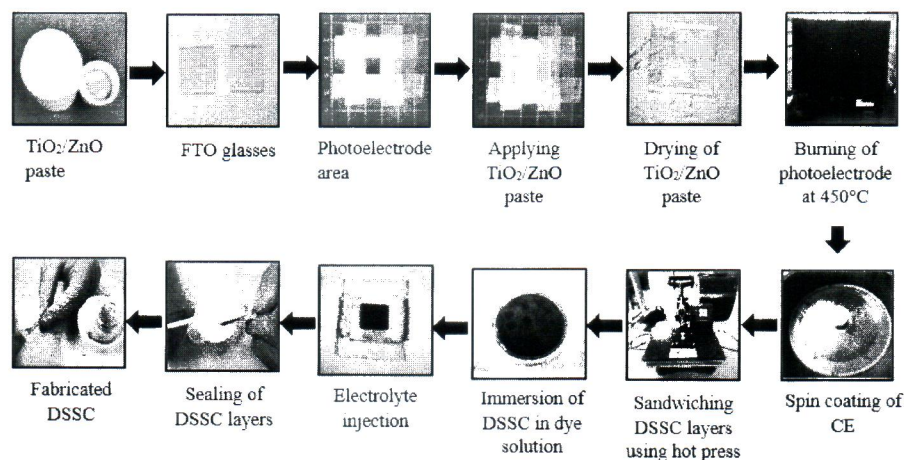
of DSSC. A low thickness of the film may reduce the dye absorption capacity hence reducing the PCE [2-3]. While thick thickness will cause the electron to exceed the diffusion length. As a result, it causes the electron transport to become slower, and the electron will be recombined with the oxidizing dye and redox couple [4]. Therefore, experimental work to compare TiO<sub>2</sub> and ZnO substrates can be done to fabricate the DSSC photoelectrode by using doctor-blading method to optimise the photoelectrode thickness of the solar cell.

**Photovoltaic properties.** The photovoltaic properties of a DSSC can be determined by plotting current-voltage relationship known as I-V curve. The key performance parameter of DSSC is the efficiency of the cell to convert solar energy into electricity. The efficiency of the solar cell also determines the amount of energy that can be produced by a system. Thus, the efficiency can be calculated by using **Equation** Error! Reference source not found., where the input power (P<sub>in</sub>) is the incident light power (100 mW/cm<sup>2</sup> as the standard cell irradiation condition, J<sub>sc</sub> is short current density and FF is fill factor of DSSC.

$$\eta = \frac{V_{oc} \times J_{sc} \times FF}{P_{in}} \times 100 \quad \text{Equation Error! Reference source not found.}$$

### Method

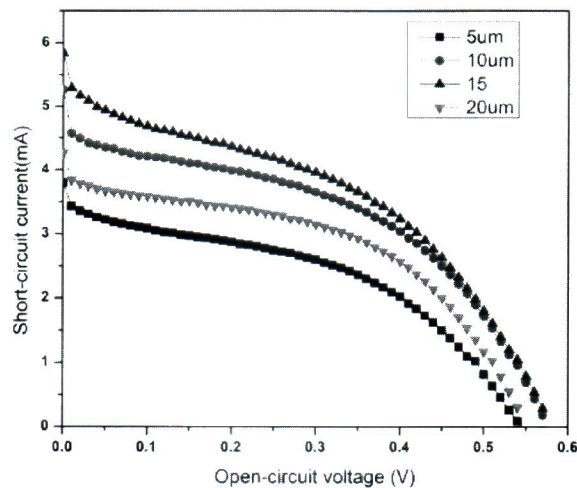
Material and technique used in TiO<sub>2</sub> photoelectrode of DSSC fabrication is based on reference [5]. For preparation of ZnO paste, all steps in **Fig. 1** were repeated by replacing TiO<sub>2</sub> nanoparticles with ZnO nanoparticles to produce ZnO paste. The TiO<sub>2</sub> and ZnO paste is deposited on the conductive side of the glasses on active area of 10 mm x 10 mm. Then, the samples are sintered in the furnace for 30 minutes with a temperature of 450°C, A completed photoelectrode is attached with platinum counter electrode in the sandwich form and the DSSC cell is measured using a digital source-meter (Keithley 2400) to obtain the open-circuit photovoltage and the short-circuit photocurrent of the DSSC.



**Fig. 1 Preparation of DSSC elements**

## Results and Discussion

**Fig.2** shows the J-V characteristics of DSSC of four different layers. The values of PV parameters obtained from the experiment is shown in Error! Reference source not found.. The highest efficiency achieved by DSSC is at 1.30 % with ( $J_{SC}$  5.84 mA/cm<sup>2</sup>,  $V_{OC}$  0.58 V, and FF 0.38) at the thickness of 15  $\mu$ m. The values of  $J_{SC}$  and  $V_{OC}$  increase with increasing thickness of the TiO<sub>2</sub> film. This is because a high thickness of the film will enhance the absorption of the dye molecules into the layer [6]. Besides, increasing value of  $V_{OC}$  also indicates in increasing light absorption into the FTO glass. The photon generated will excites the dye molecules and the potential of charges moving into the active layer will be increase. Hence, the PCE of DSSC increase from 0.83 % to 1.30 % with an increasing thickness from 5  $\mu$ m to 15  $\mu$ m. At a thickness of 20  $\mu$ m, the efficiency of the cell reduced from 1.30 % to 1.04 %. Although a higher area of TiO<sub>2</sub> layer will usually improve the absorption of dye molecules, but a too thick film will cause high electron transport resistance and enhances electron recombination with iodide ions on the TiO<sub>2</sub> surface [7]. Moreover, the thick film will result in lower transmittance of the TiO<sub>2</sub> film and reducing the incident light intensity on the dye molecules [8]. Therefore, the values of  $J_{SC}$ ,  $V_{OC}$ , FF and PCE of the cell will become be decreasing as shown at a thickness of 20  $\mu$ m in Error! Reference source not found.. However, at the lowest thickness, which is 5  $\mu$ m, the efficiency of DSSC is very low at 0.83 %. This is because only a small amount of light being absorbed by the layer thus, causing the values of  $J_{SC}$  and  $V_{OC}$  to decrease as well.



**Fig. 2** Current-voltage plot for TiO<sub>2</sub> photoelectrode at 5  $\mu$ m, 10  $\mu$ m, 15  $\mu$ m and 20  $\mu$ m thickness.

**Table 1.** PV characteristics of DSSC with different thickness of TiO<sub>2</sub> layer.

Thickness ( $\mu$ m)	5 $\mu$ m	10 $\mu$ m	15 $\mu$ m	20 $\mu$ m
Open-Circuit Voltage, $V_{OC}$ (V)	0.540	0.570	0.580	0.550
Short-Circuit Current Density, $J_{SC}$ (mA/cm <sup>2</sup> )	3.798	5.259	5.842	4.270
Maximum Output Power, $P_{max}$ (W)	0.001	0.001	0.001	0.001
Fill-Factor, FF	0.405	0.406	0.385	0.442
Efficiency, $\eta$ (%)	0.830	1.216	1.303	1.038

**PCE of DSSC by different thickness of ZnO.** Fig. 3 shows the J-V characteristics graph of four different ZnO thickness. Generally, photovoltaic characteristics of ZnO will show the same pattern as TiO<sub>2</sub> where the efficiency increased with increasing film thickness [9]. The highest efficiency reached by DSSC is at 1.29 % with ( $J_{SC}$  6.21 mA/cm<sup>2</sup>,  $V_{OC}$  0.55 V, and FF 0.37) at the thickness of 15  $\mu$ m. The values of  $J_{SC}$  and  $V_{OC}$  also increase significantly with the thickness of the film. This is because a high thickness of the film will enhance the absorption of the dye molecules into the layer and increase the light absorption into the FTO glass [10]. Hence, the PCE of DSSC increase from 0.74 % to 1.29 % with an increasing thickness from 5  $\mu$ m to 15  $\mu$ m. At a thickness of 20  $\mu$ m, the efficiency of the cell reduced from 1.29 % to 0.76 %. The thick film results in increasing rate of electron recombination and lower light transmittance into the layer [11]. Therefore, the values of  $J_{SC}$ ,  $V_{OC}$ , FF and PCE of the cell will become decreasing as shown at a thickness of 20  $\mu$ m in **Error! Reference source not found.**. The lowest thickness of 5  $\mu$ m shows a low PCE of 0.74 %. This is because only a small amount of light being absorbed by the layer thus, causing in low values of  $J_{SC}$  and  $V_{OC}$ .

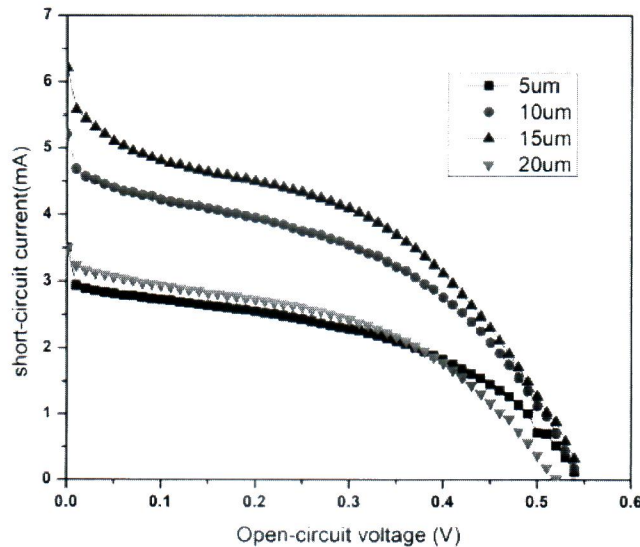
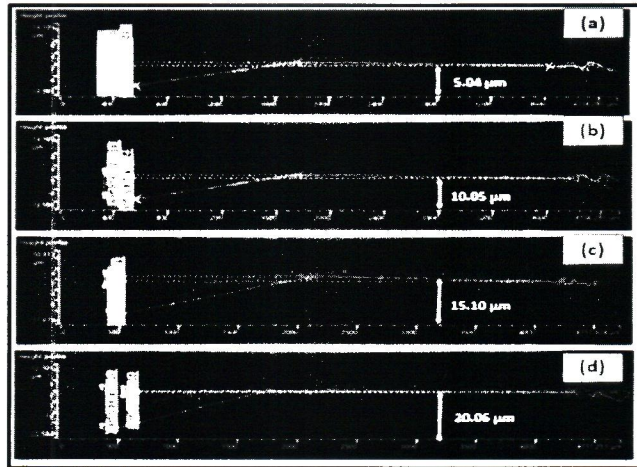


Fig. 3 Current-voltage plot for ZnO photoelectrode at 5  $\mu$ m, 10  $\mu$ m, 15  $\mu$ m and 20  $\mu$ m thickness.

Table 2. PV characteristics of DSSC with different thickness of ZnO layer

Thickness ( $\mu$ m)	5 $\mu$ m	10 $\mu$ m	15 $\mu$ m	20 $\mu$ m
Open-Circuit Voltage, $V_{OC}$ (V)	0.540	0.540	0.550	0.520
Short-Circuit Current Density, $J_{SC}$ (mA/cm <sup>2</sup> )	3.505	5.213	6.215	3.498
Maximum Output Power, $P_{max}$ (W)	0.001	0.001	0.001	0.001
Fill-Factor, FF	0.392	0.405	0.379	0.419
Efficiency, $\eta$ (%)	0.741	1.140	1.296	0.762

As comparison, the PCE of TiO<sub>2</sub> is much better than the PCE of ZnO. The first layer with a thickness of 5 μm, the PCE of TiO<sub>2</sub> is 0.83 % while ZnO is 0.74 %. Next, the second layer with a thickness of 10 μm, TiO<sub>2</sub> has an PCE of 1.21 % while ZnO is 1.13 %. The third layer with a thickness of 15 μm is an optimum thickness of both metal oxide. At this point, the PCE of both TiO<sub>2</sub> and ZnO is the highest and is quite similar which is 1.30 % and 1.29 % respectively. The last layer with a thickness of 20 μm, both PCE of DSSC drop where TiO<sub>2</sub> drop from to 1.03 % and ZnO drop to 0.76%. Even though both metal oxides is used for DSSC application, TiO<sub>2</sub> is more preferable as it has PCE than ZnO [12-14]. The PCE of ZnO is less due to low internal surface area that will decrease the dye absorption capability. It also has low electron transport from the dye surface to the conduction band of ZnO. Hence, the chemical instability of ZnO will significantly decrease the PCE of DSSC compared to TiO<sub>2</sub> film [15-16].



**Fig. 4: TiO<sub>2</sub> photoelectrode thickness**

**Fig. 4** shows the measurement thickness of TiO<sub>2</sub> and ZnO with different thickness in 2D. The images cross-sectional of TiO<sub>2</sub> and ZnO are using a laser step where the film was setup from the substrate using different layers of scotch tape from one layer to four layers. The results obtained shows the thickness of one layer is at 5 μm + 0.04 μm, two layer is at 10 μm + 0.05 μm, three layer is at 15 μm + 0.1 μm and four layer is at 20 μm + 0.06 μm.

**Conclusion.** it can be concluded that the PCE of DSSC is increased as the thickness increased. In this experiment, the optimum thickness of TiO<sub>2</sub> and ZnO layer obtained is at 15 μm with an efficiency of 1.30% and 1.29% respectively. The study also concluded when the thickness exceeded 20 μm, the efficiency of the solar cell will decline. Thus, the efficiency of both TiO<sub>2</sub> and ZnO obtained from this simulation is dropped to 1.03% and 0.76% respectively as the layer were too thick. Therefore, it will reduce the light absorption and the collection of charges efficiency.

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