Electrical Performance based on the Thickness of Electrode using Anatase TiO₂ Dye Sensitized Solar Cell

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Abstract. Solar cell research is an ongoing process to obtain a trade-off between the efficiency to price ratio. In the process to obtain high efficiency at lower cost, the dye sensitized solar cell (DSSC) emerge as the potential candidate. There have been many calls for an alternative method to a solar cell production compared to the current Si-solar cell production. This paper briefly discusses the comparison of using Anatase based titanium dioxide (A-TiO₂) at different thickness to the electrical performance of the DSSC. The Dr. Blade method was employed to the fabrication of the DSSC with a reference dyes and platinum deposition technique which acts as a counter electrode. Overall result shows that the 10µm thickness displays improved performance in the solar cell efficiency as compared to other electrode thickness fabricated and tested. The factors that improves the electrical performance based on the electrode thickness have been discussed in the paper.

1. Introduction

The topic introduces the research conducted by other researcher on the thickness aspect of the DSSC towards the photo to electrical conversion efficiency [10 -13]. An investigation on the thickness of the TiO₂ substrate combined with a substantial amount of graphene on the efficiency of the DSSC by using 8 layers of screen printing method was shown in [1], the result shows an optimum efficiency of 5.52 %. Meanwhile different combinations of TiO₂ layers and the characterisation techniques was done by [2] to study the factors affecting or improving the solar cell efficiency of the DSSCs. The experiment resulted in concluding that thicker anatase TiO₂ could provide higher and better crystallinity which subsequently leads to an optimum cell’s efficiency. Some researchers [3] even
experienced the thinner TiO₂ thickness in the range of 0.5 - 2.0 µm by using the sol gel method in combination of high temperature annealing process for the fabrication of the electrode. The experiment states that thicker TiO₂ film tends to have higher adsorption of dyes which could improve the short circuit density current (JSC) and open circuit voltage (VOC). The paper states that the TiO₂ film thickness of 1.5 µm manage to deliver 2.9 % of photo to electrical conversion efficiency. The researchers in [4] sets out to fabricate DSSC by using the anodizing method and characterized the sample based on structure and properties of the electrode thin film, photoelectric conversion efficiency investigation and electrochemical impedance properties in different thicknesses. The result of the experiment shows that the efficiency of the DSSC from the method increased to 6.5 % from 5.43 %.

2. Method

2.1. Fabrication technique
The fabrication techniques of the dye sensitized solar cell were thoroughly described in [5-9]. The techniques used in the electrode fabrication were by Dr. Blade method. The platinum was used for Counter electrode using sputtering method.

3. Results and Discussion

3.1. Effect of Anatase based TiO₂ (A-TiO₂) Electrode thickness on DSSC electrical performance
This section presents the photoelectric effect of Anatase (A) based TiO₂ crystalline material with a thickness of 9 µm – 90 µm with an input light intensity of 80 mW/cm² to 120 mW/cm². The open circuit voltage, VOC, short circuit current ISC, fill factor and photoelectric conversion efficiency; η were discussed in each subtopic. Note that the photo electrical performance was obtained after the DSSC samples were immersed to a reference dye and platinum (Pt) counter electrode (CE).

3.2. Effect of A-TiO₂ Thickness on Open Circuit Voltage (VOC)
Table 1 shows the open circuit voltage data characteristic of 9 µm - 90 µm thickness. Result shows that as the thickness of TiO₂ increases from 9 µm -15 µm the Voc values increases and exhibits a sharp decrease beyond 15 µm. This result is concurrent when the light intensity was increased to 120 mW/cm². Figure 1 shows the intensity pattern graph which clearly shows a decrease of VOC as the thickness increases.

| Table 1. Data of A-TiO₂ with various light intensity and thickness on open circuit voltage (Voc). |
|-------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Light Intensity (mW/cm²) | 9 | 10 | 15 | 30 | 40 | 60 | 80 | 90 |
|-------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| 80 | 0.432 | 0.463 | 0.473 | 0.232 | 0.213 | 0.11 | 0.09 | 0.01 |
| 100 | 0.511 | 0.528 | 0.528 | 0.276 | 0.252 | 0.11 | 0.10 | 0.023 |
| 120 | 0.522 | 0.533 | 0.537 | 0.288 | 0.252 | 0.12 | 0.10 | 0.030 |


Figure 1. A-TiO$_2$ film thickness and Light Intensity on the V$_{OC}$ of the DSSC.

Table 1 shows that as the thickness increases the V$_{OC}$ decreases. This can be explained by higher charge recombination and restricted mass transport in thicker films due to an extension of surface area. For the record, anatase material has particle size of less than 100 nm and high surface area. The result is also concurrent with those obtain from many thickness related investigation.

3.3. Effect of A-TiO$_2$ Thickness on Short Circuit Current (I$_{SC}$)

The variation of short circuit current as a function of light intensity and film thickness of anatase based TiO$_2$ is shown in table 2. It shows that I$_{SC}$ improves as the thickness increases from 9 $\mu$m - 15 $\mu$m and decreases if further thickness is applied to the film. As the light intensity increases along with TiO$_2$ thickness, the ISC shows an increment as well, but further increase on TiO$_2$ film thickness has made the value of ISC to reduce.

| Light Intensity (mW/cm$^2$) | 9   | 10  | 15  | 30  | 40  | 60  | 80  | 90  |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 80                          | 0.49| 0.52| 0.49| 0.26| 0.22| 0.15| 0.08| 0.007|
| 100                         | 0.55| 0.55| 0.52| 0.28| 0.26| 0.16| 0.11| 0.080|
| 120                         | 0.57| 0.58| 0.52| 0.32| 0.27| 0.24| 0.15| 0.010|

Figure 2 shows the intensity pattern graph at varied film thickness and light intensity. The I$_{SC}$ reduces as the TiO$_2$ film thickness increases due to the raise of electron transport resistance which makes it hard for the electrons to travel (longer distance of travel) to the front contact. It causes the electrons to be prone to recombination (electron losses) with the electrolyte ions in which, also reduces the electron lifetime in the TiO$_2$ film.
3.4. Effect of A-TiO$_2$ Thickness on Solar Cell Efficiency

The overall photovoltaic conversion efficiency for anatase based TiO$_2$ film is shown in Table 3 and the intensity pattern is shown in Figure 3. As the thickness of the film increases from 9 µm - 10 µm, the solar cell efficiency increases, it will further decrease as the film substrate thickens. Based on Table 3 the highest conversion efficiency obtained are from film thickness of 10 µm which is 0.14 % at 100 mW/cm$^2$ and increases to 0.15 % at higher light intensity. The overall photovoltaic conversion starts diminishing as TiO$_2$ film thickens due to the lowering of $I_{SC}$ and $V_{OC}$.

**Table 3.** Data of A-TiO$_2$ with various light intensity and thickness on solar cell efficiency ($\eta$).

| Light Intensity (mW/cm$^2$) | Thickness, d (µm) | 9  | 10  | 15  | 30  | 40  | 60  | 80  | 90  |
|-----------------------------|-------------------|----|-----|-----|-----|-----|-----|-----|-----|
| 80                          |                   | 0.07 | 0.12 | 0.11 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 |
| 100                         |                   | 0.10 | 0.14 | 0.12 | 0.04 | 0.03 | 0.01 | 0.00 | 0.00 |
| 120                         |                   | 0.12 | 0.15 | 0.14 | 0.06 | 0.04 | 0.01 | 0.00 | 0.00 |

Figure 2. A-TiO$_2$ Film thickness and Light Intensity on the $I_{SC}$ of the DSSC.

Figure 3. A-TiO$_2$ Film thickness and Light Intensity on Solar Cell Efficiency.

Though thicker film tends to have large surface area that allows more adsorption of the dyes, yet it also causes the electron transport resistance to increase which also encourages recombination with $I_3^-$ ions on the TiO$_2$ surface. The result of it is that thicker film ends up lowering the photo to electrical conversion (%). Based on table 4 investigation regarding the comparison of thickness of the oxide
substrate used, result shows that the 10 µm has the highest photon to electrical conversion efficiency which is 0.1 4% at 100 mW/cm².

3.5. **Overall performance of A-TiO₂ based on various film Thickness**
Table 4 shows the overall electrical parameter of anatase based TiO₂ with a reference dye and platinum counter electrode. The fabricated solar cells were tested under 100 mW/cm² light intensity. Overall, the efficiency of 0.14 % is produced from electrode film thickness of 10 µm which shows a suitable electrode thickness used for the fabrication of DSSC.

| Thickness; d (µm) | 9   | 10  | 15  | 30  | 40  | 60  | 80  | 90  |
|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Voc (V)           | 0.51| 0.53| 0.53| 0.28| 0.25| 0.11| 0.10| 0.02|
| Isc (mA/cm²)      | 0.55| 0.55| 0.52| 0.28| 0.26| 0.16| 0.11| 0.08|
| FF                | 0.35| 0.47| 0.45| 0.47| 0.47| 0.42| 0.25| 0.01|
| η %               | 0.10| 0.14| 0.12| 0.04| 0.03| 0.01| 0.00| 0.00|

4. **Conclusions**
The paper has presented an investigation on electrode thickness effect on the solar cell’s efficiency. The solar cell was fabricated using a reference dye with the electrode material from anatase based TiO₂ and platinum sputtered counter electrode. The fabricated solar cells were tested under 3 different light intensities according to standard test condition. Based on the experiment conducted for thickness from 9 µm -90 µm, the efficiency of 0.14 % was produced from electrode film thickness of 10 µm. Further increase in the thickness shows decreased of the efficiency, especially the short circuit current. This anomaly is due to the recombination with the I₃⁻ ions on the TiO₂ substrate and also higher resistance for the electron to regenerate. From the experiment conducted, it shows the 10 µm is suitable trade-off to the size of the oxide film. Further investigation is needed to verified the electron transfer efficiency and recombination rate in thicker/thinner films.

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