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Earth and
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To cite this article: Nair Gomesh *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **616** 012023

IOP Conf. Series: Earth and Environmental Science **616** (2020) 012023 doi:10.1088/1755-1315/616/1/012023

Effect of Dye Sensitized Solar Cell Fabricated with Different Thickness of Rutile-Anatase TiO_2 Electrode on the Electrical Performance

Nair Gomesh[1], Ragunathan Santiagoo[2,3], Zawawi Daud[4], Husnul Azan Tajarudin[5], Song-Quan Ong[1], and Syafinar Ramli[1],

[1]Centre for Research and Innovation (CRI), UOW Malaysia KDU Penang University College, Pulau Pinang, Malaysia
[2]School of Environmental Engineering, Universiti Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 3, 02600, Jejawi, Pelis, Malaysia
[3]Sustainable Environment Research Group (SERG), Center of Excellence Geopolymer and Green Technology, School of Material Enginering, Universiti Malaysia Perlis, Kompleks Pengajian Jejawi 2, 02600 Arau, Perlis, Malaysia
[4]Solid Waste Management and Resource Recovery Team, Micropollutant Research Centre, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia
[5]School of Industrial Technology, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia

E-mail: gomesh.nair@kdupg.edu.my

Abstract. DSSC is in the third generation of PV technology which employ easily available raw material with low cost manufacturing methods. Dye- Sensitized Solar Cell (DSSC) consist of a photo electrochemical cell of oxide semiconductor layer, dye molecules, electrolyte and counter electrode. This paper presents the comparison of the thickness of the TiO_2 using Rutile-Anatase composition at 1:4 ratioto the electrical performance of the DSSC. The Dr. Blade method was employed to the fabrication of the DSSC with a reference dyes and platinum sputtered technique counter electrode. The result shows that solar cell with an efficiency of 0.36 % of was produced from electrode film thickness of 10 µm. Further increase in the thickness shows decreased of the efficiency, especially the short circuit current. From the experiment conducted, it shows the 10 µm is suitable size to fabricate the DSSC using the RA-TiO_2 but further investigation is needed to verify the electron transfer efficiency and recombination rate in thicker/thinner films.

1. Introduction

Since the last century, the world has witnessed an incredible amount of technological advances that has changed a man's life style considerably. Extensive use and growing dependence on electrical and electronics equipment have increased the energy/power requirement on a global scale. The national electrical utility provider still had to burn fossil fuel, including gas and coal, which constituted more than 90% of its total fuel mix, to generate electricity for the country [3]. Solar photovoltaic (PV) power generation is an attractive technique to reduce consumption of fossil fuels [4]. A DSSC is in the third generation of PV technology which employ easily available raw material with low cost manufacturing methods. Dye- Sensitized Solar Cell (DSSC) consist of a photo electrochemical cell which comprises of oxide semiconductor layer, dye molecules, electrolyte and counter electrode. Therefore, to understand the essence of DSSC, fundamental research in the area of device physics, construction as well as characteristic of synthetic and nature based dyes is in need to identify the most promising cell configuration. TiO_2 is also called as a photo anode which allows electron circulation in the same energy level. Crystals of titanium dioxide exist in three crystalline forms which is rutile, anatase and brookite [3]. Among three crystalline forms as stated previously, the anatase and rutile have fine pigmentary assets in which rutile is more thermally stable than anatase. Most titanium dioxide pigments, be it from rutile or anatase, is produced from titanium mineral through a chloride or sulfate process. Venturing into nanoscience and nanotechnology, nanoscale (NS) materials as the NS–TiO_2 have shown high potential as a semi conductive material. Having size in the nano scale of less than 100 nm, the NS–TiO_2 has attractive features in numerous applications at various research. For TiO_2 powder with an average particle size in the range of 100-1000nm scale which is normally the scale size for rutile crystalline form are widely produced for the purpose of paint, ink coatings, paper and plastic industries, and for the range of below 100nm (normally anatase), with a combination of high surface area and enhanced semiconductor properties, the anatase becomes suitable for the application in the photovoltaic devices [5].

2. Fabrication of the Dye Sensitized Solar Cell.

The test tools and equipment used for implementation and data recording of this project were consist of Elmasonic ultrasonic cleaning unit, Holmarc's spin coater, Hot Plate, Universal 320 centrifuge, dielectric analyzer, Elcometer 456/4 thickness gauge, Evolution 201 Double Beam UV-Vis Spectroscopy, Solar Light's Model LS1000 Solar Simulator for I-V measurement, DektakXT Profiler for thickness measurement, SEM tool for particle morphology image, and the auto fine coater for platinum (Pt) sputtering. Materials which were used in this study are the indium tin oxide (ITO) coated transparent conducting oxide (TCO) glass with sheet resistance of 8~12 Ω/ , binder clips to hold both the electrode and counter electrode together. Dr. Blade method was used to fabricate the electrode on the ITO glass. The complete fabrication procedure of the DSSC can be obtain from [1].

3. Results and Discussions

This topic presents the performance of a mixture based TiO_2 electrode which consists of rutile and anatase phases in a composition of 1:4 towards thickness of the electrode oxide [1]. The RA-TiO_2 nanocrystalline mixing phase was synthesized and composed of 20 wt % rutile nanorods with diameter of ~20 nm and 80 wt % anatase which contain particle size of less than 100 nm. This topic investigates the photovoltaic parameter at varied film thickness and light intensities. The open circuit voltage; V_{OC}, short circuit current; I_{SC}, and current conversion efficiency; η are discussed in each subtopic. Note that the photoelectrical performance was obtained after the DSSC samples were immersed to a reference dye and Pt as CE.

3.1. Effect of RA-TiO_2 Thickness on Open Circuit Voltage (V_{OC})

Table 1 shows the open circuit voltage performance of RA-TiO_2 with film thickness of 9 µm - 90 µm at varied light intensity. Figure 1 shows the intensity pattern of the graph from table 1. The V_{OC} increases from 9 µm to 10 µm and slowly decreases as film thickness increases 10 µm onwards. The highest V_{OC} value was obtained from TiO_2 with 10 µm film thicknesses at 100 mW/cm^2 which is 0.664 V. The reduction of V_{OC} could be explained due to higher charge recombination and restricted mass transport in thicker films due to an extension of surface area. For the record rutile-anatase material has a mixture of particle size less than 100 nm to 1000 nm and relatively high surface area compare to the anatase form [2].

Table 1. Data of RA-TiO_2 with various light intensity and thickness on open circuit voltage (V_{oc}).

Light Intensity	Thickness, d (μm)							
(mW/cm²)	9	10	15	30	40	60	80	90
80	0.610	0.633	0.543	0.247	0.211	0.198	0.123	0.118
100	0.642	0.664	0.556	0.298	0.278	0.232	0.158	0.123
120	0.655	0.637	0.565	0.300	0.291	0.242	0.160	0.154

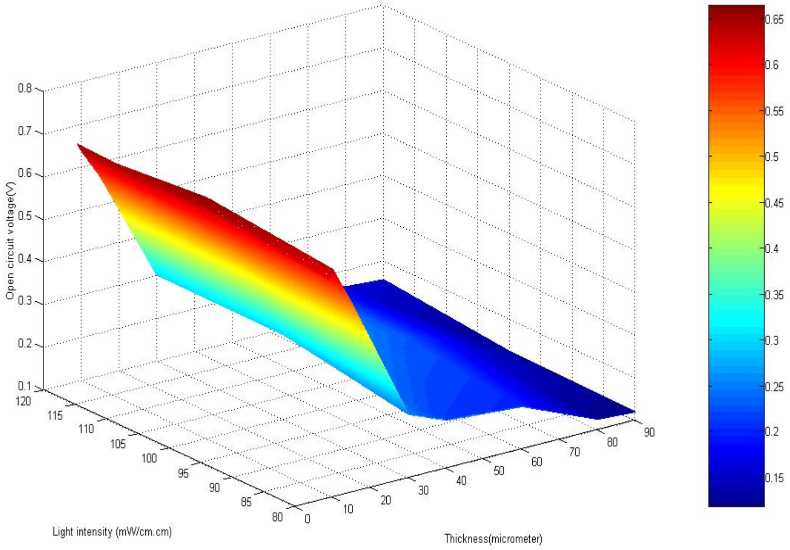

Figure 1. RA-TiO_2 film thickness and Light Intensity on the V_{OC} of the DSSC.

3.2. Effect of RA-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 RA based TiO_2 is shown in Table 2. It shows that the I_{SC} improves with thickness from 9 μm -10 μm and further declines with thicker films. Figure 2 shows the intensity pattern of I_{SC} as the thickness and light intensity increases. The I_{SC} reduces as the thickness increases; this is due to, as the thickness of the TiO_2 film increases, electrons encounter longer distance of travel to the front contact, this also causes the electron transport resistance to increases in the TiO_2 substrate and thus is prone to recombination (electron losses) with the electrolyte ions thus decreases the electron lifetime in TiO_2 film.

Table 2. Data of RA-TiO_2 with various light intensity and thickness on short circuit current (I_{SC}).

Light Intensity	Thickness, d (μm)							
(mW/cm²)	9	10	15	30	40	60	80	90
80	0.547	0.801	0.809	0.432	0.376	0.222	0.122	0.100
100	0.585	1.030	0.842	0.478	0.412	0.233	0.178	0.130
120	0.599	1.273	0.879	0.532	0.477	0.257	0.184	0.135

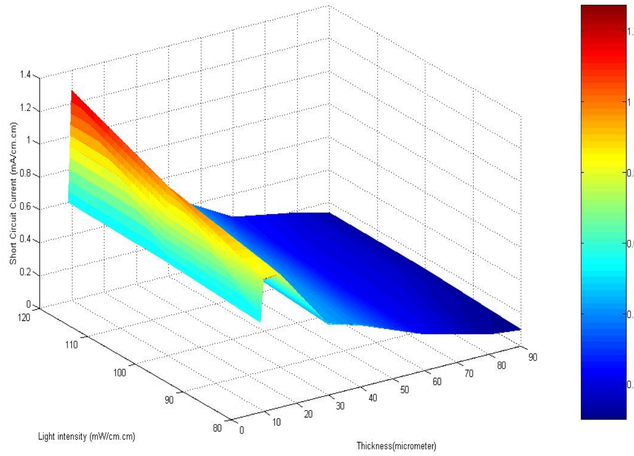

Figure 2. RA-TiO_2 Film thickness and Light Intensity on the I_{SC} of the DSSC.

3.3. Effect of RA-TiO_2 Thickness on Solar Cell Efficiency

The overall photovoltaic conversion efficiency for RA based TiO_2 film is shown in table 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 0.36 % at 100 mW/cm^2 and increases 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 RA-TiO_2 with various light intensity and thickness on solar cell efficiency (η).

Light Intensity (mW/cm^2)	Thickness, d (µm)							
	9	10	15	30	40	60	80	90
80	0.16	0.26	0.20	0.06	0.04	0.02	0.01	0.00
100	0.18	0.36	0.24	0.07	0.07	0.03	0.01	0.01
120	0.23	0.45	0.25	0.08	0.08	0.03	0.01	0.01

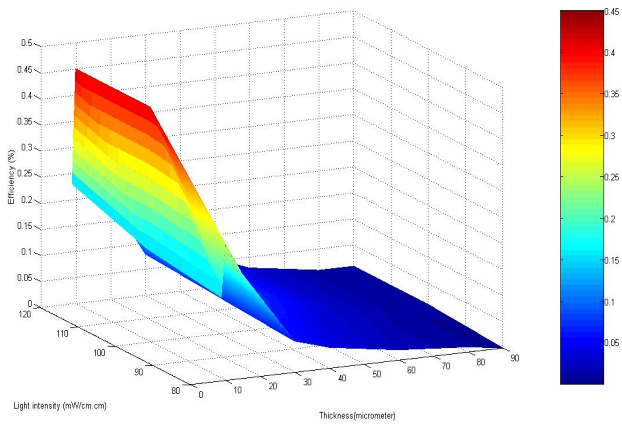

Figure 3. RA-TiO_2 Film thickness and light intensity on solar cell efficiency.

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Based on figure 3, the intensity pattern shows the highest efficiency obtained from the RA TiO_2 is at 10 µm thickness. Although thicker films have larger surface area thus improves dye adsorption; it also causes higher electron transport resistance and thereby enhances the recombination with I_3^- ions on the TiO_2 surface, resulting in lowering of efficiency. Among all the cells in the present study on RA substrate, the higher efficiency calculated is 0.45 % for film thickness of 10 µm at 120 mW/cm^2 and 0.36 % at STC.

3.4. Overall performance and optimum thickness of TiO2 Rutile-Anatase (RA) Electrode in DSSC

Table 4 shows the overall electrical performance of DSSC with varied thickness from 9 µm - 90 µm. Based on table 4, the values clearly show the increment of V_{OC}, I_{SC} and conversion efficiency of the DSSC fabricated using RA-TiO_2 electrode as the thickness expands more than 9 µm to 10 µm and declines as the oxide substrate thickens. Although many of these electrode performance is dependent on surface area, porosity, series resistance and charge transport resistance, the increment of TiO_2 electrical performance can be clearly seen by the use of a mixture content of rutile-anatase composition.

Table 4. Summary of photoelectrical characteristic of RA-TiO_2 film thickness at STC.

Thickness; d (µm)	9	10	15	30	40	60	80	90
Voc (V)	0.64	0.66	0.56	0.30	0.28	0.23	0.16	0.12
Isc (mA/cm^2)	0.59	1.03	0.84	0.48	0.41	0.23	0.18	0.13
FF	0.48	0.52	0.52	0.47	0.59	0.58	0.36	0.55
η %	0.18	0.36	0.24	0.07	0.07	0.03	0.01	0.01

4. Conclusions

The paper has reported the fabrication of DSSC using Rutile-Anatase TiO_2 with the ratio of 1:4 to get the best performance from both type of materials with higher dye adsorption rate and large porosity. The DSSC uses a reference dye with the counter electrode from the platinum sputtered. The DSSC was put under the solar simulator and tested under 3 different light intensities and the result referred was from the 100mW/cm^2 of light intensity. The experiment tested the thickness of electron from 9 µm -90 µm to obtain the V_{OC}, I_{SC}, FF and η. Result shows that a 0.36 % of η 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 is due to, as the thickness of the TiO_2 film increases, electrons encounter longer distance of travel to the front contact, this also causes the electron transport resistance to increases in the TiO_2 substrate and thus is prone to recombination (electron losses) with the electrolyte ions thus decreases the electron lifetime in TiO_2 film. From the experiment conducted, it shows the 10 µm is suitable size to fabricate the DSSC using the RA-TiO_2but further investigation is needed to verify the electron transfer efficiency and recombination rate in thicker/thinner films.

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