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The Thickness and Firing Duration Dependence of Titanium Dioxide (TiO_2) Nanoparticle Against to the Output Power of Dye-sensitized Solar Cell (DSSC)

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Abstract
In this research, a doctor blading deposition method for layering TiO_2 has been used to fabricate Dye-sensitized solar cell (DSSC). The conductive glass material or TCO (Transparent Conductive Oxide) was used for charge current. According to the doctor blade method, the thickness of TiO_2 was arranged by controlling mask layer, Nanoparticle of TiO_2 organic or natural dyes, electrolyte and electrode were arranged and combined with multulayer structure as the donor-acceptor layer. The test of DSSC using LED lamp 7 watt resulting V_{OC} 321 mV and I_{SC} 13.8 µA while the maximum power reaches 4,429 x 10^{-9} W. The test of cell firing duration of 75 minutes resulting V_{OC} 388 mV and I_{SC} 47.9 µA while the maximum power reached.

Keywords: Dye-sensitized solar cell (DSSC), layer thickness of TiO_2, firing duration of TiO_2, doctor blade, output power.

Introduction
The energy need of the world, especially Indonesia is increasing throughout the years. According to Energy Outlook of Indonesia, primary energy demand was increased by 5% back in 2010 and gave the impact of higher CO_2 emission. Fossil energy subsidies jumped more than 400 million USD along with the increase of the world's oil prices and the trend of inefficient consumption behavior. Fossil energy is one of the main energy sources, but its availability is limited and dwindling. According to the National Energy Management blueprint issued by the Ministry of Energy and Mineral Resources (ESDM) in 2005, oil reserves in Indonesia in 2004 is expected to be discharged within a period of 18 years [1].
Utilization of solar generated energy is the right alternative energy use because of its continous availability. Geographical condition of Indonesia which located on the equator causes Indonesia receives more solar heat than other countries, reaching 4 $kW/m^2/day$ [2]. The solar cell is one technology that can be used to convert solar energy into electrical energy. The electrical energy generated by the solar cells do not have a byproduct in the form of harmful gases and garbage nuclear [3].
Existing obstacles in the utilization of solar energy is the cost of the required investment is relatively expensive. That is because conventional solar cells are widely used today based on silicon technology, which is the result of the development of electronic semiconductor technology. In addition, the use of silicon solar cells has a relatively dangerous impact in the fabrication process due to the use of chemicals. To avoid more hazard in the use of these chemicals, other development of DSSC is using organic materials which are relatively safer. Along with the development of nanotechnology, organic-based solar cells have been found by Professor Michael Grätzel in 1991, namely Dye-sensitized Solar Cell (DSSC) [4].
DSSC has potential as a solar cell which has a level of security that is relatively more secure in the fabrication process and are relatively cheaper. At the DSSC, absorption of light and separation of electrical charge occurs in a separate process. Absorption of light is carried by the dye molecules and charge separation carried by inorganic semiconductor nanocrystal that has nanoporous. Dye in DSSC role as light catcher (photons) which is a process of excitation of electrons in the dye molecules to produce electrical energy. Therefore, the ability of the dye to absorb photons become a very important characteristic in DSSC as absorbance levels of chlorophyll are very influential based on wavelengths that can be absorbed and affects the result. Absorbance level of chlorophyll was strongly influenced by the concentration of

chlorophyll itself. Dye which is needed can be obtained by utilizing plant pigments, ie the pigment chlorophyll, carotenoids, betalains, and flavonoids. The leaf were used in this study to obtain chlorophyll substance is jatropha leaf [5-6]. DSSC is a technology that can be used to convert energy produced by the sun into electrical energy directly using previous material combination [7] and several fabricaation method [8]. DSSC efficiency is continously developed to get maximum efficiency about 11% [4]. In this research DSSC had been designed with a variation of the thickness and drying time of TiO_2 to determine the effect on the output power DSSC.

Method

DSSC research methods used in this study is the experimental method which includes three steps including:

1. Material Preparation.

This preparation includes the manufacture of electrolytes, manufacture of dye which is derived from the leaves of jatropha, and the manufacture of TiO_2 paste.

2. Fabrication of DSSC.

The TiO_2 coating thickness variation is calculated based on the number of mask and variations in drying time during the process of firing. There are three variation of layers used for coating that is 1, 2, and 3 layers of pasta mask on TCO. After TiO_2 coated on TCO glass, firing process is carried out in an electric furnace in a temperature of 450° C for 30 minutes. Other sample which is uses 2 plies masks pasta on TCO, fired with duration varies from 30, 45, 60, 75, and 90 minutes. After the firing process of TiO_2 layer, then soaked in a dye solution/chlorophyll solution from the jatropha leaves. After that the making of counter-carbon electrodes, electrolyte and assembly DSSC must be conducted.

3. Testing and Analysis

Test was conducted on chlorophyll absorption by spectrophotometer at a wavelength of 300-800 nm, a thickness and shape of the TiO_2 test using Scanning Electron Microscopy (SEM), voltage testing of the light intensity using 250W mercury lamp with luxmeter and ampermeter, and cell test for variations of TiO_2 thickness. All the data obtained in the various tests were compared against all the independent variables, analyzed and concluded.
Data as the input variable obtained by conducting thickness variation and drying time of TiO_2 ad DSSC fabrication process. Variations in the thickness are 1, 2, and 3 layers of pasta TiO_2 mask on TCO, each with a drying time of 30 minutes. While the variation of drying time for 2 layer masks of TiO_2 pasta on TCO and firing duration varies from 30, 45, 60, 75, and 90 minutes.
This research conducted to determine the effect of concentration and chlorophyll absorbance to the power output and efficiency of DSSC. Output variables used in this study are:

1. DSSC output voltage (Voc)
2. DSSC output current (Isc)
3. Fill Factor (FF)
4. The output power

Result and Discussion

Based on fabrication that had been done, the model of DSSC is shown below:

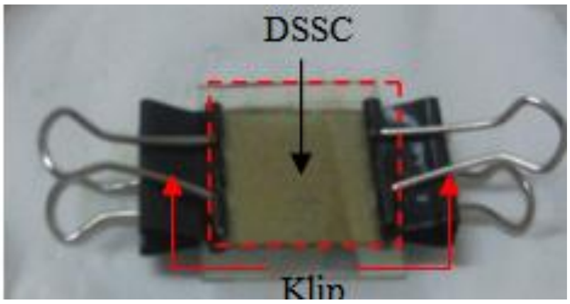

Figure 1. The completely assembled of DSSC

The test was conducted on the chlorophyll absorption by spectrophotometer at a wavelength of 300-800 nm. The ratio of leaves mass: volume of solvent is 30 grams: 50 ml. The test results are shown below:

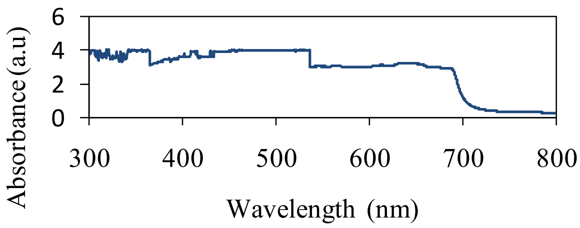

Figure 2. Absorbance Graph of Jatropha Leaves

TiO_2 thickness and shape test performed by Scanning Electron Microscopy (SEM) at the magnification of 4000 times for the top view and 250 times for the thickness of a side view of DSSC. There are three variance of thickness that is 1, 2, and 3 layer of masks. Figure 3 show the result of SEM investigation.

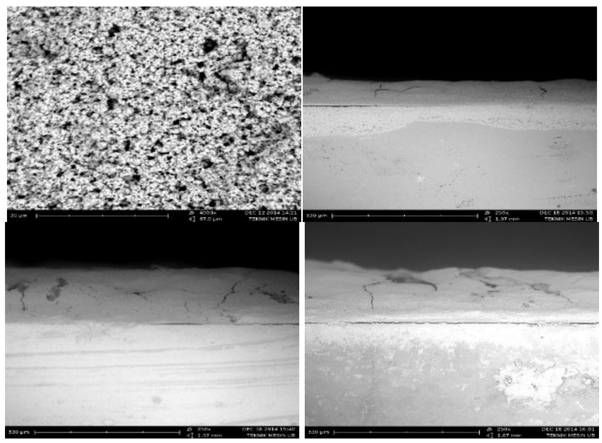

Figure 3. (a) The Top View of TiO_2 with 4000 Times Magnification (b) a Layer Mask Thickness of TiO_2 with 250 times Magnification (c) 2 Layer Masks Thickness of TiO_2 with 250 Times Magnification (d) 3 Layer Masks Thickness of TiO_2 with 250 Times Magnification

The voltage test of the light intensity was using luxmeter and voltmeter with 250 W mercury lamp. Light intensity variations are: 500, 2000, 5000, 10000, 20000, 30000 Lux.

Table 1. Results of Voltage Tests of The Light Intensity

Lux(Lux)	V_{137}(mV)	V_{284}(mV)	V_{292}(mV)
500	11	179	149
2000	31	240	205
5000	60	274	244
10000	98	290	262
20000	135	312	282
30000	166	330	307

Electrical current test of the light intensity was performed by luxmeter and ampermeter with 250 W mercury lamp. Light intensity variations are: 500, 2000, 5000, 10000, 20000, 30000 Lux. The table below is the result of electrical current test of the intensity of light.

Table 2. Result of The Electrical Current Test of Light Intensity

Lux	I_{137}(uA)	I_{284}(uA)	I_{292}(uA)
500	0.4	0.4	0.5
2000	1.2	0.8	3.7
5000	2.4	1.6	7.3
10000	3.7	1.9	9.6
20000	5.3	2.4	11
30000	8.3	2.7	15.2

Results of TiO_2 cell thickness variations test using LED lamps 7 watts with the luminance of 5000 lux. Testing was done by measuring the open circuit voltage (Voc) and short circuit current (Isc) using the test circuit. After Voc and Isc was obtained, Vmax and Imax was calculated to obtain FF (fill factor) and maximum power (Pmax). The calculation result Vmax and Imax DSSC with the thickness of TiO_2 are shown in table 3.

Table3. Calculation Result of V_{max} and I_{max} Thickness of DSSC:137 µm

x(V)	y(I)	x.y
0	7.3	0
25	6.57	164.25
50	5.84	292
75	5.11	383.25
100	4.38	438
125	3.65	456.25
150	2.92	438
175	2.19	383.25
200	1.46	292
225	0.73	164.25
250	0.01	2.5
260	0.001	0.26

Measurements and calculations of DSSC using TiO_2 with a thickness of 284 µm and 292 µm was done in the same manner with the measurement and calculation of DSSC with 137 µm thickness. Table below is the summary of test result based on thickness variation.

Table 4. Test Results of Thickness Variation of TiO_2 in DSSC

Variable (um)	Voc (mV)	Isc (µA)	Pmax (watt)
137	260	7.3	456.25×10^{-9}
284	363	2.1	184.975×10^{-9}
292	321	13.8	1008×10^{-9}

Cell test results showed that cells with a thickness of 292 micrometers has the best Isc and Pmax with the value 13.8 uA and 1008×10^{-9} watts.
Testing variations of TiO_2 drying time by LED lights Cool Daylight 7 Watt with illumination of 50,000 lux. Vmax and Imax DSSC calculation results with 30 minutes drying time of TiO_2 are shown in the table 5:

Table 5. Vmax and Imax Calculation Results of DSSC with 30 minutes of TiO_2 Drying Time

Voltage (mV)	Current (µA)	Maximum Power (nW)
0	20.400	0.000
20	19.424	388.480
40	18.448	737.920
60	17.472	1048.320
80	16.496	1319.680
100	15.520	1552.000
120	14.544	1745.280
140	13.568	1899.520
160	12.592	2014.720
180	11.616	2090.880
200	10.640	2128.000
220	9.664	2126.080
240	8.688	2085.120
260	7.712	2005.120
280	6.736	1886.080
300	5.760	1728.000
320	4.784	1530.880
340	3.808	1294.720
360	2.832	1019.520
380	1.856	705.280
400	0.880	352.000
418	0.002	0.669

Measurements and calculations on DSSC prototype with the variation of TiO_2 drying times at 45, 60, 75, and 90 minutes, also performed in the same manner with the measurement and calculation of DSSC with the variation of TiO_2 firing time for 30 minutes. Summary data from the fifth test the drying time variation shown in Table 6.

Table 6. DSSC Test Results of Drying Time Variation of TiO_2

Firing Time (menit)	Voc (mV)	Isc (μA)	Pmax (W)
30	418	20.4	2128×10^{-9}
45	373	3.6	334.469×10^{-9}
60	430	25.5	2735.44×10^{-9}
75	388	47.9	4642×10^{-9}
90	327	12.1	984.375×10^{-9}

The cells test results showed that solar cells with 75 minutes of TiO_2 firing time obtaining the best value for Isc and Pmax that is 47.9 μA and 4642 x 10-9 watts. While the best result Voc is TiO_2 with 60 minutes firing time which obtained 430 mV.

Conclusions

Based on test results of the thickness of TiO_2 and DSSC that had been carried out, it was concluded as follows that DSSC had been successfully designed and tested with 3 variations in the thickness of the layer mask. 1 layer mask to produce 137 μm, 2 layer masks to produce 284 μm and 3-layer masks to produce 292 μm. The thickness of 137 μm produces Voc =260 mV, Isc= 7.3 uA and maximum power =456.25 x 10^{-9} watts. Thickness of 284 μm produces Voc=363 mV, Isc=2.1 μA and maximum power =184 975 x 10^{-9} watts. Thickness of 292 μm produces Voc =321 mV, Isc=13.8 uA and maximum power =1008 x 10^{-9} watts. The thicker TiO_2 then the greater the power output of DSSC. It was proved on the thickness of 292 μm generate 1008 x 10^{-9} watts.

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