International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 1 (2015) pp. 193-205
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Characterization of Dye-Sensitized Solar Cell (DSSC) Based on Chlorophyll Dye

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Abstract

Performance of Dye-Sensitized Solar Cell (DSSC) based on chlorophyll dye that extracted form papaya and jatropha leaves was analyzed in this paper. The optical and electrical characterization DSSCs were investigated using solar radiation and under variation of light illuminations. A sandwich structure was designed by 2x2 cm active area of TCO which has a surface sheet resistivity of 15-25 ohms/sq. Photo-electrode layer using TiO_2 paste is deposited using doctor-blade technique and the counter electrode layer substrate coated with carbon that produced by candle. The parameters that affect to the electrical characteristics of the solar cells were also analyzed and measured using cool daylight and warm white LED. The output DSSC of papaya leaves chlorophyll-based was achieved when Air Mass 1.5 at 8:38 am under solar radiation of Voc and Isc are 393.8 mV and 60 μA, respectively. Thee I-V characteristic was obtained fill factor of 24.9%. Measured electrical characteristic between two lamps indicated that the cool daylight LED was produce the Voc and Isc greater than warm white LED. The output voltage and current response both of two lamps were investigated increasing exponentially.

Key words: DSSC, Chlorophyll Dye, light illumination, Air Mass.

Introduction

Increasing energy demand and limited of non-renewable energy resources have been attracted attention the researchers during industry development in recent years. The use of fossil fuels such as oil and gas is up to 55% and coal of 25% from the total available energy supply. While the utilization of renewable energy such as geothermal, wind, solar energy, and biomass only 3% are produced [1]. Utilization unlimited sources such as solar radiation energy is one of the efforts to reduce the use of fossil energy sources. Indonesia is located in the tropics area potentially to develop solar energy resource [2]. Solar radiation energy can be converted directly into electrical energy through a conversion device using Solar Cell. The most existing solar cell technologies today is still dominated by inorganic material-based technology such as single crystalline, poly-crystalline and amorphous [3]. The high costs and high energy use in the fabrication of solar cell technology based on inorganic materials makes this technology needs to be re-examined or need further development [4]. Eventually emerged solar cells based on dye-sensitized commonly called the DSSC (Dye-sensitized Solar Cell) with low cost production, low temperature process, variations from flexible substrates that can be used and the fabrication can be developed with clean environmentally [5-7].

Dye molecules that are commonly used to study the DSSC is ruthenium (*Ru*) complex dye [8-9]. Although the DSSC using ruthenium complexes have reached a high efficiency, but this type is quite difficult to be synthesized, and more expensive commercially [10]. Naturel dye that used in the fabrication of this DSSC is chlorophyll-extracted from of papaya leaves and jatropha leaves due to these obtained easily and chlorophyll number is quite high [11]. The basic principle [12] of the dye-sensitized solar cells that have been developed is shown in Figure 1. Photo-electrode layer of DSSC is deposited by TiO_2 paste using variation method such as simple brush painting, spin coating and doctor blading [13-14].

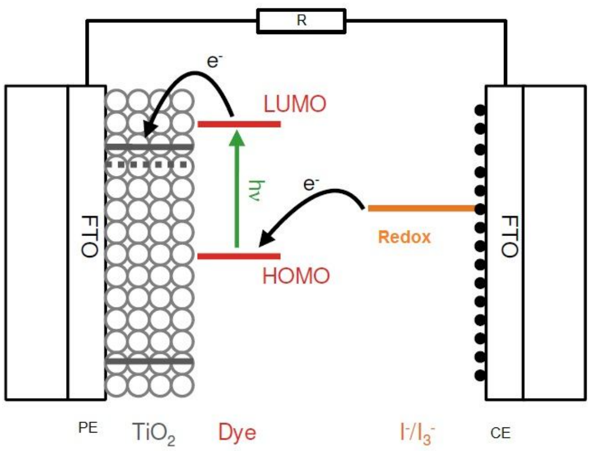


Figure 1: Basic principle of DSSC

Measurement of the DSSC output can be observed by utilizing solar radiation. Normally, the sunlight scatters 7% ultraviolet, 47% visible light, and 46% infrared. The sunlight will provide the highest visible light spectrum at the time of *Air Mass* (*AM*) 1.5 is to 54% [15]. Characterized performance of DSSC during AM 1.5 will be measured to find out the best performance of prototype that has been designed. Incident solar radiation spectrum at earth surface is shown in Figure 2.

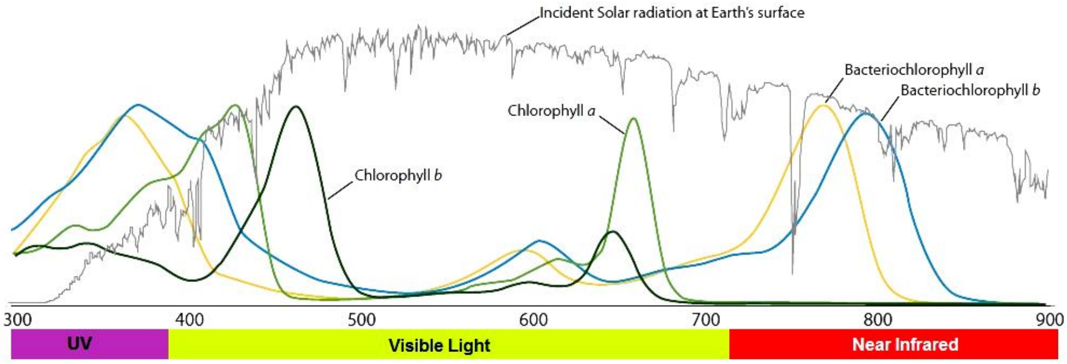
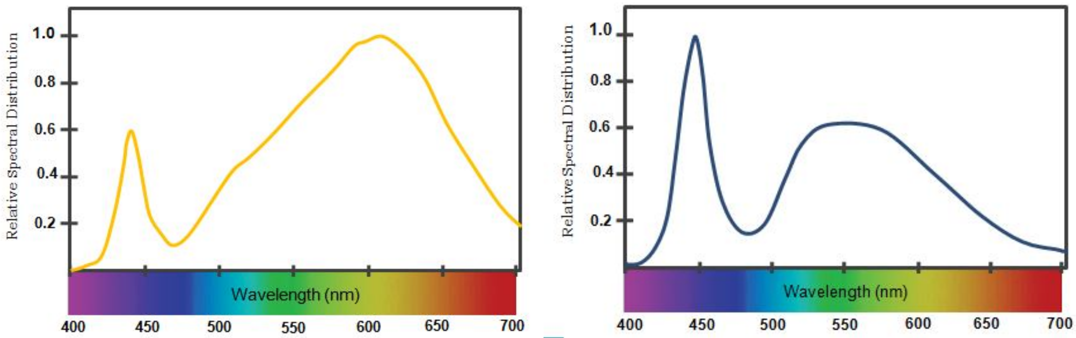


Figure 2: Spectrum of Solar Radiation and chlorophyll absorbance [16]



1.

Figure 3: Spectral Characteristic of LED (a) Warm White and (b) Cool Daylight.

Measuring at a certain intensity levels were also necessary observed the performance of a particular light spectrum by using several types of lights that have different light spectrum. Type LED Color Temperature Warm White has (CT) of 3000 Kelvin and Cool Daylight LED types of 6500 Kelvin [17]. Figure 2 (a) and (b) show the characteristics of the light spectrum types of warm white and cool daylight LED were used to characterize the DSSC.

Method

Dye-sensitized Solar Cell was designed using material of TCO substrate, nanoporous TiO_2, electrolyte solution, chlorophyll-extracted dye from papaya leaf, chlorophyll of jatropha leaf, and the carbon coating from candle soot. DSSC structure arranged in the form of a sandwich layer with the top layer as photo-electrode and bottom layer as the counter electrode. Flow diagram of DSSC fabrication process is shown in Figure 4 by following several steps.

A. Substrate Preparation

Two types of TCO-ITO (Indium Tin Oxide) glass of with resistivity of 10-25 Ω/sq cut with a size of 2 cm x 2 cm using a glass cutter. The glass is take placed in a clean container and immerses in ethanol for 10 minutes for sterile or that there are no additional resistance in TCO glass. After the cleaning is completed the substrate removed from the container and allowed to advance until all the solvent evaporates. Two substrates have a different role, these were photo-electrode and a counter electrode.

B. Preparation of TiO_2 Paste

TiO_2 paste was made to coat the substrate which acts as photo-electrode layer. TiO_2 should be made in the form of a paste that can stick to the TCO glass very well. Paste preparation procedure is as follows:

1. Preparation of the binder solution were made by mixing the Polyvinyl Alcohol (PVA) 1.5 grams into 13.5 ml of distilled water, then the mixture is stirred with a rotary motor at temperatures of 80°C for 30 minutes until thickened and homogeneous solution. PVA serves as a binder in the manufacture of TiO_2 paste.
2. The suspension has been created is added to the TiO_2 powder slowly to obtain a paste with the desired viscosity. The degree of viscosity of the paste to obtain optimal paste obtained by adjusting the amount of binder solution.

C. Preparation of Dye Solution

Preparation of dye in this study using the principles of extraction of chlorophyll from the leaves of papaya and also from jatropha leaf chlorophyll. The steps of extraction of chlorophyll are:

1. Prepare 10 grams of papaya and jatropha leaves.
2. The leaves are washed distilled water and dried.
3. The leaves are pounded on porcelain cup.
4. The leaves are finely put in 50 ml of 96% ethanol.
5. Papaya leaves that had been mixed with ethanol was stirred using a rotary motor for 30 minutes to produce chlorophyll extract.
6. The chlorophyll extract put in a dark bottle and allowed to stand for 24 hours to maximize the extraction process.
7. The extract was filtered with filter paper up to the substance separate completely between chlorophyll and leaves, then stored in a dark bottle that has been wrapped in aluminum foil and stored in the refrigerator.

D. Electrolyte Preparation

Electrolyte solution of iodide/tri-iodide prepared by the following procedure,

1. Mixing 0.8 g (0.5 M) of potassium iodide (KI) into 10 ml of acetonitrile and then stirred.
2. Addition of 0.127 g (0.05 M) Iodine (I2) is then stirred into the solution.
3. The solution was stored in a sealed bottle.

E. Counter Electrode Preparation

Counter-electrode on DSSC act as a catalyst. Catalysts are needed to accelerate the reaction kinetics tri-iodide reduction process at TCO. One of the substrate which acts as a counter electrode so that the candle flame burned using soot meet conductive area of the substrate.

F. DSSC Assembly

DSSC assembly was prepared by following several procedure:

2. The substrate is cut into a size of 2.5 cm x 2.5 cm as the area of TiO_2 deposited with the help of scotch tape on the side of the TCO conductive glass forming an area of 2 x 2 cm^2. Scotch tape is used to control the thickness of the TiO_2 paste.
3. A TiO_2 Paste deposited over the substrate area with a doctor blade method by the driving rod to flatten TiO_2 pasta starting from the side of the frame to a flat surface.
4. Substrates coated TiO2 paste is sintered in a furnace at a temperature of 450°C for 30 minutes. This process aims to establish the contact and adhesion well between the TCO glass substrate with TiO_2 Paste.
5. TiO_2 layers immersed in the dye solution for approximately 30 minutes and then a layer of TiO_2 will be green leaf. In this process occurs chlorophyll adsorption to the surface of TiO_2.
6. After the TiO_2 coated-substrate has been fused with leaf chlorophyll substance, the electrolyte solution was dropped evenly on the substrate area.
7. The final step in the assembly of DSSC is combining the two electrodes. Photo-electrode substrate attached together with the substrate which has been a counter-electrode at each end be offset by 0.5 cm as electrical contacts. Substrates are combined together using binder clips, these are positioned close to the edge to allow the maximum amount of the light that can be received cells. Assembled DSSC is shown in Figure 6 (a).

G. Experimental Measurement

1) Chlorophyll dye Measurement

Absorbance profile of chlorophyll dye solution from papaya and jatropha leaves were observed using UV–1601 UV-VIS *Spectrophotometer* Shimadzu at wavelength of 400-800 nm.

2) *Air Mass* (*AM*) Measurement

Air Mass is a measure of how much sunlight goes through atmosphere to reach the earth's surface which is denoted as *AM* (*x*) at certain condition, where *x* is the inverse of the cosine of solar zenith angle. Standards measurement of solar cell is AM 1.5 which means that the sun is at angle of 48° [18]. Air Mass can be obtained by calculation method of the ratio between object and shadow length that shows in Figure 5. Based on the Pythagoras theorem can be determined how much Air Mass [19] by the following equation (1).

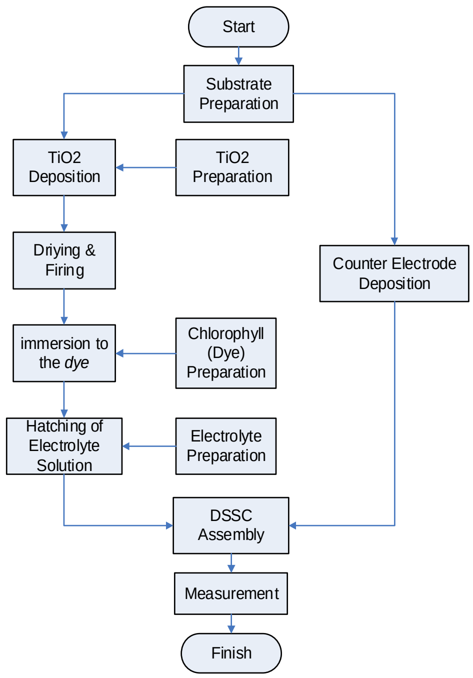


Figure 4: Fabrication process of DSSC

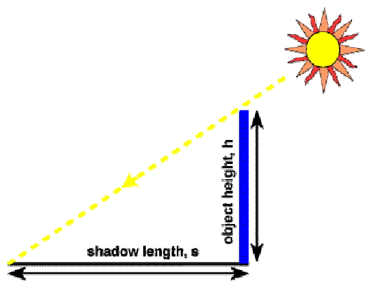


Figure 5: Measurement method of *air mass* (*AM*)

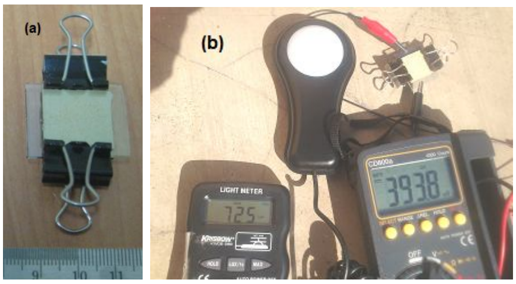


Figure 6: (a) DSSC Prototype and (b) measurement

$$AM = \sqrt{1 + \left(\frac{s}{h}\right)^2} \quad (1)$$

3) Electrical Characteristic Measurement

The electrical characteristic measurement method of DSSC is conducted under light illumination directly to determine the IV characteristics, performance and efficiency when the object is exposed to the variation of light intensity in the upper electrode (anode). In this research, the light source form direct solar radiation and two kind of lamps were used with different spectrum. The DSSC solar radiation measurement was conducted in Malang with coordinate of (7°57'02.2"S, 112°36'44.2"E) at February 3rd 2014. The lamps of warm white and cool daylight LED were used to characterize the electrical characteristics. The lights are used to determine the effect of light intensity and the different spectrums of the DSSC output.

The parameters were measured include the output circuit open circuit voltage *Voc*, short-circuit current *Isc*, maximum output power *Pmax*, Fill Factor (*FF*), efficiency (η), and Air Mass (*AM*). Configuration of the I-V characteristic measurement under solar radiation is shown in Figure 6 (b). Measurements carried out on the I-V characteristics of each solar cell using an ampere meter and voltmeter are arranged in series and parallel connection. Refer to the characterization of *Voc* and *Isc*, the maximum voltage *Vm* and maximum current *Im* of DSSC can be obtained and the fill factor were also can be calculated by Equation (2). The FF is defined the ratio between maximum output power *Pmax* consist of *Im* and *Vm* to the *Isc* and *Voc* [20].

$$FF = \frac{Im \times Vm}{Isc \times Voc} \quad (2)$$

Result and Discussion

H. Absorbance Spectra of Dye Solution

Spectrophotometric measurement results of papaya and jatropha leaves chlorophyll extract which acts as a dye using UV-VIS is shown in Figure 7. Based on the absorbance spectrum profile of chlorophyll, the both of dye have almost same absorption spectrum. The wavelengths differences of absorption spectrum only occur between range 500 nm – 600 nm. Overall, the measurement indicated that characteristics of papaya leaves chlorophyll to the photon absorption is higher than jatropha leaves due to the number of chlorophyll naturally.

I. Air Mass Measurement and Analysis

The measurement results of the shadow length from reference of 14.65 object length was obtained *AM* 1.5 occurred at 8:34 am. The AM 1.5 has a zenith angle θ of 48.2°. Measurement data of *AM* and zenith angle θ are shown in Table 1. The measurement of solar radiation intensity is shown in Figure 8. It was obtained correlation between AM and light intensity when the intensity is decreasing, the *AM* is increasing.

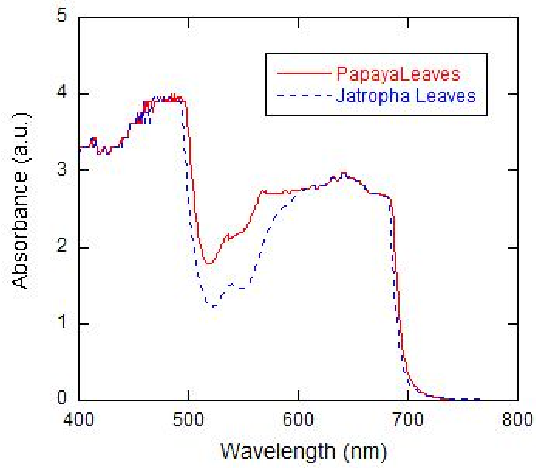


Figure 7: Absorbance spectra of chlorophyll dye extracted from papaya and jatropha leaves

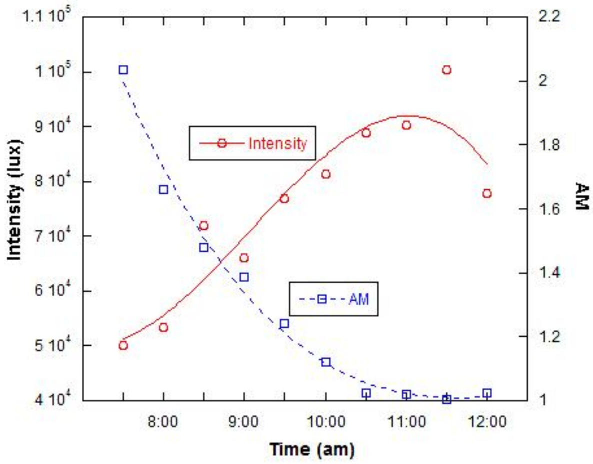


Figure 8: Measured *AM* and intensity from solar radiation

Table 1: Measurement data of *Air Mass* and *Zenith Angle*

Time	Object length (cm)	Shadow length (cm)	AM	θ (°)
7.00	14.65	33.8	2.515	66.567
7.45	14.65	26	2.037	60.600
8.00	14.65	20.5	1.720	54.449
8.10	14.65	19.4	1.659	52.942
8.30	14.65	17.5	1.558	50.066
8.34	14.65	16.4	1.501	48.226
8.38	14.65	16	1.481	47.522
8.45	14.65	15	1.431	45.676
8.50	14.65	14.1	1.388	43.904
9.00	14.65	12.7	1.323	40.922
9.30	14.65	10.8	1.242	36.398
10.00	14.65	7.5	1.123	27.110
10.30	14.65	5.1	1.059	19.194
10.45	14.65	3.2	1.024	12.322
11.00	14.65	2.9	1.019	11.197
11.15	14.65	2	1.009	7.774
11.30	14.65	1.2	1.003	4.683
11.46	14.65	1.5	1.005	5.846
12.19	14.65	3.3	1.025	12.694
13.03	14.65	6.5	1.094	23.926

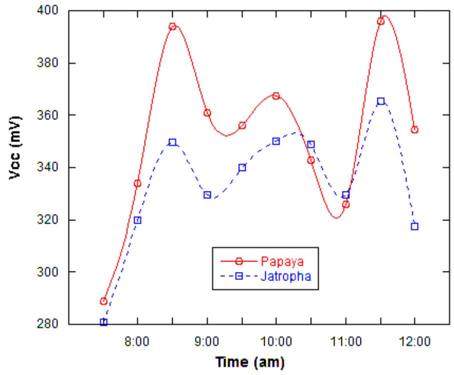


Figure 9: Open Circuit Voltage (V_{oc}) measurement of DSSC under solar illumination

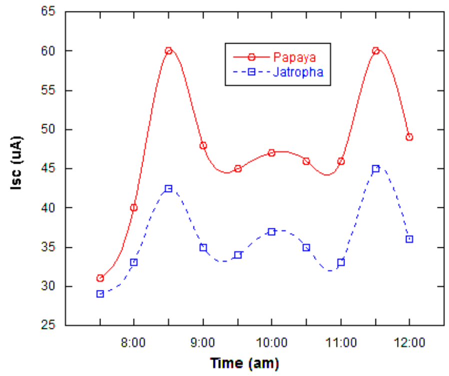


Figure 10: Short circuit current (I_{sc}) measurement of DSSC under solar illumination

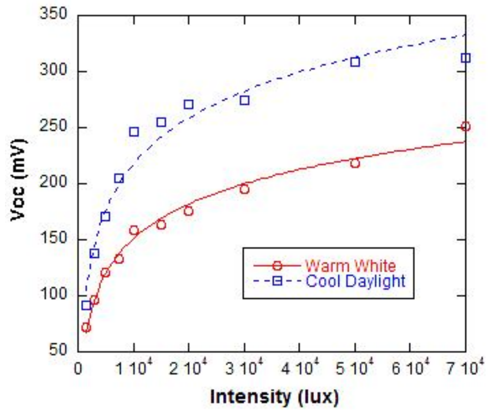


Figure 11: Open Circuit Voltage (V_{oc}) measurement of DSSC based on papaya leaves dye under illumination of different lamp intensities

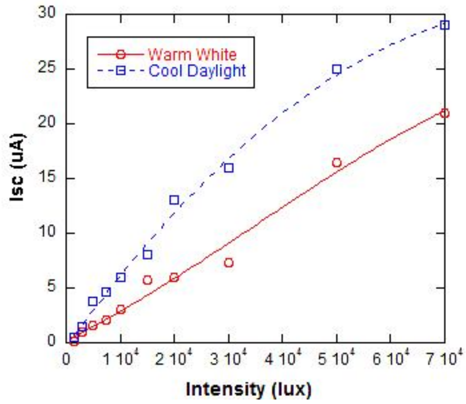


Figure 12: Short circuit current (I_{sc}) measurement of DSSC based on papaya leaves dye under illumination of different lamp intensities

J. I-V Characteristic under Solar Illumination

The electrical characteristics measurements were acquired the different voltage and current at certain hours. This phenomenon occurs due to the intensity of solar radiation varies according to the time, clouds and the Air Mass (AM). Open circuit voltage Voc and sort circuit current Isc were shown if Figure 9 and Figure 10, respectively. At 11:31am, illumination intensity of sunlight was received higher, it was 100400 lux at AM 1 then the output power generated is higher than any other time. Both of Voc and Isc to be maximum of 396 mV and 60μA for papaya leaves-based DSSC. Jatropha leaves-based DSSC was obtain Voc of 365 mV and Isc 45μA. During sunlight conditions at AM 1.5, papaya leaves-based DSSC produced open-circuit voltage Voc of 394μV and short circuit current Isc of 60μA. The Jatropha-based DSSC was achieved Voc and Isc of 350 mV and 43μA, respectively. The current that has been generated DSSC is still less, it shows the electron collection efficiency is low, so the diffusion of electrons running slow and thus lower photon conversion efficiency. The performance of the solar cell are shown in Table 2.

Table 2: Electrical performance of DSSC measured under solar illumination at AM 1.5

Parameters	*Papaya*	*Jatropha*
Voc (mV)	393.8	349.5
Isc (μA)	60	42.5
Vm (mV)	200	170
Im (μA)	25.1	21.83
Pm (μW)	5.02	3.7
Fill factor	0.2499	0.2498

K. DSSC Characteristic under lamp measurement

The measurements are conducted on prototype DSSC made from papaya leaves chlorophyll dye materials under irradiation lamp warm white and cool daylight. Figure 11 and 12 show the performance characteristics of DSSC dye made from papaya leaves chlorophyll. Based on these characteristics were shown that the increasing intensity produced both of the Voc and Isc DSSC increasing. Measurements with cool daylight indicates the voltage and current generated by the DSSC is greater than the warm white LEDs. Both of characteristics increase exponentially.

Conclusion

Based on the design and characterization that has been implemented, it can be concluded:

1. The DSSC has been developed using doctor blading method for TiO_2 deposition process on the substrate. Dyes are used derived from an extract of papaya leaves and jatropha chlorophyll.
2. The output power of DSSC made papaya leaf chlorophyll and leaf chlorophyll-based DSSC jatropha do not differ much when at 8:00 until noon. In solar light illumination greater than 50000 lux which occurred from 8:00 until noon obtained Voc around 300-396 mV and Isc 30-60μA.
3. During *AM* 1.5 at 8:38, DSSC made from papaya leaves chlorophyll produce 393.8 mV Voc and 60μA Isc. DSSC made within the jatropha leaves chlorophyll produces 350 mV *Voc* and 43μA *Isc*.
4. The increasing of the light illumination produced the increasing the DSSC output performances. At the same illumination, LED-type Cool Daylight produce Voc and Isc higher than Warm White light.

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