Fabrication and Characterization of *Sansevieria trifasciata*, *Pandanus amaryllifolius* and *Cassia angustifolia* as Photosensitizer for Dye Sensitized Solar Cells

Cari[a)], Agus Supriyanto[b)], Ulfa Mahfudli Fadli[c)], Ashari Bayu Prasada[d)]

[1]Physics Department Faculty of Mathematics and Science, Sebelas Maret University, St. Ir. Sutami 36A Kentingan Surakarta 57126, Indonesia

[a]carinln@yahoo.com, [b]*agusf22@yahoo.com, [c]oasis.190712@gmail.com, [d]asharidulhasyim@yahoo.co.id

Abstract: Dye sensitized Solar Cells (DSSC) is one of the electric cells photochemical consisting of photoelectrode, dye, counter electrode, and electrolyte. The aims of the research to determine of the optical and electrical characteristic of the extract *Sansevieria trifasciata*, *Pandanus amaryllifolius*, and *Cassia angustifolia*. The study is also aimed to determine the effect of natural dyes extract to increase the efficiency of solar cells based DSSC. Sandwich structures formed in the sample consisted of working electrode pair Titanium dioxide (TiO_2) and the counter electrode platinum (Pt). Dye extraction process is performed by stirring for 1 hour and then allowed to stand for 24 hours. Absorbance test is measure by using UV-Vis spectrophotometer Lambda 25, conductivity test by using a two-point probes Elkahfi 100, and characterization of current and voltage (I-V) by using a Keithley 2602A. The results showed that the greatest efficiency of 0.160% at Dye *Pandanus amaryllifolius*.

Keywords: **Dye Sensitized Solar Cells, TiO_2, Photosensitizer, Natural Dyes.**

1. Introduction

Solar cells based on current technological developments and manufacturing materials can be divided into three: first, solar cells made from silicon single and multi-crystalline silicon, second, the type of thin-layer solar cells, and third, organic solar cells (DSSC). Conventional solar cells in the form of a p-n junction made of a semiconductor material such as silicon, is still expensive to develop because it uses sophisticated technology. Until invented by Gratzel that organic solar cells, DSSC as a solar cell with a dye sensitizer of organic materials can be developed at low cost and low fabrication [1].

DSSC is different from a commercial silicon-based solar cells, in which the solar cells DSSC is a separation between the functions of light absorption to transport cargo carrier [2]. DSSC advantages compared to commercial silicon-based solar cells including a cheap, easy to manufacture, and has a high efficiency even at low light intensity [3]. DSSC is a photoelectrochemical solar cells that use an electrolyte as charge transport medium. DSSC is divided into sections consisting of nanopori TiO_2, dye molecules are adsorbed on the surface of TiO_2 and catalysts which are all deposited between two conductive glass. DSSC structure looks like Figure 1.

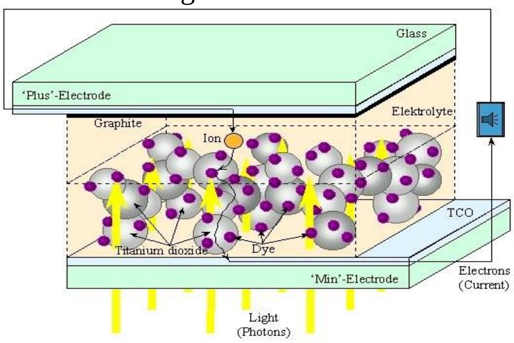


Figure 1. Structure of Dye-Sensitized Solar Cells (DSSC) [3]

Basically the working principle of DSSC convert light into electrical energy in a molecular scale in the form of electron transfer reactions. The first process starts with the excitation of electrons in the dye due to the absorption of energy photons. Where it is one of the roles of the nature of TiO_2. When photons of sunlight impinge on the working electrode DSSC, the photon energy is absorbed by the electron dye attached to the surface of TiO_2. Thus get energy for the excited electron. Photoexcitation of the dye results in the injection of electron into the conduction band of TiO_2. TiO_2 acts as an electron acceptor and dye acts as an electron donor. Furthermore, the electrons are transferred past the outer circuit to the reference electrode of platinum layer. Electrolytes containing I^-/I_3^- which acts as an electron mediator so that it can produce in the cell cycle process. Triodide ions capture electrons originating from outside the circuit with the help of platinum molecules as catalyst. Excited electrons back into the cell and aided by the platinum that can react with the electrolyte which causes the addition of iodide ions on the electrons. Then one of iodide ions in the electrolyte to deliver electrons that carry the energy to the oxidized dye. Electrolytes provide replacement electrons to oxidized dye molecules. So that the dye back to its initial state. As shown in Figure 2.

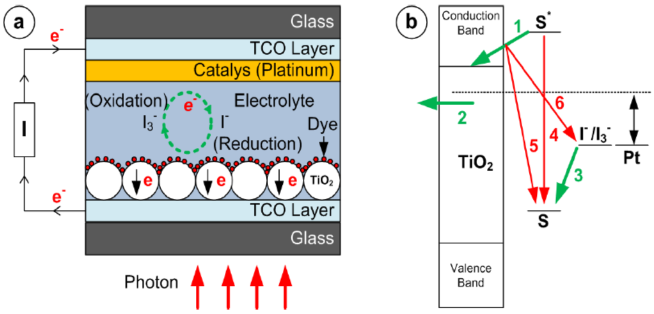


Figure 2. (a) The working principle and (b) diagrams of solar cell energy [5]

DSSC is inseparable from Dye, in this case the color has an important role as an absorber of sunlight and convert it into electrical energy. In the studies that have been conducted, the ruthenium complex dye of the compound can achieve efficiencies of 11-12% [6]. However, the amount of ruthenium complex dye is limited and the price is quite expensive. For these reasons, developing research towards finding natural dyes extracted from flowers, leaves, and fruits [7]. Natural dye that is used as a sensitizer in DSSC classified as environmentally friendly, making it too easy and cheap despite its low lifetime [8]. Several studies using material from platinum (Pt) as the counter electrode in the DSSC.

In this study, used platinum (Pt) as the counter electrode in DSSC made from organic extracts of *Sansevieria trifasciata*, *Pandanus amaryllifolius*, and *Cassia angustifolia*.

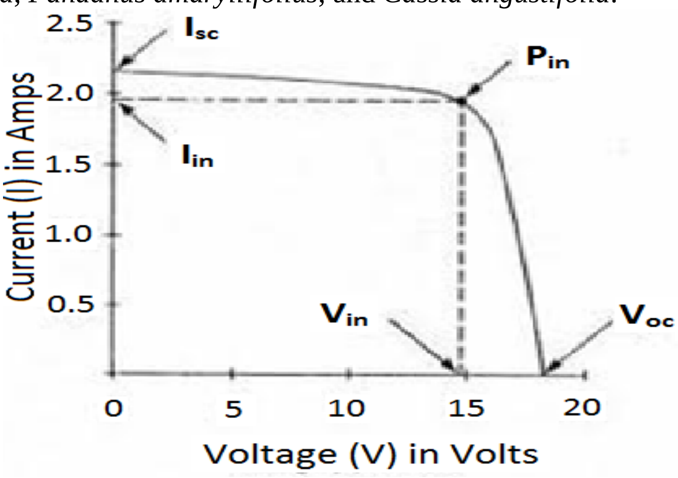


Figure 3. Graph Characteristics I-V DSSC [4]

Performance solar cells is the ability to convert light into electrical energy. Performance solar cells is measured using Keithley 2602A to find the value of short circuit current (I_{sc}) and open circuit voltage (V_{oc}). Figure 3. shows I_{sc} vs $V_{oc.}$ The value of I_{sc} is determined based on the data in which the voltage value starts from a negative to a positive. Similary for the value of V_{oc} is determined by the current value starts from a negative to a positive value. Then the value maximum voltage (V_{max}) and maximum current (I_{max}) are obtained by multiplication of voltage and current to find the maximum value of power. Performance solar cell is determined by comparing maximum power and multiplication result V_{oc} and I_{sc}.

Fill factor (FF) is a measure of the quality of the performance of the solar cells [9], as well as the size of the square area of I_{sc} – V_{oc} curve. The value of FF can be obtained using equation (1):

$$FF = \frac{V_{maks} \times I_{maks}}{V_{oc} \times I_{sc}} \qquad (1)$$

The maximum power (P_{max}) produced by the solar cell can be obtained through the equation (2):

$$P_{maks} = V_{oc} \times I_{sc} \times FF \qquad (2)$$

Efficiency (η) produced by solar cells can be obtained through the equation (3):

$$\eta = \frac{P_{maks}}{P_{in}} = \frac{V_{oc} \times I_{sc} \times FF}{I(t) \times A_c} \qquad (3)$$

From equation (3), the solar cell efficiency is a quantity of the ratio between the maximum power generated cells (P_{maks}) and the power of the incoming light (P_{in}).

2. Experiment

2.1. Preparation of TiO_2 Solution.

TiO_2 nano powders as much as 0.5 grams dissolved in 2 ml of ethanol, then stirred using a vortex stirrer with a speed of 200-300 rpm for 30 minutes. Pasta TiO_2 that has been formed is inserted into the bottle covered with aluminum foil and stored in an area free from direct sunlight to reduce evaporation process.

2.2. Preparation of Natural Dye Sensitizers.

Sansevieria trifasciata, *Pandanus amaryllifolius*, and *Cassia angustifolia* using digital scales weight 10 grams. Furthermore, these materials crushed and pulverized using a mortar. The materials that have been refined dissolved in 40 ml of ethanol, then stirred for 60 minutes using a vortex stirrer with a rotational speed of 300 rpm at 60°C. Once the material is dissolved, allowed to stand for 24 hours and filtered with a filter paper quality no. 42. Extraction result is stored in closed containers and protected from the sun.

2.3. Preparation of Electrolyte

Potassium iodide (KI) 0.5 M of 0.8 grams in the form of solids are mixed into 10 ml polyethylene glycol then stirred. Further to the solution is added iodine (I_2) 0.05 M of 0.127 grams was stirred with a vortex stirrer at 300 rpm for 30 minutes. Electrolytes solution that is so, is stored in closed containers lined with aluminum foil.

2.4. Preparation of Counter Electrode

The counter electrode in the form of FTO conductive glass that has been coated with a thin layer of platinum (Hexachloroplatinic (IV) acid 10%). The step of making the counter electrode is 1 ml Hexachloroplatinic (IV) acid 10% was mixed with 207 ml of isopropanol was stirred using a vortex stirrer at 300 rpm for 30 minutes. FTO glass is heated using a hotplate at a temperature at 250^0C for 15 minutes and then a few drops of a solution of 3 ml of platinum onto the surface of the glass substrate FTO with drip method. Glass that has been spilled platinum is then cooled at room temperature.

2.5. Preparation of TiO_2 Electrode.

The working electrode is made of glass on which the FTO conductive paste deposited TiO_2 nano with spin coating techniques. At the FTO glass with size 2 x 2 cm formed for area deposition of TiO_2 at 1 x 1 cm on the conductive surface. FTO side masking tape affixed as a barrier. Pasta TiO_2 dripped on FTO glass that has been glued in the spinner, then stirring with a speed of 200-300 rpm. FTO glass that has been coated with TiO_2 is heated using a hotplate at temperature of 500^0C for 60 minutes, then cooled at room temperature.

2.6. Assembly of Sandwich DSSC

The composition of the DSSC in the form of glass FTO that has been coated with TiO_2 and has been soaked in a dye solution is called the working electrode. The working electrode is etched with an electrolyte solution and then covered with glass that has been coated with platinum, called the counter electrode. Then the composition of DSSC is clamped with a clamp on both sides of the right and left before a measuring to get a data.

3. Result and Discussion

3.1. Absorption Spectra of extract natural dye

Before being used as a sensitizer, extract *Sansevieria trifasciata*, *Pandanus amaryllifolius* and *Cassia angustifolia*, first characterized using UV-Vis Spectrophotometer. Absorbance spectra measured in the wavelength range of 200-800 nm.

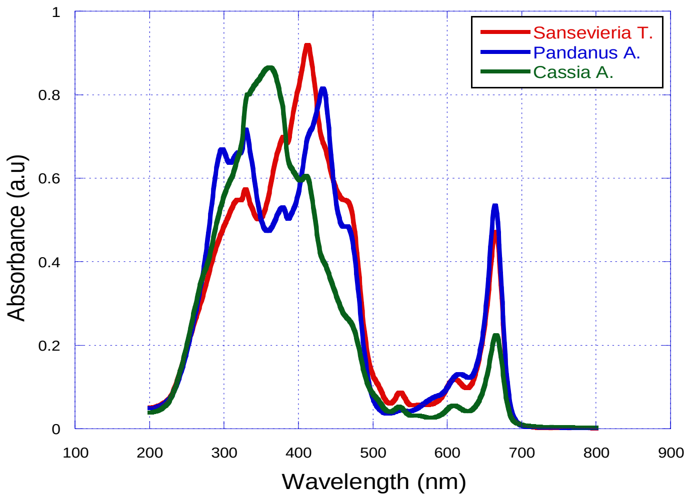


Figure 4. Absorption Spectrum of extract *Sansevieria trifasciata*, *Pandanus amaryllifolius*, and *Cassia angustifolia*

Figure 4 shows a maximum absorption around 300-670 nm, absorbance maximum extract *Sansevieria trifasciata* at 0.919 and 0.471 a.u with wavelength between 412 nm and 665 nm. Extract of *Pandanus amaryllifolius* at 0.815 and 0.535 a.u with wavelength between 433 nm and 664 nm, and extract *Cassia angustifolia* is at 0.865 and 0.224 a.u with wavelength between 362 nm and 666 nm. Absorbance dye of the three materials showed that the value of wavelength of these material are able to work on the visible light. From Figure 4, it can be concluded that the third material of organic compounds can be used for DSSC.

3.2. Conductivity of extract natural dye

Further characterization is conductivity testing of dye using Elkahfi 100/IV-Meter under irradiation halogen lamp 100 mW/cm^2 and the energy intensity of 680.3 W/m^2.

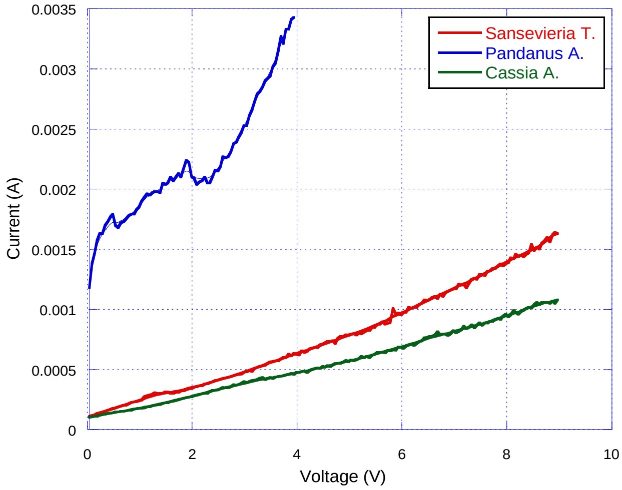
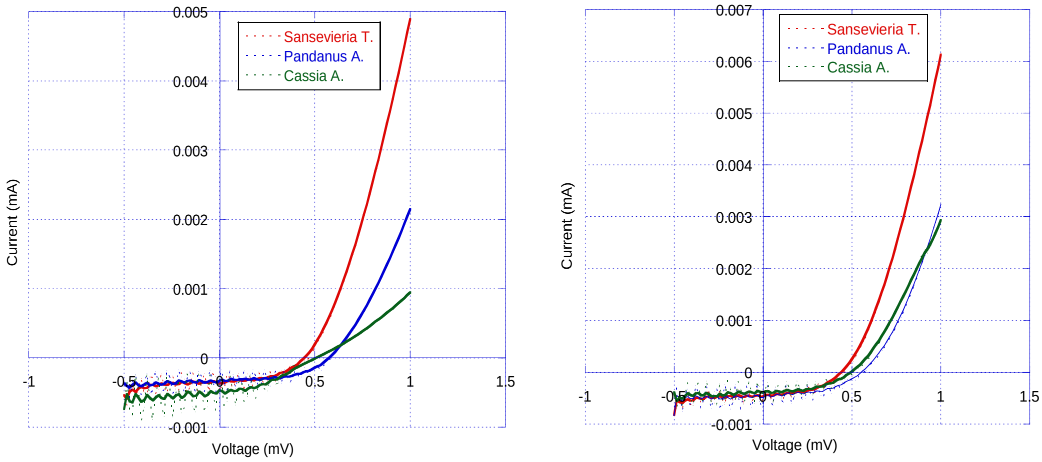


Figure 5. Conductivity Curve for *Sansevieria trifasciata*, *Pandanus amaryllifolius* and *Cassia angustifolia* extract sensitized solar cell

Figure 5 shows the conductivity value of the *Sansevieria trifasciata* is 8.34 x 10^{-3} Ω^{-1}m^{-1}, *Pandanus amaryllifolius* is 9.73 x 10^{-2} Ω^{-1}m^{-1}, and *Cassia angustifolia* is 6.39 x 10^{-3} Ω^{-1}m^{-1}.

3.3. Photovoltaic Properties

Characterization of the current-voltage (I-V) is a method to determine how much ability DSSC can convert light into electrical energy. Measurements using Keithley 2602A conducted in the dark and the light that is under irradiation with a halogen light intensity of 1000 W/m^2. The test results I-V with a variety of immersion during 12 hours and 24 hours.



(a) (b)

Figure 6. Current-Voltage curve for; (a) DSSC natural dye within 12-hours immersion, (b) DSSC natural dye within 24-hours immersion

Based on the graph in Figure 6, it can be shown the area of *Pandanus amaryllifolius* dye the largest, because the value of V_{oc} intercept at 5,50 x 10^{-1} mV and the value I_{sc} intercept at 4,79 x 10^{-4} mA. Therefore, it has the largest value of efficiency. So based on the calculations of equation (1-3) have been carried out, The results of the efficiency of the extract *Sansevieria trifasciata*, *Pandanus amaryllifolius* and *Cassia angustifolia* by 12 hours and 24 hours immersion, are shown in Table 1.

Table 1. Photovoltaic performance with natural dyes from different sources

Dye Source	Isc (mA)	Voc (mV)	FF	immersion	η (%)
Sansevieria trifasciata 	4,25 x 10^{-4}	4,60 x 10^{-1}	1,07 x 10^{-7}	12 hours	0,116
	4,25 x 10^{-4}	4,75 x 10^{-1}	8,83 x 10^{-8}	24 hours	0,098
Pandanus amaryllifolius 	4,79 x 10^{-4}	5,50 x 10^{-1}	1,39 x 10^{-7}	12 hours	0,160
	1,74 x 10^{-4}	5,95 x 10^{-1}	3,80 x 10^{-8}	24 hours	0,130
Cassia angustifolia 	3,74 x 10^{-4}	5,20 x 10^{-1}	8,80 x 10^{-8}	12 hours	0,122
	3,26 x 10^{-4}	5,05 x 10^{-1}	7,70 x 10^{-8}	24 hours	0,119

The value of efficiency is calculated by using equation 3, see Table 1. From Table 1 and figure 6, it can be concluded that the DSSC that produces the best performance is dye of *Pandanus amaryllifolius* with efficiency value is 0.160% in 12-hour immersion. In general, the value efficiency of the third material of organic compounds is still very small (under 1%). There are two kind of efforts to increase the performance DSSC. The first, using different counter electrode with polyaniline (PANI), because PANI can increase efficiency from 6,90% using platinum to 7,15% using PANI [10]. The second, using the kind of electrolyte which has viscosity is smaller than iodine electrolyte such as PEO polymer gel [11].

4. Summary

From the results of this study concluded that the solar cell DSSC has been successfully created by using dye *Sansevieria trifasciata*, *Pandanus amaryllifolius* and *Cassia angustifolia*. The results of the absorbance dye of the three materials showed that the value of wavelength these material are able to work on the visible light. The largest conductivity value is *Pandanus amaryllifolius* dye, whereas the greatest efficiency in achieved by using the extract samples *Pandanus amaryllifolius* on 12 hour immersion in the amount of 0.160%.

Acknowledgement
This research was partly supported by LPPM Postgraduate UNS Grant with contract no. 698/UN27/PN/2015 May 11th, 2015.

Journal of Physics: Conference Series **710** (2016) 012027 doi:10.1088/1742-6596/710/1/012027

References

[1] V. Ekasari, G. Yudoyono, Fabrikasi DSSC dengan Dye Ekstrak Jahe Merah (*Zingiber Officinale Linn Var. Rubrum*) Variasi Larutan TiO_2 Nanopartikel Berfase Anatase dengan Teknik Pelapisan *Spin Coating*, vol. 2, no. 1, 2013, pp. B-15-B-20.

[2] A. Hagfeldt, B. Didriksson, T. Palmqwist, H. Lindstrom and S. Lindsquist, Solar Energy Matter and Solar Cells Verification of high efficiencies for the Gratzel-cell a 7% efficient solar cell based on dye-sensitized colloidal TiO2 films, vol. 5, 1994, pp. 481-488.

[3] M. Akiyama, E. Abe and I. Imai, High efficiency dye-sensitized solar cell based on a nitrogen doped nanostructured titania electrode, vol. 5, 2005, pp. 2543-2547.

[4] Alfa, B. *et al*., *Fabrication and Characterisation of Titanium Dioxide Based Dye Sensitized Solar Cell using Flame of the Forest Dye*, Applied Physics Research, vol.4, no.1, 2012, pp 48-56.

[5] Xu, F., and Sun, L. 2011. *Solution-Derived ZnO Nanostructures for Photoanodes of Dye-Sensitized Solar Cells*, Energy Environ. Sci. 4, 818.

[6] S. Agustini, D.D. Risanti dan D. Sawitri, Fabrikasi *Dye Sensitized Solar Cell* (DSSC) Bersadarkan Fraksi Volume TiO_2 Anatase-Rutile dengan *Garnicia mangostana* dan *Rhoeo Spathacea* sebagai *Dye Fotosensitizer*, vol. 2, no. 2, 2013, pp. B-131-B-136.

[7] H. Zhou, W. Liqiong, G. Yurong and M. Tingli, Dye-Sensitized Solar Cells Using 20 Natural Dyes As Sensitizers, *Journal of Photochemistry and Photobiology A Chemistry*, 2011, pp. 188-194.

[8] J.K. Lee and Y. Mengjin, Progress In Light Harvesting and Charge Injection of Dye-Sensitized Solar Cells, *Material Science and Engineering* B 176, 2011, pp. 1142-1160.

[9] Cari, Nurussaniah, Biosandi, Anita, A. Supriyanto dan R. Suryana, Studi Penggunaan Poly(3-Hexylthiophene) P3HT dan Grafit Terhadap Kinerja Solar Cells, vol. 3, no. 1, 2013.

[10] Qinghua Li. Jihua Wu. Qunwei Tang. Zhang Lan. Pinjiang Li. Jianming Lin. Leqing Fan, *Application of Microporous Polyaniline Counter Electrode for Dye Sensitized Sollar Cells*, Electrochemistry Communications, Elseiver, 2008.

[11] Duangkaew, P., Chindaduang, A., Tumcharem, Efficiency and Stability Enhanchement of Dye Sensitized Solar Cell using PEO Polymer Gel and Imidazolium-Based Ionic Liquid Electrolyte, Science Jurnal Ubonratchathani University. Vol 1. No 1 (January-June), 2010, pp. 9-14.