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Performance Stability and Optical Properties of *Musa Acuminata* bracts-based Dye-Sensitized Solar Cell

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Abstract

The study of stability and optical properties of the dye-sensitized solar cell (DSSC) based extract of *Musa Acuminata bracts* have been done.Banana flowers extract was used as photoactive material because it contains anthocyanin. This study focuses on the optimization of semiconductor, natural pigment, and the counter electrode.The ZnO coating used spray coating method. Anthocyanin and polyethylene glycol (PEG) coating were conducted using droplet method.Fabrication of plated copper counter electrode was performed using the electrochemical method. PEDOT:PSS electrolyte is coated on the final process after the two electrodes are coupled by inserting between the two electrodes. The highest efficiency reached $6.24 x 10^{-2}$%.

Keywords: anthocyanins; musa acuminata bracts; droplet method; DSSC Pt-free; electrochemical method

1. Introduction

DSSC is the development of solar cells by utilizing organic materials. This study was developed by utilizing the whole plant parts such as roots, stems, branches, leaves, fruits, bark, seeds and flowers as a photoactive material.

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DSSC advantages include low production cost, ease of fabrication, colourful, semi-transparent, low electrical energy consumption and the device is easily integrated with the building [1]. It also benefited from the high potential of energy conversion efficiency achieved, non-toxic [2], easy to use, environmentally friendly, and easily biodegraded [3].

There are three main components making up the DSSC, the working electrode as photoanode, a counter electrode as the cathode, and the electrolyte solution that is influential in redox reactions [4]. The working electrode includes transparent conductive glass, such as fluorine-doped tin oxide (FTO), TiO_2 semiconductor layer and the active layer of dye [5]. DSSC consists of photoanode made of n-type semiconductor (usually titanium dioxide (TiO_2) and zinc oxide (ZnO) [6]. The counter electrode consists of transparent conductive glass (TCO) coated carbon [7]. While the electrolyte used is triiodide iodine electrolyte with a redox couple (I^-/I^{3-}) [5] which has the highest efficiency [6].

ZnO semiconductor layer has high electron mobility that is 115-155 $cm^2 V^{-1} s^{-1}$ compared with TiO_2. Various studies have been developed specifically to optimize the performance of ZnO. Some of the methods used for superimposing ZnO such as electrodeposition, sol-gel, pulsed laser deposition, chemical vapor deposition, magnetron sputtering and hydrothermal, spray pyrolysis [6].

The counter electrode was made of copper (Cu) to replace Pt due to it is rare and expensive [8]. Copper can play a role as a catalyst. Metallic coating on other metals more easily using electrochemical deposition method [9]. Due to the growth of the film take place in which the electrons flow in the electrodeposition process, the conductive properties of the films are guaranteed without any heating [10].

Best photovoltaic performance in terms of conversion results and long-term stability has been achieved using ruthenium and osmium complexes polypyridyl [2].

Natural pigments were obtained from extracts of roots, branch, leaves, flowers, and fruits of plants. Pigments plant is a type of coloured chemical substances produced by plants during absorption of radiation between 380-780 nm. The main types of plant pigments classified based on colour are chlorophylls, anthocyanins, betalanin and carotenoids [11]. The highest efficiency of DSSC with natural pigments achieved using a modified leaf spinach chlorophyll which is 4.2% [12].

In this study the anthocyanin banana flowers extracts have been used as a natural pigment photovoltaic layer. It is used because its abondances in Indonesia, with the name *Musa Acuminata*. Utilization of banana flowers at present only as a food ingredient although it has a broad range of absorbance spectrum (violet-red, 350-700 nm) [13] available for the active layer of the DSSC. Anthocyanin extract of banana can perform electron donor in the active layer components [13].

2. Materials and methods

The materials used for the fabrication DSSC is Indium Tin Oxide (ITO) $7\Omega/cm^2$, ZnO powder, polyethylene glycol (PEG), and PEDOT:PSS from Sigma Aldrich, 96% ethanol, acetic acid, distilled water, copper sulfate ($CuSO_4$), and copper rod from Semarang, Indonesia. The basic structure of the DSSC made a layered called sandwich layer. There are three main components making up the DSSC, the working electrode, a counter electrode and an electrolyte solution [4], DSSC structure can be seen in Fig. 1.

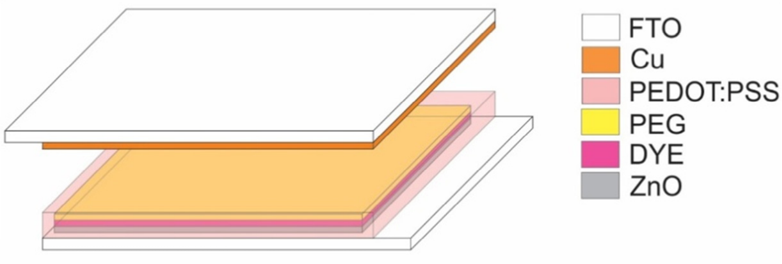

Fig. 1. Structure and design of DSSC

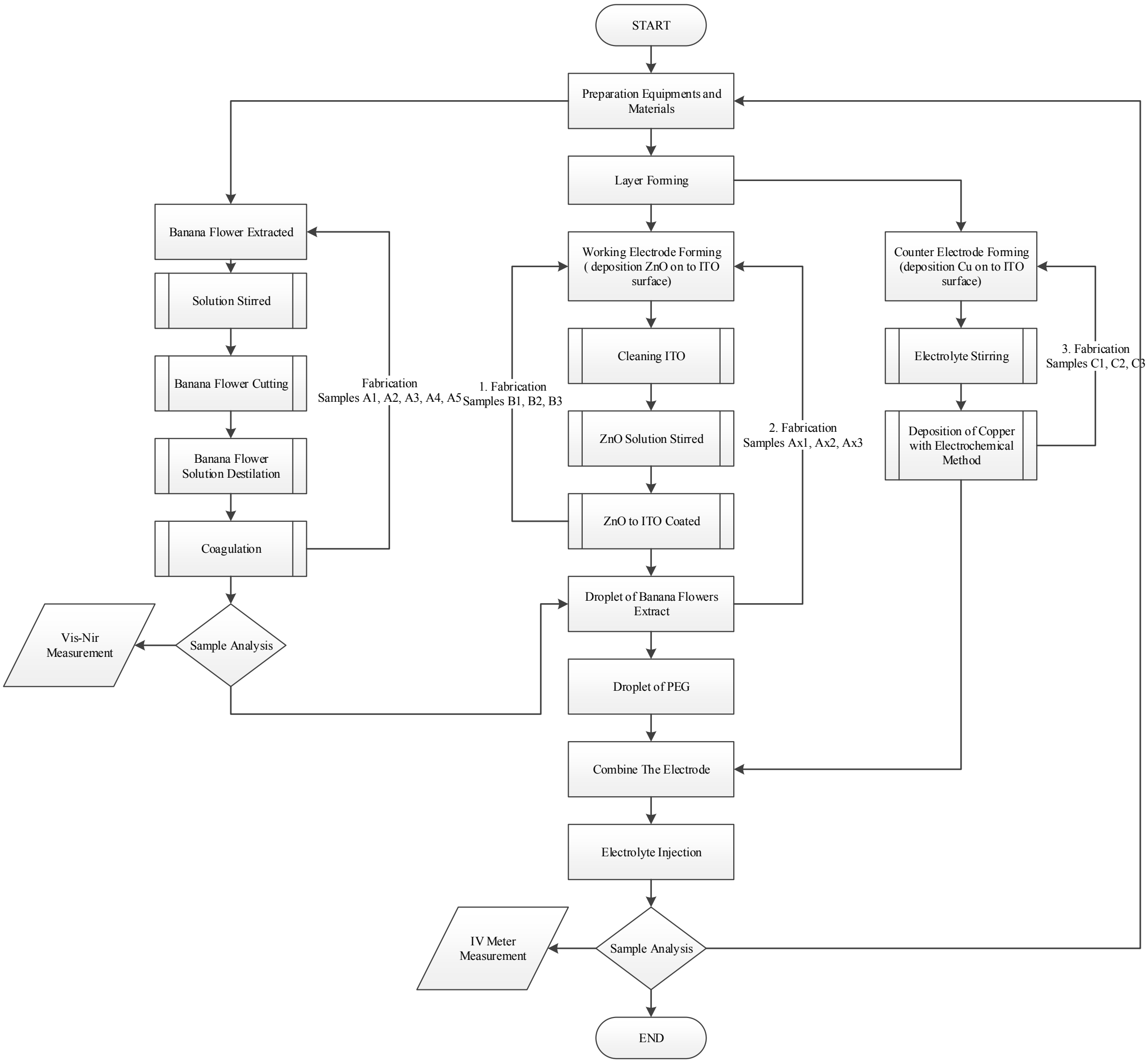

Fig. 2. Flow-chart of DSSC fabrication technology.

The device had been fabricated based on the research procedure as Fig. 2. The concentration of banana varied by changing the weight of banana 21 g, 47 g, 80 g, 124 g and 186 g for the sample code in a row A1, A2, A3, A4, and A5 using the same steps in the Sutikno et al. 2014 research's and the same fraction on Sutikno et al. 2016 research's [13-14], DSSC fabrication was done in several stages.

ZnO coating on ITO glass substrate according to Fig. 2. used the spray coating method. ITO glass size of 1 cm x 1 cm was cleaned and soaked with ethanol by insulation around it to get a layer of ZnO 0.8 cm x 0.8 cm. ZnO powder (4 g) was stirred using a magnetic stirrer with 32 ml of ethanol for 15 min at a speed of 1500 rpm and a temperature of 55 °C. Air brush pressure of 4 bar was used for superimposing ZnO. ZnO sprayed over 5 times the ITO glass substrate at a distance of 30 cm between the tip of the brush with ITO glass of water placed in a box measuring 25 cm x 50 cm x 30 cm. Then it was heated with a Bunsen and spraying again on it as much as 5, 15 and 25 times for B1, B2 and B3, respectively. The volume of ZnO solution was sprayed correspond B1 (1.2 ml), B2 (2.4 ml), and B3 (3.6 ml). After completion of the coating, insulation attached to the ITO glass was released so as not burned by Bunsen and to be the crust. ZnO-coated ITO substrate was heated over a Bunsen further for 3 h.

Anthocyanin was deposited on a substrate of ITO-coated ZnO according to Fig. 2. using droplet method. Previously, anthocyanin thickened using a magnetic stirrer for 1 h to facilitate coating anthocyanin extract of banana on ZnO. ITO-coated ZnO substrate was heated at 100 °C and then spilled with anthocyanin as much as 0.2 ml and allowed to stand for 1 min. The working electrode and anthocyanins then spilled by as much as 0.2 ml PEG using droplet method. The counter electrode was prepared by coating the copper above the ITO glass using an electrochemical method at 55 °C for 20 s and the distance between the electrodes 3 cm. The area of ITO submerged $CuSO_4$ solution is 0.8 cm x 1 cm so that the copper coated on ITO in accordance with the size. The working electrode was then combined with a counter electrode and clipped with a paper clip. Between the two electrodes were inserted PEDOT: PSS through a gap right and left as many as 0.2 ml.

Fabrication performed again using the best banana flowers extract absorbance, the best spraying ZnO, and the best volume droplets by varying a time electrochemical process 10 s, 20 s, and 30 s. Microstructures of ZnO layer were observed using a Scanning Electron Microscope (SEM) to determine the distribution of ZnO. Characterization of anthocyanin extract of banana was done using a spectrometer Ocean Optics USB 4000 Vis-nir light absorbance to obtain the data. DSSC relationship of current and voltage was measured using IV Nachriebe 101 meters. Current and voltage data was processed to obtain an efficiency of DSSC fabricated.

3. Results and Discussion

Distribution of ZnO on the ITO substrate can be seen in Fig. 3, the sample B1 has gaps that spread over the sides. Samples B2 has a surface that is more homogeneous even than the other samples, whereas the samples B3 buildup of ZnO layer, a gap formed by the thick layer of ZnO. This is in contrast with the samples B1 occurs because a thin layer spread over the entire surface so that there is the surface part that is not covered. Based on Fig. 3, sample B1 has the largest of 2.26 μm and the smallest gap of 598 nm. In sample B2, largest and the smallest gap are 2.56 μm and 619 nm. While the sample B3 has the largest gap of 1.41 μm and the smallest gap is 626 nm.

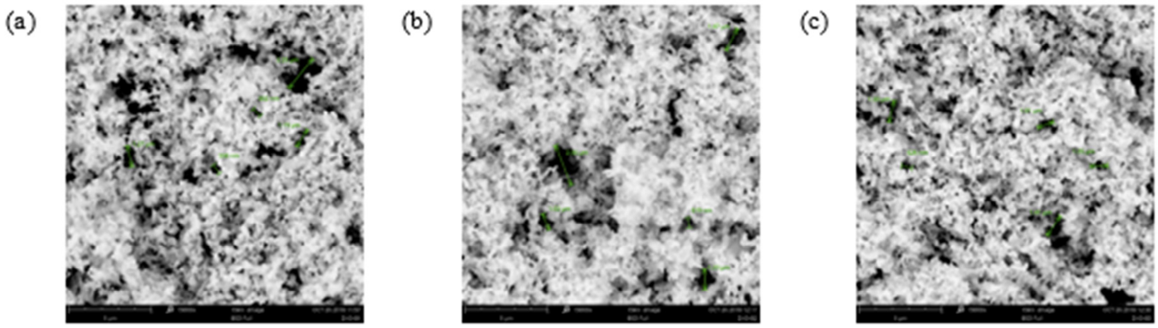

Fig. 3. SEM images of ZnO thin film surface in 15.000x magnification for samples: (a) B1 (1.2 ml ZnO); (b) B2 (2.4 ml ZnO); and (c) B3 (3.6 ml ZnO).

Based on Fig. 4, the five-absorbance value of the sample appears at a wavelength of 350-700 nm. The greater absorbance of the molecules is presented in the compound [13]. Achieved the highest absorbance at each wavelength for each sample are shown in Fig. 4. The highest light absorbance occurs at a wavelength 412.51 nm for sample A4. The maximum absorbance of the sample A2, A3, A4, and A5 are on the same wavelength at 412.51 nm (violet). Only sample A1 with the lowest absorbance is 511.22 nm at the green spectrum. It means that the sample A4 requires the smallest energy compared with other samples and sample A1 molecules require the greatest energy to transfer electrons.

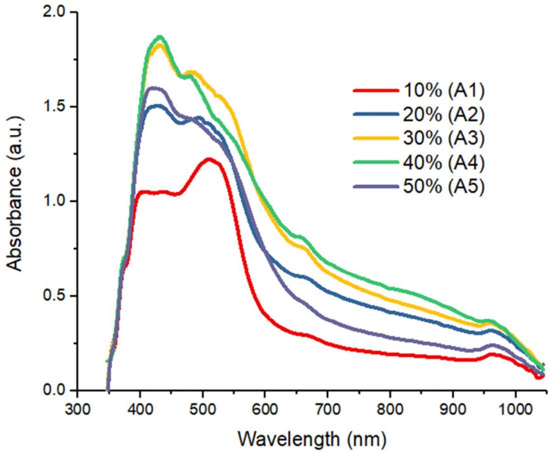

Fig. 4. The absorbance of Musa acuminata bracts at different volume fraction.

However, it should be noted on the chart that the stability of the sample A4 was not better than the sample A3. Differences in absorbance of the sample A4 and A3 only 0.06. Absorbance stability will affect the stability of the DSSC it self and also the range of the wavelengths that are absorbed. High absorbance in the wavelength range of the most wide-based drawing the sample A3 with 80 g of banana.

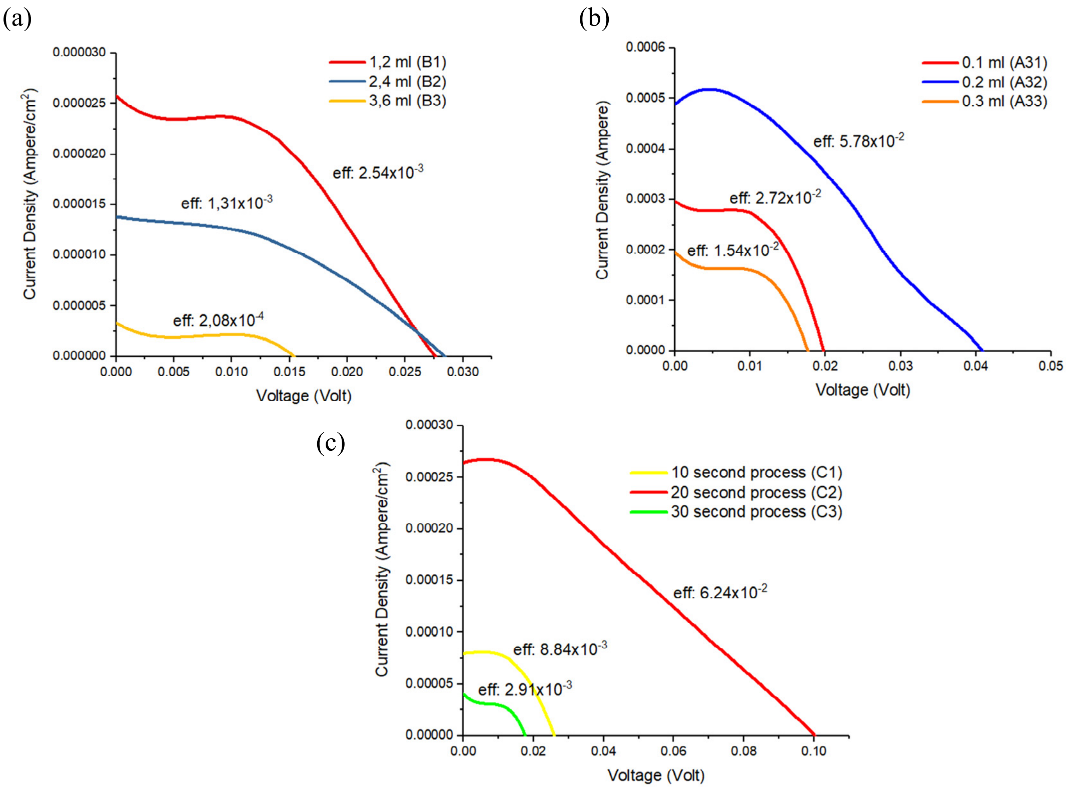

Fig. 5. DSSC I-V curve at (a) different ZnO amount; (b) different pigment amount; and (c) different times of counter electrode deposition.

Current and voltage measurements of DSSC used a 50-watt halogen lamp in a box measuring 20 cm x 20 cm x 20 cm so that the average power generated is 125 mW/cm^2. The parameters of the output of solar cells consist of the maximum voltage (V_{max}), maximum current density (J_{max}), the open circuit voltage (V_{oc}) and meeting short-circuit current (J_{sc}). Then those parameters are substituted in an equation to obtain the fill factor (FF) and the efficiency.The first test was conducted to determine the efficiency changes that occur to the repetition of ZnO spraying process. The DSSC of B1, B2, and B3 produce different efficiency described in Fig. 5(a). Anthocyanins are dropped as much as 0.2 ml and electrochemical processes carried out for 20 s. The highest efficiency was achieved at the B1 sample $2.54x10^{-3}$%. This is because formed ZnO has an optimal thickness. The more the spraying process produces excess ZnO thickness, thereby reducing the performance of the DSSC. The DSSC perfomance is tabulated in Table 1.

Table 1. Performance parameters of fabricated DSSC.

No	Performance parameter	Measured Value
1	Current-Voltage (V_{oc})	$1x10^2$ mV
2	Current Density (J_{sc}) 1 cm^2	$2.66x10^{-1}$ mA/cm^2
3	Fill factor (FF)	$2.93x10^{-1}$
4	Highest efficiency (η)	$6.24x10^{-2}$%
5	Peak power (P_{max})	7.8 mW/cm^2

Based on the current and voltage graph Fig. 5(b), the highest efficiency A32 samples is accomplished by $5.78x10^{-2}$% for 0.2 ml banana flower extract. Proven droplet method avalable as a natural pigment coating method of DSSC. If the pigment is too little the light-harvesting less than maximum, inversely if the pigmen are too thick the displacement of electrons is inhibited in the layer. Measurement then was performed on the counter electrode. The thickness of the electrochemical process significantly affects the efficiency of DSSC. Based on Fig. 5 (c), the electrochemical process was best performed for 20 s with an efficiency reaching $6.24x10^{-2}$%. This is due to the influence of time as in the study of Chen et al. (2006) states that the thickness of the layer by electrochemical deposition process can be influenced by long repetition of electrochemical processes [15].

4. Conclusion

Dye-sensitized solar cells (DSSC) based anthocyanin banana flowers extract has been fabricated and characterized. The best fraction of the extraction of banana is 0.3. ZnO coating used the spray coating method is best performed 10 times spraying. Banana flowers extract and PEG superimposed using droplet method by 0.2 ml. The highest efficiency and Peak power (P_{max}) can be achieved at $6.24x10^{-2}$% and 7.8 mW/cm^2, respectively.

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