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Natural Dye of *Musa acuminata bracts* as Light Absorbing Sensitizer for Dye-Sensitized Solar Cell

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Abstract

Dye-Sensitized Solar Cell (DSSC) has attracted researcher attentions because of its ability in converting light and has good performance at relatively low costs. The highest conversion efficiency is 4%. *Musa acuminata bracts* extract and a spin coating method are used. DSSC is fabricated based on *musa acuminata bracts* extract in a variation of mass fraction 0.1–0.5 with an increase of 0.1. The absorbances of organic dyes are determined using Vis-Nir and the highest one is found at 0.3 mass fraction with a wavelength spectrum of 500-600 nm. Conversion efficiency is determined using the Nachriebe 101 tool.

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Keywords: dye-sensitized solar cell; *musa acuminata bracts*; natural dye; photosensitizer, thin film

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1. Introduction

DSSC has the marketing potential of renewable energy devices and attracted attention because of their cheap compared to conventional solar cell [1]. Other advantages of DSSC sinclude flexibility, transparency, color diversity and inductor superior [2]. Their main components consist of dyes that are used as sensors that absorb solar energy and convert it into electrical energy, the dyes available in organic and inorganic compounds [3]. DSSC inorganic with ruthenium dyes have been extensively investigated because of their high efficiency reaching 11% and good stability, but ruthenium-based dyes are very expensive and availability is limited [4]. In order to overcome these problems, organic dyes are used but on the other hand the highest efficiency achieved by organic solar cells is still low at 4% [5].

Plant dyes are classified into chlorophyll, anthocyanins, betalains and carotenoid. Chlorophyll absorbs red and blue light from sunlight and therefore appears green [6]. The active materials that will be developed include flowers, leaves, fruit peels, fruits, stems and roots [7]. Anthocyanin compounds have carbonyl and hydroxyl groups in their molecular structure, making capable chemically bonded to the surface of semiconductor materials. Anthocyanin has a broad spectrum of light, so anthocyanin has the potential as a photosensitizer. Whereas in chlorophyll there are alkyl groups in the molecular structure that cannot chemically bind semiconductor materials so that chlorophyll is not optimally absorbed by the semiconductor layer [8].

Musa acuminata bracts is found in many countries of Southeast Asia and its surroundings. In Indonesia, the use of *musa acuminata bracts* has been still for traditional dishes. Therefore, the selection of *musa acuminata bracts* extract as a natural dye of DSSC is one of the ways to optimize the use of *musa acuminata bracts*. In previous studies, *musa acuminata bracts* extracted can be used as an alternative active ingredient for the development of organic solar cells and there is a certain amount of anthocyanin in *musa acuminata bracts* extract. Another reason for using *musa acuminata bracts* extract is that it is cheap, environmentally friendly, does not cause pollution and is easy to obtain [9].

DSSC consists of working electrode components, counter electrodes and electrolyte solutions [3]. This device was manufactured with the dye-sensitized TiO_2 electrode on the glass substrate, the Pt or carbon counter electrode (thickness 25 μm) and an electrolyte [10]. Regeneration of sensitizers by iodide occurs with the electron donor process in the valence band of oxidized dye. Iodide (I^-) is regenerated by reducing triiodide (I_3^-) at the counter electrode by utilizing electrons from the external circuit [11].

Power conversion efficiencies using natural dye DSSC extracted from rosella, blue peas, a mixture of rosella and blue peas were reported to be 0.05%, 0.37% and 0.15% [12]. DSSC is made with dyes extracted from red frangipani flowers and pumpkin ivy are reported to reach 0.30% and 0.08% efficiency [13]. The best DSSC performance was obtained by Ziziphus jujuba, where the efficiency reached 1.077% [14]. Photoelectric conversion efficiency of natural dyes of purple, mulberry, purple grape skin, potatoes and carrots in a sequence are 0.162%, 0.051%, 0.051%, 0.012% and 0.011% [15].

However, in the DSCC fabrication the use of liquid electrolytes causes problems, namely having a long-term low level of stability caused by evaporation and release of organic solvents, the solubility of limited inorganic salts such as KI, LiI and NaI in organic solvents and difficulties in sealing devices [16]. Efforts to increase cell efficiency are also still hampered by low electron mobility [17].

2. Experimental

2.1 Preparation of banana flower extract

The dyes of *musa acuminata bracts* were first prepared by the distillation method. The *musa acuminata bracts* were sliced and measured based on the mass fractions 0.1 - 0.5 with increase interval 0.1 and mixed with 150 g of ethanol, 6 g of acetic acid and 30 g of distilled water (25: 1: 5). It was blended for 2 min and filtered using 70 mesh sieve filter and then filtered again using 0.45 μm porous filter paper. The solution which was not mixed with the pulp was distilled to separate the anthocyanin from the remaining solution, using a magnetic stirrer at a speed of 500 rpm and heated at 82 °C for 2 h.

2.2 Thin film ZnO preparation

ZnO pastes were prepared through the mixing of 2 g of ZnO powder (Merck, CAS 1314-13-2), 10 ml of ethanol 96% (Merck, 1009832511) and 0.2 ml of acetic acid 98% and stirred for 30 min. Then the solution was dripped on conductive ITO glass and rotated using spincoater in speeds of 1.000-4.000 rpm for 30 s with increased interval of 1000 rpm. The ZnO layer was annealed using the oven for 30 min at 100°C, then dropped the natural dye and PEG (Sigma Aldrich, 88440).

2.3 Counter electrode preparation

The counter electrode was made of active carbon paste by mixing 2 g active carbon, 2 g Carboxy Methyl Cellulose (CMC), 16 ml distilled water and 8 ml ethanol using a magnetic stirrer. The carbon paste was deposited onto conductive ITO glass with spincoating technique at a speed of 2000 rpm for 30 s and annealed using an oven at 100 ° C for 30 min.

2.4 Preparation of DSSC

DSSC fabrication was made on by two glass substrate (electrodes). After a sandwich layer formed, the two ITO glass pieces were dropped by PEDOT: PSS (Sigma Aldrich, 655201) as an electrolyte solution. The DSSC structure is shown in Fig. 1.

2.5 Characterization of DSSC

Characterization of the dye was done using Ocean Optics Vis-Nir USB4000 spectrophotometer measurement to determine the absorbance value (a.u) of high on the particular wavelength (nm). The distribution and microstructures of the ZnO thin layer were characterized using a Phenom ProX Desktop Scanning Electron Microscopy (SEM). The I-V characteristics of the DSSC were measured using an IV-meter Nachriebe 101 device. The performance of DSSC based on natural dyes as sensitizers was determined from the photoelectric parameters. Photoelectric characterization can be done by measuring voltage and current (J-V). The J-V curve was done by direct irradiation using Xe 450 W lamp (125 mW/cm^2). The current density (Jsc), maximum current (Jmax), open circuit voltage (Voc), maximum voltage (Vmax) power conversion efficiency (η) and fill factor (FF) were calculated using formulas (1) and (2).

$$\mathrm{FF} = \frac{\mathrm{Vmax\ x\ Jmax}}{\mathrm{Voc\ x\ Jsc}} \tag{1}$$

$$\eta = \frac{\mathrm{Jsc\ x\ Voc\ x\ FF}}{\mathrm{Pin}} \tag{2}$$

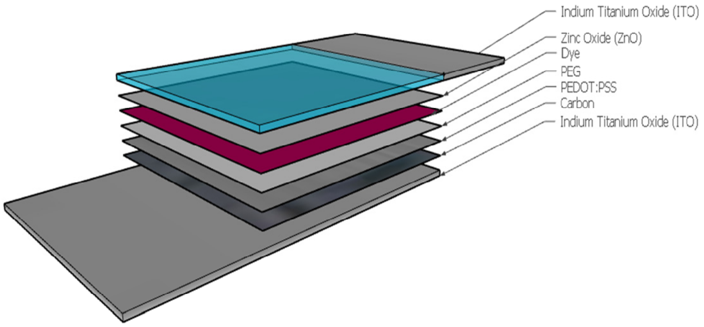

Fig. 1. DSSC structure with *Musa acuminata bracts* as photosensitizer and ZnO as a semiconductor layer

3. Results and discussions

3.1 Absorbance of natural dye extract

Fig. 2. is an absorbance spectrum of the dye of *musa acuminata bracts* extract, exist on the wavelength of 350-900 nm. The highest absorption of *musa acuminata bracts* extracts found on the sample with a mass fraction of 0.4 at wavelength 400 nm. For red color, the maximum wavelength is obeyed on the sample with the fraction of 0.2. Red color exists on the range wavelength of 500-600 nm.

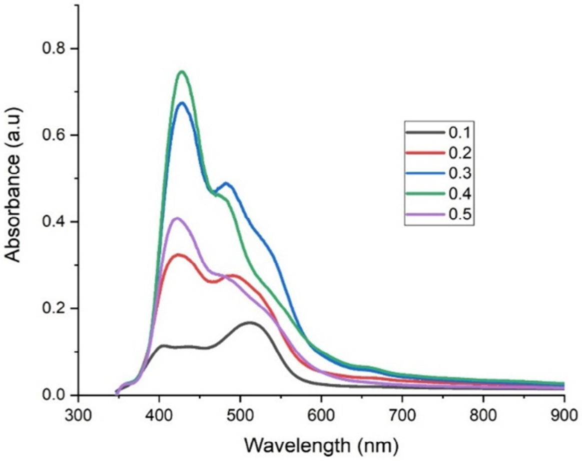

Fig. 2. Absorbance spectrum of dyes of *Musa acuminata bracts* extract

3.2 Surface morphology of ZnO

The microstructure of the ZnO thin film surfaces is shown in SEM images Fig. 3. with a magnification of 10,000 x and 15,000 x. It is known that the ZnO nanoparticle system tends to clot and form colloids which show that mixing of ZnO powder, ethanol and acetic acid requires a longer time. However, ZnO can be attached and spread evenly over the glass ITO substrate using the spin coating method. Thus, the deposited ZnO layer plays a role as a semiconductor material.

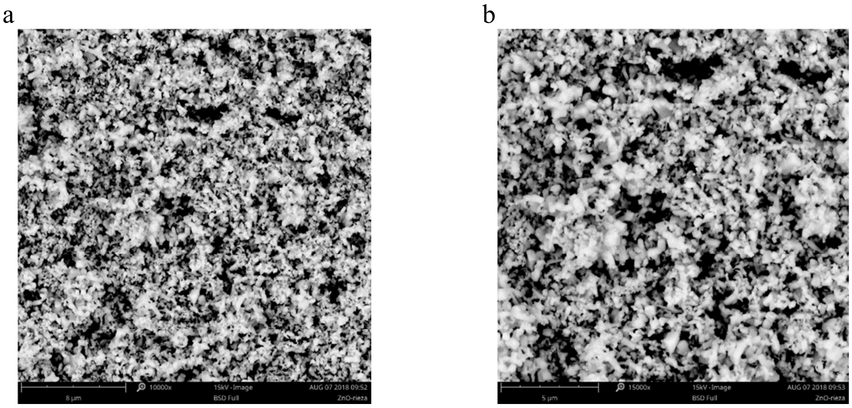

Fig. 3. Microstructures of ZnO thin layer in magnification of (a) 10000x; and (b) 15000x.

3.3 Performances of DSSC

In the I-V measurement, we used 50 watt halogen lamp on a medium 20 x 20 x 20 cm without gaps and produced power 125 mW/cm^2. In the measurement of the solar cell voltages, the working electrode and the counter electrode are attached like a sandwich. Fig. 4. is the characteristic curve of J-V resulted of ZnO deposition into a thin film with *Musa acuminata bracts* dye volume of 0.05 ml each. The maximum conversion efficiency of DSSC, 0.099% is found at sample which spincoated at 3.000 rpm. DSSC samples that are fabricated of other volume fractions can not perform characteristics J-V curves.

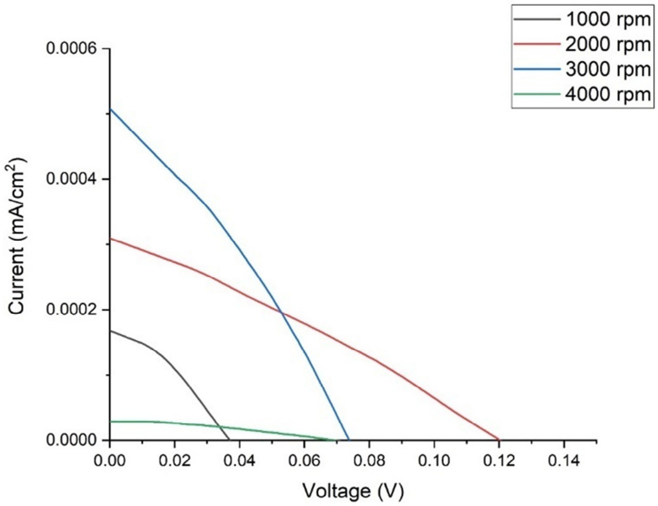

Fig. 4. J-V curves for the DSSC with variation of speed spin coater

Table 1. Photoelectric parameters of the DSSC.

Speed (rpm)	Voc (mV)	Jsc (mA/cm^2)	FF	η(%)
1000	37	1.0E-3	62.7	0.019
2000	119	3.0E-3	28.4	0.081
3000	73	4.0E-3	42.7	0.099
4000	69	3.0E-4	34.0	0.006

Fig. 5. shows the characteristic curve of J-V with different volume of *Musa acuminata bracts* dye (0.05 ml, 0.1 ml and 0.15 ml). The maximum conversion efficiency of DSSC (0.097%) is found at a sample of 0.05 ml dye volume.

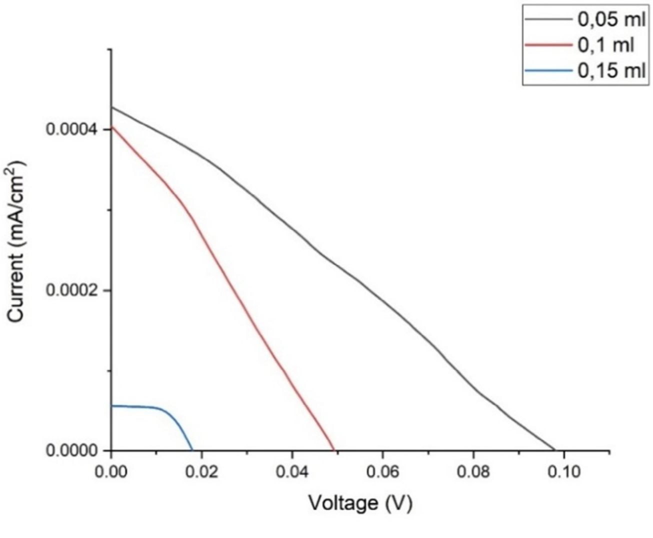

Fig. 5. J-V Curves for the DSSC under different dye volume

The photoelectric parameters of DSSC which produce a maximum conversion efficiency are shown in Table 1. The maximum conversion efficiency of DSSC, 0,99%, found at spincoater speed 3000 rpm. In Table 2, the maximum photoelectric parameter of DSSC is obtained by dye volume modification in which the maximum conversion efficiency at dye volume 0,05 ml is 0,097%.

Table 2. Performance of the DSSC under different dye volume

Dye (ml)	Voc (mV)	Jsc (mA/cm^2)	FF	Ƞ(%)
0.05	97	1.4E-2	8.88	0.097
0.1	50	8.0E-3	14.3	0.046
0.15	18	8.3E-3	4.91	0.006

4. Conclusion

Natural dyes are prepared by extracting from *Musa acuminata bracts*. The absorbance characterization that the 0.3 volume fraction produces a relatively high and stable absorbance value at a wavelength of 500-600 nm. *Musa acuminata bracts* showed optimum and efficient performance on 3000 rpm ZnO deposition with a diffusion of 0.05 ml of dye reaching 0.099%. In this research the highest efficiency (0.097%) is found in a sample of 0.05 ml dye volume variation with ZnO 3000 rpm deposition speed with short-circuit photocurrent density (Jsc) of 0.014 mA/cm^2, open circuit voltage (Voc) of 0.097 V and fill factor (FF) of 8.88.

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