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Dye-sensitized Solar Cells Fabricated Using Natural Dyes from Indonesian Plant as Sensitizers

Darmawati Darwis*, Satrio Amrullah and Firmansyah

Centre for Organic Electronics Tadulako University

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* Coresponding Author :
darmadarwis@yahoo.com

Abstract

This study aims to utilize various natural dye extracts from Indonesian plants to be applied as sensitizers to DSSC. The dye extract is derived from the turmeric plant (Curcuma longa Linn), henna tree (Lawsonia inermis L.) and pandan (Pandanus amaryllifolius). TiO_2 nanoparticles was used as semiconductor material for DSSC as they have a good crystallization structure and a wide surface area. The results showed that the DSSC using turmeric extraction produced a maximum power of 2.53x10-3 mWcm-2 with an efficiency level of 0.04%. While the henna tree extract produced a power of 1.27x10-2 mWcm-2 with an efficiency level of 0.25% and pandan extract produced a power of 4.01x10-2 mWcm-2 with an efficiency of 0.8%. Thus the dye extract from pandan is the best sensitizer that can be applied to the DSSC.

INTRODUCTION

Energy is one of the greatest challenges faced by every country in the world. It is predicted that in 2055 the energy problem will be a big problem that will befall mankind (Smalley, 2005). The depletion of reserves of fossil energy sources makes humans look for new and renewable energy sources. Of the many candidates for the newest energy source, Dye Sensitized Solar Cell (DSSC) is now a very potential alternavtive to be used as renewable energy source of solar cells. One of the most promising factors of this DSSC is the relatively cheap manufacturing cost, considering that cost is the biggest barrier factor for commercialization of conventional Silicon based solar cells (Ramakrishnan *et al*., 2020). In contrast to silicon solar cells, in dye-concentrated solar cells, the photons are absorbed by the dye which adheres to the surface of the TiO_2 particles. In this case dye acts as an electron donor that is generated when it absorbs light, similar to the function of chlorophyll in the photosynthetic process (Omar *et al*., 2020, Umale *et al*., 2019, Kumara and Prajitno, 2012).

DSSC using ruthenium dye has achieved an efficiency of up to 14% (Kakiage *et al*., 2015). However DSSC with this tipe of ruthenium dye is not commontly found in nature and is not friendly to environment, so it is consideration for the application on a large area DSSC (Dahlan *et al*., 2016). Dyes from the leaves, fruit, seeds, roots and stems of plants are very potential to be used as sensitizers in DSSC because they are abundant in nature and are environmentally friendly. Substances such as chlorophyll, beta-carotene, anthocyanins, tannins, curcumin, etc. in plants can be used in application as a sensitizer (Iqbal *et al*., 2019). This paper describes the analysis of the utilization of nature dye such as Turmeric (Curcuma longa Linn), Henna Tree (Lawsonia inermis L.), and Pandan (Pandanus amaryllifolius). This is useful information for selecting the right type of dye to be applied to the DSSC.

MATERIALS AND METHODS

TiO2 Paste Formation

The first step was dissolving 1 gram of powdered TiO_2 into 10M NaOH solvents to form TiO_2 nanoparticles powder and then ultrasonic process for 2 hours at a temperature of 80^oC. The nanoparticle then washed repeatedly with 2% of HCl and distilled water to leave TiO_2 nanoparticles precipitate. This precipitated material was then dried and grounded to form TiO_2 powder. Next, the TiO2 powder was heated in a furnace for 2 hours at 400^oC to form nano TiO_2 powder with anatase phase. TiO_2 Paste was prepared by grinding 0.1 grams of TiO_2 powder using a mortar produces TiO_2 paste then drop cast 2 drops of 10% wt PVA and subsequently crushed to form a homogeneous TiO_2 paste.

Dye Solution Preparation

Each 10 g of turmeric, henna tree leaves and Pandan leaves was crushed separately using a mortar then soaked them in 6 mL of ethanol and then stirred for 1 hour. The solution was then filtered after leaving it for 1 day. While the electrolyte solution was prepared by mixing 12 mL of KI solution (0.1 M) and 12 mL of I2 (0.01 M) solution and subsequently added with 1 gram of polyethylene oxide and stirred until homogeneous.

Constructing the DSSC

TiO_2 paste was deposited on the on the 3x3 cm2 glass conductor using doctor blade method then the layer was dried for 15 minutes. It was immediately heated in a furnace at a temperature of 450^oC for 30 minutes and immersed in the dye solution for approximately 30 minutes. Prior to the deposition, the TCO counter-electrode was then placed on top of the TiO_2 layer with a sandwich structure. The electrolyte solution was then dropped into the space between the two electrodes. And the solar cells were ready to be tested for IV characterization.

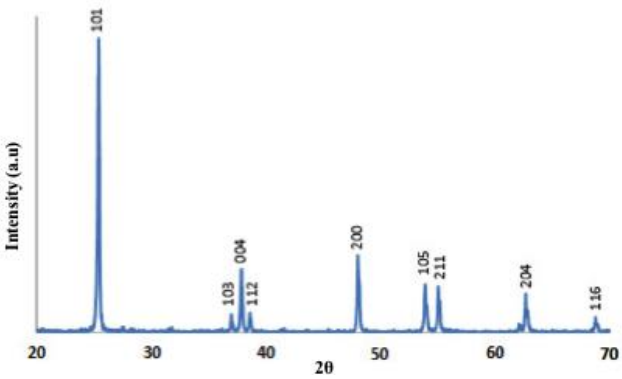

Fig 1. Difractogram of TiO_2 sample

RESULT AND DISCUSSION

XRD results (figure 1) show that the TiO_2 has an anatase structure, which is compatible with the International Centre for Diffraction Data (JCPDS) no: 21-1272. The anatase structures were identified by a strong intensity in the region 2θ = 25.28o; 37,80o; 48.05o; 53.89o and 55.06o. In addition, the intensity of the sample diffraction pattern is quite high, indicating that the TiO_2 has a good crystallinity degree which accelerates the process of electron diffusion in the TiO2 layer, which means that the electron transfer process of the devices will be faster and will improve the performace of solar cells (Tamarani *et al*., 2019).

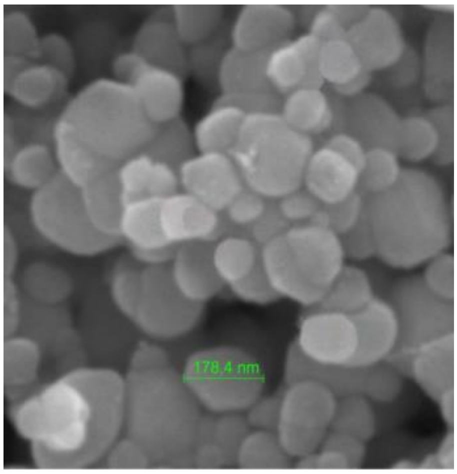

Fig 2. The morphological structure of the TiO2 sample

The morphological structure of the TiO_2 sample was tested using a Scaning Electron Microscopy (SEM) instrument (Figure 2). The SEM result shows that the TiO_2 particle size was less than 200 nm. The sample also contains a number of particle networks that form the nanopore structures of the TiO_2 material; the sample has good interconnection between particles. This particle interconnection is needed so that the electron diffusion path is shorter (Dong and Fei, 2020).

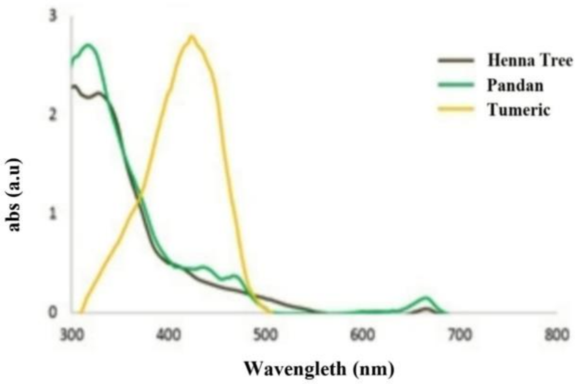

Fig 3. The absorption rate of Turmeric, Henna Tree & Pandan

The Ultraviolet-visible spectroscopy (UV-Vis) spectra showing the absorption of the samples. The absorption peak of henna tree, pandan and turmeric of 238 nm, 319 nm and 426 nm, respectively. These results indicate expected absorption spectra for turmeric, henna tree and pandan (Masek *et al*., 2013, Sathyajothi *et al*.,2017, Al-awani *et al*., 2017).

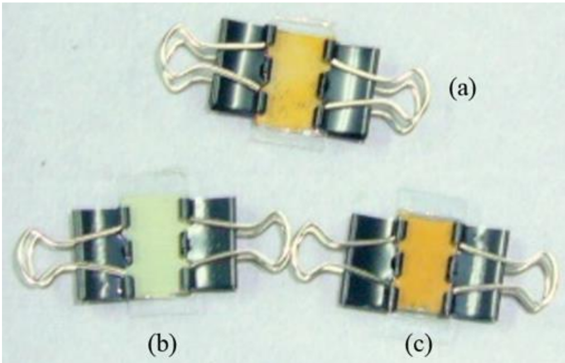

Fig 4. DSSC Prototype (a) Henna tree dye (b) Chlorophyll Pandan dye (c) Turmeric dye

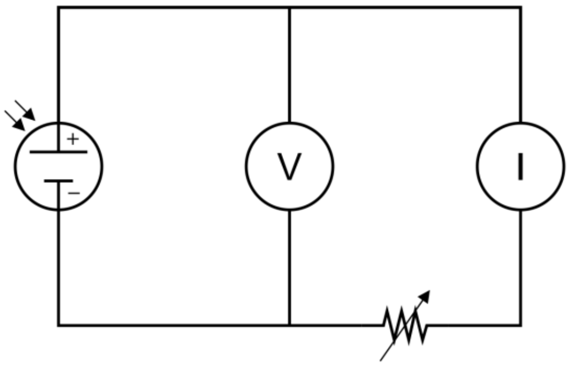

Fig 5. The circuit of I_V characteristic measurement

Solar cells are assembled in a sandwich arrangement with a TiO_2 / Dye / Electrolyte / TCO coating. The results of the solar cell prototype that have been assembled can be seen in Figure 4.

The solar cell prototypes are then characterized to determine Voltage-Current curves produced. This characterization test circuit is shown in Figure 5. The measurements were conducted directly under sunlight source with the measured intensity of 50.401 Wcm-2 The I-V characteristics can be seen in Figure 6 and the device parameters are presented in table 1.

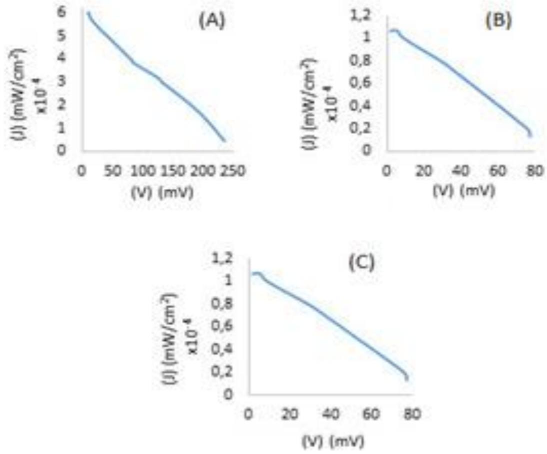

Fig 6. I-V characteristics of TiO2 solar cells with various dyes (A) Pandan (B) Henna Tree and (C) Turmeric

Of the three dyes used, pandan extraction is the best material that can be utilized for DSSC which produces a maximum a a power of 4.01x10-2 mWcm-2 with an efficiency of 0.8%. The difference in the maximum voltage value (Vmax) is probably due to a decrease in the amount of free charge (excitons) that is generated when the dye interacts with the photons continuously. Good dye will produce a large free charge, which is then converted into current when it reaches the electrodes (Li *et al*., 2019, Low *et al*., 2020).

Table 1. Solar cells parameters

Sel	V_{oc} (mV)	I_{sc} (mA)	V_{max} (mV)	I_{max} (mA)	P_{max} (mW/cm2)	FF	η (%)
Pandan	235,5	$6{,}0x10^{-4}$	128	$3{,}13x10^{-4}$	$4{,}01x10^{-2}$	0,28	0.8
Henna tree	98,2	$4{,}4\ x10^{-4}$	53,2	$2{,}4x10^{-4}$	$1{,}27x10^{-2}$	0,31	0,25
Tumeric	77,4	$1{,}0x10^{-4}$	34,6	$7{,}33x10^{-5}$	$2{,}53x10^{-3}$	0,30	0,04

CONCLUSION

Dye Sensitized Solar Cell which uses turmeric extraction produces a maximum power of 2.53x10-3 mW / cm-2 with an efficiency level of 0.04%. While the nail henna extract produced a power of 1.27x10-2 mW / cm-2 with an efficiency level of 0.25% and pandan extract produced a power of 4.01x10-2 mW / cm-2 with an efficiency of 0.8%. Thus the dye extract from fragrant pandanus is the best sensitizer that can be applied to DSSC.

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