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Fabrication and Low Light Characterization of Dye-Sensitized Solar Cell (DSSC) From Red Dragon Fruit (*Hylocereus Polyrhizus*) Skin and Meat as an Organic Dye

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Abstract. Dye-Sensitized Solar Cell (DSSC) is a cheap alternative energy option to overcome the world energy crisis. DSSC fabrication and characterization have been done as an organic dye. DSSC is a photo-electrochemical-based solar cell where organic color substances are used as sunlight absorbers and inorganic semiconductors as a place for the separation of electrical charge. DSSC can convert sunlight into electrical energy by using electrolytes as charge transfer. The study was conducted with dye from Red Dragon fruit skin and meat. The variations of immersion time of semiconductor TiO_2 in the dye for 12 hours, 24 hours, and 48 hours were also carried out. Characterization was conducted in low light 20 Watt LED light source. The test results obtained a higher and stable voltage and current in DSSC with dye from red dragon fruit in Ethanol compared to DSSC with dye red dragon fruit skin in Ethanol. Based on low-light characterization, we found the best Photo Conversion Energy (PCE) using red dragon fruit skin as dye were obtained at 48 hours immersion with a current of 1 mA, voltage of 2.5 mV and efficiency of 0.0093%. The best PCE using red dragon fruit meat as the dye was obtained at 48 hours immersion with a current of 4.7 mA, voltage of 8 mV, and efficiency of 0.2394%.

INTRODUCTION

Renewable energy is suggested to overcome the current crisis, including solar energy, biomass, wind, and hydropower. Solar energy for countries with a caps climate, such as Indonesia, is one of the widely used alternatives because it is very promising. One of them is abundant in nature and health aspects such as cleanliness, safety, and enabling as an energy generator in remote areas. Solar energy is a conversion of solar radiation into electrical energy called photovoltaic cells. The first commercial solar cells were made using silicon. This conventional solar cell has high efficiency up to 25%, but the cost of making it is relatively more expensive than other solar cells [1]. The conventional solar cells must use high purity silicon and hazardous chemicals at a high cost. Therefore, a new generation of solar cells was developed without using silicon to cost less than conventional solar cells. This device is known as Dye-Sensitized Solar Cell (DSSC), which mimics the photosynthesis process to convert the sun energy into electrical energy [2].

DSSC utilized dye as an electron generator in solar cells was developed as an alternative concept of conventional photovoltaic devices. Many studies on DSSC have been developed, such as semiconductor variation, dye synthesis, and structure modification [3-5]. Titanium Oxide (TiO2), which has a mesopores structure, is the most frequently used semiconductor material in DSSC. Titanium semiconductors have a 3.2 eV energy gap and absorb light in the ultraviolet

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range. This material was chosen for a variety of reasons, including its affordability, widespread use, non-toxicity, and widespread use as a primary component of health products and paint pigment [6].

DSSC comprises four main components: dye, working electrode, the counter electrode, and electrolyte solution. The working electrode is a thin layer of semiconductor material, such as TiO_2 and SnO_2, on a transparent conductive oxide substrate (TCO) that absorbs the dye substance as a sensitizer. While the counter electrode in the form of transparent conducted glass substrate coated with platinum (Pt) or carbon as a redox reaction catalyst. The electrolyte solution used is the redox couple I^-/I_3^- in organic solvents [7].

The working principle of the DSSC is essentially a reaction to electron transfer (Figure 1). First, The occurrence of electron excitation in dye molecules due to photon absorption. Electrons are excited from the dye ground state (Dye) to the dye excited state (Dye*). Then after the excited state, electrons are directly injected into the titania conduction band so that the dye molecule is oxidized. In the presence of an electron donor by an electrolyte (I^-/I_3^-), the dye molecule returns to its ground state and prevents the recapture of electrons by oxidized dyes (recombination). Electrons will flow towards the counter electrode through an external circuit before reaching the working electrode. In the presence of catalysts in the counter electrode, electrons are received by the electrolyte. Due to the electron donor in the previous process, the hole formed in the electrolyte (I_3^-) combined with electrons to form iodide (I^-). Iodide redox couple is used to donate electrons to oxidized dyes to form an electron transport cycle. There will be a direct conversion of sunlight from this cycle into electricity.

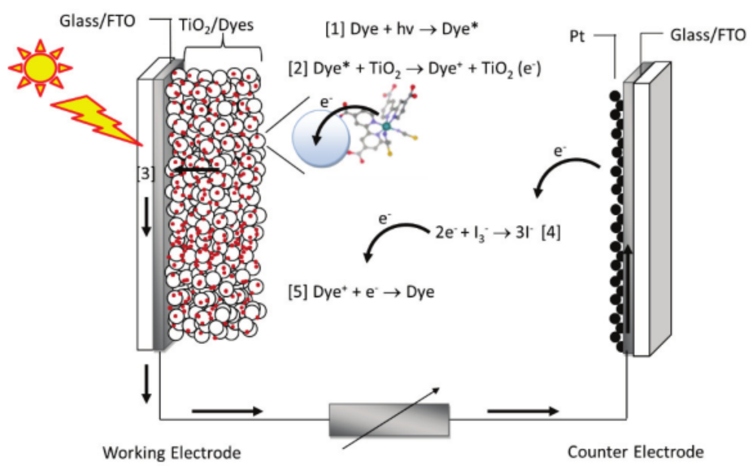

FIGURE 1. Electron Transfer of DSSC.

In this study, Red dragon fruit (*Hylocereus Polyrhizus*) as a dye substance was used in DSSC. Red Dragon fruit is a plant that comes from dry tropical climates[8]. In addition to the fruit's meat, dragon fruit skin can be utilized in food production as a natural food coloring and a primary ingredient in the manufacture of cosmetics. The skin of dragon fruit contains compounds that can be useful as antioxidants, one of which is the content of compounds on the skin of dragon fruit is anthocyanins [9]. The development of DSSC using a dye from red dragon fruit skin and meat extract as a sensitizer became a good choice because this plant is available in sufficient quantities in nature.

RESEARCH METHOD

Dye Preparation

The Red dragon fruit meat and skin are separated from the fruit and cut into small pieces. Each part (skin or meat) was mixed with a solvent with a ratio of 10:1. The solvent used in this study was Ethanol and distilled water. This mixture is then finely ground in a blender. It was stored for seven days in the dark in a closed container. After seven days, the extract is filtered with filter paper. The filtered dye solution is then put into a bottle that has been coated in aluminum foil and stored in a dark place.

Working Electrode Preparation

TCO Preparation

Lime glass was cut with 2 cm x 2 cm size and washed thoroughly using detergent with running water. The glass was cleaned again using acetone for up to 20 minutes in ultrasonic cleaner after blow-dry, then cleaned again using Ethanol in the ultrasonic cleaner for 20 minutes. After that, we cleaned glass stored in a closed container containing Ethanol.

The conductive layer was coated on the cleaned glass surface. The solution of $SnCl_2$ in Ethanol (ratio 1:3, vol./vol.) is stirred until a homogeneous solution is formed. After that, the mixture was injected into a nano sprayer. Cleaned glass in ethanol container was dried with hand blower then preheated using a heat gun for 10 minutes at a temperature of 500°C. While the glass was still in a hot state, $SnCl_2$ solution with Ethanol sprayed on the surface of the glass was exposed to the heat earlier by using a nano sprayer for 3 seconds with a distance of 5 cm at a 90-degree angle. After the entire glass surface has been covered with $snCl_2$ solution, then reheated using a heat gun for 30 minutes at a temperature of 500°C. After the transparent conductive oxide (TCO) glass cooled, the resistance value of each TCO glass was measured. The TCO glass with the lowest resistance and the transparent surface was selected for the next step.

Semiconductor TiO_2 Preparation

Titanium dioxide (TiO_2) paste is made using 6 grams of TiO_2 powder, 9 ml of acetic acid, 1 gram hydroxyl ethyl cellulose (HEC), and 25 ml of Ethanol. HEC and Ethanol were mixed in the mortar until all the HEC dissolved with Ethanol. Then the TiO_2 powder was added to the HEC mixture. Acetic acid (1 ml) was added gradually in the mixture while stirred; when the paste has started to dry, add acetic acid until the paste was formed. The total stirring time is done for 30 minutes, and at the end of the stirring, two drops of Triton X-100 detergent were added until the desired TiO2 paste was obtained. The paste was then coated into the TCO glass with the doctor blade method. After drying in a hotplate (100°C) for 5 minutes, the TCO coated TiO_2 was baked in the furnace for 30 minutes at 500°C. After cooling down to 80°C, TCO coated TiO_2 immersed in dye solution for 12, 24, and 48 hours variation. Dye solution used from extracted skin and meat red dragon fruit.

Counter electrode Preparation

TCO glass fabricated in the previous step was burned on the fire from the candle until a layer of carbon was formed from the soot of wax smoke. The side of coated carbon TCO was then cleaned using cotton buds to create a boundary. The uncoated side of the counter electrode serves as a contact medium for cell fabrication.

Cell fabrication

The DSSC is made by arranging an offset layer of the working electrode (TCO coated TiO_2 and dye) with a layer of counter electrodes (TCO coated with carbon). The sandwich structure of the working electrode and counter electrode is separated with a 50 µm plastic spacer preventing short-circuit and serving as an electrolyte container gap. The structure was filled with electrolytes from iodine solution then glued together on both sides. It is intended that the electrolyte fluid does not spill. The cell was fabricated using dye extract of red dragon fruit skin and red dragon fruit meat.

DSSC characteristic

DSSC testing was conducted by measuring the characteristics of I-V of DSSC made with the dye of red dragon fruit meat and red dragon fruit skin with the variation of solvent and immersion time. The multi-meter probe connected to solar cells on both sides. Current and voltage measurements are used to characterize the DSSC. The light source is angled perpendicular to the cell's surface. A 20 watt LED light source was used in the test.

The resulting data is plotted in a graph of current to voltage (I-V curve). The I-V curve can be determined by open-circuit voltage (Voc), short-circuit current (Isc), fill factor, and cell efficiency. Empirically fill factor obtained through equations:

$$FF = \frac{V_{OC} - \ln(V_{OC}+0{,}72)}{V_{OC}+1} \quad (1)$$

The maximum power output of a solar cell will be calculated using the fill factor from equation one above.:

$$P_{MAX} = V_{OC} \times I_{SC} \times FF \quad (2)$$

The conversion efficiency(η)of a solar cell is defined as the percentage of optimum output power to the light energy used, which is written as:

$$\eta = \frac{P_{max}}{P_{Light}} \times 100\,\% \quad = \frac{V_{OC} \times I_{SC} \times FF}{P_{Light}} \quad (3)$$

Lux is the lumen per unit. Lux (luminous flux) can also be interpreted as the total of visible light that indicates the intensity of light on a given surface. The light will appear to be dimmer as the area is increased. Light has duality properties as matter and waves. In nature, light has a certain level of energy. The power (W) transmitted by a light source is directly proportional to illumination, Ev (lux) multiplied by the area (m^2) divided by luminous efficiency, η (lm/W), can also be obtained by dividing the intensity of irradiation (Φ) by η (lm/W) luminous efficacy. Which is spelled out as follows:

$$P_{Light} = Ev\,\frac{A}{\eta} = \frac{\Phi}{\eta} \quad (4)$$

Low light characterization was done using a 20 watt LED lamp as a lighting source obtained a lux value of 91666 lux, with luminous efficacy of 90 lumens per watt. Then obtained a P-value of 0.1018 Watts with an area of 1 cm^2, so that P_{Light} was obtained by 101.8 mW/cm^2.

RESULTS AND DISCUSSION

DSSC performance is influenced by several parameters, namely short circuit current (Isc), open-circuit voltage (Voc), and surface area (A) of irradiated solar cells. Isc is a short circuit current that occurs when the voltage can be equal to zero or close to zero. This current is equal to the number of photons converted into electron-hole pairs. The more electrons are excited, the greater the performance. Voc is the voltage value when there has not been a current flow because all excitons are combined so that in DSSC, there is no current flow. FF is the ratio of maximum power (P_{max}) to contact current (Isc) and open-circuit voltage (Voc). Fill factor increases with increased electron mobility. Increased electron mobility will increase the current. If the fill factor value is higher than 0.7 or 70%, the cell is better.

The effect of dye concentration on DSSC electrical performance due to variations in immersion time and the effect of dye solvents on DSSC electrical performance was shown in Tables 1, 2, and 3. Characterization of the I-V curve is done to see the electrical properties of the DSSC that has been fabricated. The variation used to fabricate DSSC using the extraction of dragon fruit as a dye with long variations of immersion and variations in solvent types.

TABLE 1. Efficiency Data for dragon fruit skin in Ethanol as a dye with time variations of immersion.

Immersion Time	V (mV)	A (mA)	FF	Pmax (mWatt)	Plight (mW/cm^2)	Efficiency %
12 hours	2	0.4	0.3331	0.26649	101.8	0.0026
24 hours	2.3	0.6	0.3620	0.49962	101.8	0.0049
48 hours	2.5	1	0.3801	0.95044	101.8	0.0093

TABLE 2. Efficiency Data for dragon fruit meat in distilled water as a dye with time variations of immersion.

Immersion Time	V (mV)	A (mA)	FF	Pmax (mWatt)	Plight (mW/cm^2)	Efficiency %
12 hours	3.3	1.5	0.4438	2.19724	101.8	0.0215
24 hours	3.5	1.7	0.4578	2.72399	101.8	0.0267
48 hours	4.3	2.3	0.5069	5.01324	101.8	0.0492

TABLE 3. Efficiency Data for dragon fruit meat in Ethanol as a dye with time variations of immersion.

Immersion Time	V (mV)	A (mA)	FF	Pmax (mWatt)	Plight (mW/cm^2)	Efficiency %
12 hours	4.3	3	0.506	6,539	101.8	0.0642
24 hours	6.9	3.7	0.616	15,735	101.8	0.1545
48 hours	8	4.7	0.648	24,374	101.8	0.2394

Variations in the length of immersion time were 12 hours, 24 hours, and 48 hours. Each semiconductor has a maximum limit in dye extraction absorption. The length of 48 hours of immersion TiO_2 has been seen to begin to dissolve in dye. The length of immersion affects the absorbance value. The more extended the immersion time, the higher the concentration of anthocyanin molecules absorbed on the Particle TiO_2. The longer the immersion, the darker the color of the layer. The skin and meat fruit showed different colors (Figure 2). The dye from the meat was darker.

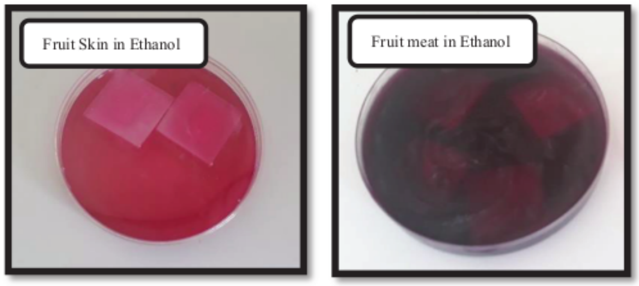

FIGURE 2. The light color of dragon fruit skin dissolved in ethanol solvent (left) compared to the darker color of dragon fruit meat dissolved in ethanol solvent (right).

Open circuit voltage (Voc) with the dye from red dragon fruit meat ethanol immersed for 48 hours shows better performance than other combinations. The Voc reached 8 mV with an Isc of 4.7 mA and efficiency of 0.2394%. The small current of the output produced is across by the resistance of the semiconductor electrode TiO_2 and the very large electrolyte. This enormous resistance value results in electrons injected from dye experiencing very large resistances within the TiO_2 layer so that the number of electrons flowing into the outer circuit becomes small. The non-optimal function of dye can cause other causes in the generation and injection of electrons into the layer of The TiO_2 electrode.

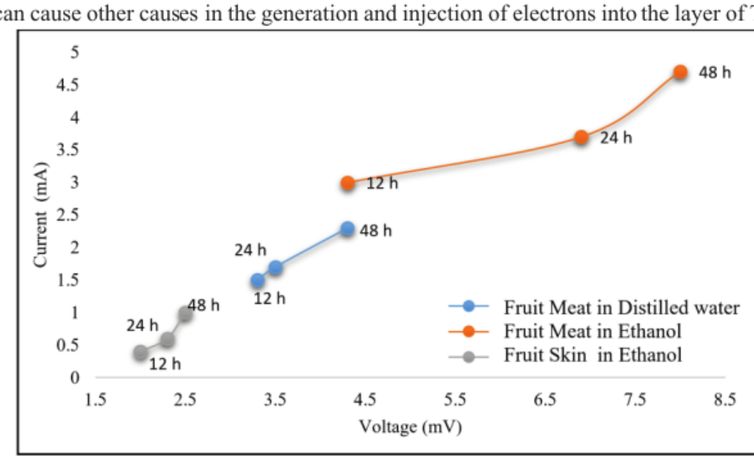

FIGURE 3. Time immersion variation for DSSC using dragon fruit skin and meat

It can be seen that performance on the dye from the red dragon fruit meat was higher than dye by using the skin of red dragon fruit because the absorption of light in the red dragon fruit flesh dye is higher than the dye of the skin of the red dragon fruit. The anthocyanin content influences absorbance in the solution and the snared on the surface of TiO_2, where the anthocyanin content is proportional to the absorbance of light [10].

Figure 3 shows that the length of immersion and the type of solvent affect the absorbance value. The length of immersion influences the voltage and current produced by DSSC. The longer the immersion time, the higher the voltage and the more substantial the current [11]. The graph above shows that all DSSC has the highest value at 48 hours of immersion, and DSSC with immersion in the dye for 24 hours has a substantial value of higher current compared to DSSC with an immersion length of 12 hours. The highest average strong current that a 48-hour DSSC can produce is 7 mA. While the average voltage value of DSSC 48 hours which is also the highest voltage of DSSC with other immersion lengths, is 8 mV. Based on low-light characterization, we found the best Photo Conversion Energy (PCE) using red dragon fruit skin as dye were obtained at 48 hours immersion with a current of 1 mA, voltage of 2.5 mV, and efficiency of 0.0093%. The best PCE using red dragon fruit meat as the dye was obtained at 48 hours immersion with a current of 4.7 mA, voltage of 8 mV, and efficiency of 0.2394%.

CONCLUSION

Fabrication and low light characterization of the DSSC using dye from the extraction of red dragon fruit skin and meat has been done. Best DSSC Photo-conversion efficiency (PCE) using red dragon fruit skin as the dye was obtained at 48 hours immersion with a current of 1 mA and voltage of 2.5 mV with an efficiency of 0.0093%. Best DSSC PCE using red dragon fruit meat as the dye was obtained at 48 hours immersion with a current of 4.7 mA and voltage of 8 mV with an efficiency of 0.2394%. The data trend still rises for immersion time. Maximum immersion time needs more confirmation in our following study.

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