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Effect of Titanium Dioxide Thickness on Performance of DSSC Solar Cell Using Red Dragon Fruit Dye

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ABSTRACT

A solar cell is an electrical device used to convert the energy of sunlight directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. One type of solar cells that uses plant dyes is the dye-sensitized solar cell (DSSC). The DSSC is in the form of a structural arrangement known as a sandwich structure, consisting of conductive glass as transparent electrode, titanium dioxide (TiO_2) sensitized by plant dyes, electrolyte, and a metal electrode as a counter electrode. The paper aims to study the effect of TiO_2 thickness on DSSC performance utilizing red dragon fruit flesh extract as a dye. Three variations in the thickness of the TiO_2 layer evenly positioned in the conductive area are tested. The thicknesses of the TiO_2 layer are 99 µm, 129 µm and 141 µm respectively. The DSSC performance is tested outdoors with sunny weather conditions from 9:30 am to 1:30 pm. A calibrated Arduino measurement kit is used to measure the voltage and current values produced by the DSSC prototype. Testing with a thickness of 141µm resulted in the highest maximum power value of 532.26 mW among the three thickness variations.

1. Introduction

The potential of solar energy in Indonesia is very large [1-4]. Most of Indonesian areas get a quite intense of solar radiation with the average daily radiation approximately around 4 kWh/m2 [5-7]. Padang city gets solar irradiance of about 700-1000 Watts/m^2 [8]. Nowadays, there is an electrical device that use the photovoltaic effect to convert the energy of sunlight directly into electricity called a solar cell [9-17]. A type of solar cells that uses plant dyes is the dye-sensitized solar cell (DSSC). The DSSC uses the color substance in fruits or plants as a dye sensitizer. The DSSC is formed by a photo-electrochemical mechanism, similar to the photosynthetic process in green leaves chlorophyll [18,19]. The difference is that the DSSC process uses a color substance that produces dye. The DSSC then absorbs sunlight through a sensitized dye. O'regan and Gratzel [20] have conducted a simple fabrication solar cell research known at this time as dye sensitized solar cell in 1991. This solar cell has received great attention for its simple fabrication process, low production costs, relatively high

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conversion efficiency and, environmentally friendly [18-34]. The largest energy conversion efficiency ever produced by this solar cell is about 11% [35,36].

Many researchers have fabricated DSSC using dyes made from fruits containing anthocyanin substances [21-25]. The anthocyanin substances play an important role in the process of absorbing light. An example of fruits that contain anthocyanin is the red dragon fruit. In testing using spectrophotometry methods that have been done at Andalas University, precisely in the instrumentation laboratory of the agricultural technology department of the faculty of agriculture, it was obtained that the anthocyanin content in red dragon fruit is about 0.185%. This test uses extract of red dragon fruit flesh with a citric acid solution solvent. From the test results, it is obtained that the flesh of the red dragon fruit has a promising prospect to be used as a dye base material for the manufacture of DSSC [25].

The DSSC is in the form of a structural arrangement known as a sandwich structure, consisting of conductive glass substrate as transparent electrode, a mesoporous semiconductor film, titanium dioxide (TiO_2) sensitized by plant dyes as a sensitizer, an Iodide electrolyte, and a metal electrode as a counter electrode. The optimization of each of them is of great importance in order to improve the overall efficiency. The performance of the DSSC depends significantly on certain properties of the nanocrystalline oxide film, such as crystal structure, crystallite size, thickness, and porosity. Selecting the dye, the electrolyte and suitable counter electrodes are also matters at which scientists working in this field are focusing [37]. Titanium dioxide or TiO_2 is used as the anode material, where this material is sensitive to light and structurally stable when exposed to sunlight. One of the important parameters that affect DSSC performance is the thickness of the TiO_2 layer. Maximum light harvesting is expected for thick photoelectrodes as a result of the increased optical path while the requirement for minimum recombination points towards thinner photoelectrodes. These two contradicting requirements lead to optimum oxide thickness. Meanwhile, there are still few studies investigating the influence of the TiO_2 layer thickness. Characterization is required to determine the ability of TiO_2 to bind to the dye and then affects the power output produced [37,38]. Therefore, the objective of this research is to utilize red dragon fruit as a dye base for DSSC manufacture and to determine the effect of TiO_2 thickness on DSSC performance by varying its thickness.

2. Theoretical Foundations

2.1 Solar Cell

Solar cells are made of semiconductor materials. The majority of solar cells are fabricated from silicon. A thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light beam strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current [8-19]. This electricity can then be used to power a load, tools, and devices such as a drone [39-41].

There are various different types of solar cell [18]. The Solar cells are typically named after the semiconducting material they are made of, such as silicon-based, compound-based and organic-based of solar cell. These materials must have certain characteristics in order to absorb sunlight. Solar cells can be classified into first, second and third generation cells. The first generation cells of solar cells also called conventional, traditional or wafer-based cells that includes materials such as polysilicon and monocrystalline silicon. Second generation cells are thin film solar cells, that include amorphous silicon, CdTe and CIGS cells. The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaics. Many uses organic materials, organometallic compounds and inorganic substances. Despite the fact that their efficiencies have been low and the stability of the absorber material is often too short for commercial applications, there is a lot of research invested into these technologies as they promise to achieve the goal of producing low-cost, high-efficient solar cells [19-34, 42-46].

Electrical power generated by solar cells when they receive light is derived from capability of the solar cell device to generate voltage over an external load and current through the external load at the same time. Several important parameters which are used to characterize solar cells are the short-circuit current (I_{SC}), the open-circuit voltage (V_{OC}), the fill factor (*FF*) and the efficiency are determined from the *I-V* curve [37].

The point on the *I-V* curve that generates the maximum current and maximum voltage is called maximum peak power (maximum power point), abbreviated as *MPP*. The power at the *MPP* (P_{mpp}) is the product of the *MPP* voltage (V_{mpp}) and *MPP* current (I_{mpp}).

Another important characteristic of solar cells is the fill factor (*FF*), with the Eq. (1)

$$FF = \frac{V_{mpp} \cdot I_{mpp}}{V_{oc} \cdot I_{sc}} \tag{1}$$

Using the fill factor, the maximum power of the solar cell results the Eq. (2),

$$P_{max} = V_{oc} \cdot I_{sc} \cdot FF \tag{2}$$

Therefore, the efficiency of the solar cell is defined as the power generated by the cell (P_{max}) divided by the power of the incident light (P_{light}) as in Eq. (3)

$$\eta = \frac{P_{max}}{P_{light}} \tag{3}$$

This efficiency value is a global measure to determine the quality of the performance of a solar cell [35,37].

2.2 Dye-Sensitized Solar Cell (DSSC)

Dye Sensitized solar cells (DSSC) are a third generation photovoltaic (solar) cell that converts any visible light into electrical energy. This new class of advanced solar cell can be likened to artificial photosynthesis due to the way in which it mimics nature's absorption of light energy. A dye-sensitized solar cell (DSSC) is a low-cost solar cell belonging to the group of thin film solar cells. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photo electrochemical system [18,19].

The Dye-sensitized solar cells (DSSC) as shown in Figure 1 is in the form of a structural arrangement known as a sandwich structure, consisting of transparent conductive glass substrate as transparent electrode and a metal electrode as a counter electrode, an Iodide electrolyte and a nanoporous semiconductor film which is titanium dioxide (TiO_2) sensitized by plant dyes as a sensitizer [37].

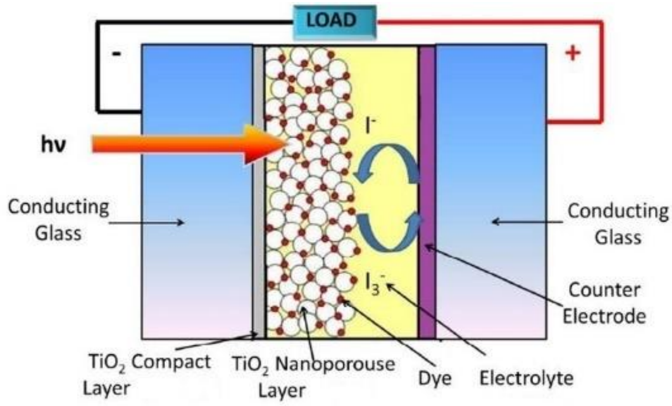

Fig. 1. Sandwich structure of DSSC [47]

3. Methodology

3.1 DSSC Manufacturing Process

The components used to make DSSC in this study are Fluorine doped tin oxide glass (FTO) as transparent conductive glass substrate, Titanium dioxide (TiO_2) as a nanoporous semiconductor film, red dragon fruit containing cyanine as a dye, Iodide electrolyte, and graphite from a pencil to make carbon electrode or counter electrode. FTO glass is a glass that has a wide band-gap semiconductor and has high optical transparency (i.e. more than 85%) as well as n-type characters due to oxygen voidness.

Several components to make the DSSC are prepared before assembling process. Those are 12 pairs of 5 x 5 cm in size of the FTO conductive glass, Titanium dioxide (TiO_2) paste, red dragon fruit flesh extract as a dye, graphite from a pencil to make Carbon electrode and Iodide electrolyte solution. On each of the FTO glass, an area of 4.7 x 4.7 cm in size is formed for the deposition of the TiO_2 layer with the help of insulation on the conductive part. Insulation acts as a determination of the thickness of the TiO_2 paste layer. There are three variants of the thickness of the TiO_2 paste layer. The first variant uses one insulation layer, the second one uses two insulation layers, and the third one uses three insulation layers.

The TiO_2 layer is deposited in the conductive zone by means of a doctor blade coating method which is one of the widely used techniques for producing thin films on large area surfaces. The method is deposition TiO_2 layer with the help of a stirring rod, so that the TiO_2 layer is evenly distributed. The TiO_2 layer is then dried for 15 minutes and then burned or sintered in an induction furnace at a temperature of 120°C for 30 minutes. Furthermore, the TiO_2 layer was soaked in the dye solution prepared from red dragon fruit extract for 30 minutes. So that the coloured TiO_2 layer approaches the colour of the dye solution. This process is carried out by the absorption of cyanine on the surface of TiO_2.

The carbon counter electrode was placed on top of the second 12 pairs of the FTO glass as a catalyst with a sandwich structure at each end offset by 0.3 cm as an electrical contact area. The finished electrolyte is deposited on the FTO glass which has been coated with carbon electrodes, as an electron conductor. After that, the TiO_2 coated FTO glass is joined with carbon coated counter electrode FTO glass according to DSSC sandwich structure. Finally, this assembled DSSC solar cell is clamped with paper binder for perfect contact. Then, the solar cell is then ready to be tested.

3.2 DSSC Measurement Circuit Schematics

The measurement process is done by connecting the DSSC prototype to the Arduino measurement kit through a jumper. An Arduino set is used to calculate the values of V_{oc}, I_{sc}, V_{mpp} and I_{mpp} generated by the DSSC prototype. To get the value of V_{oc} and I_{sc}, the test runs with an open loop circuit which is no resistance as a load. Meanwhile, to get the V_{mpp} and I_{mpp} test values, the test is conducted with a close loop circuit which is with a resistance of 15 Ω. In order to calculate two tests in one circuit, a 3-channel relay as shown in Figure 2 is used.

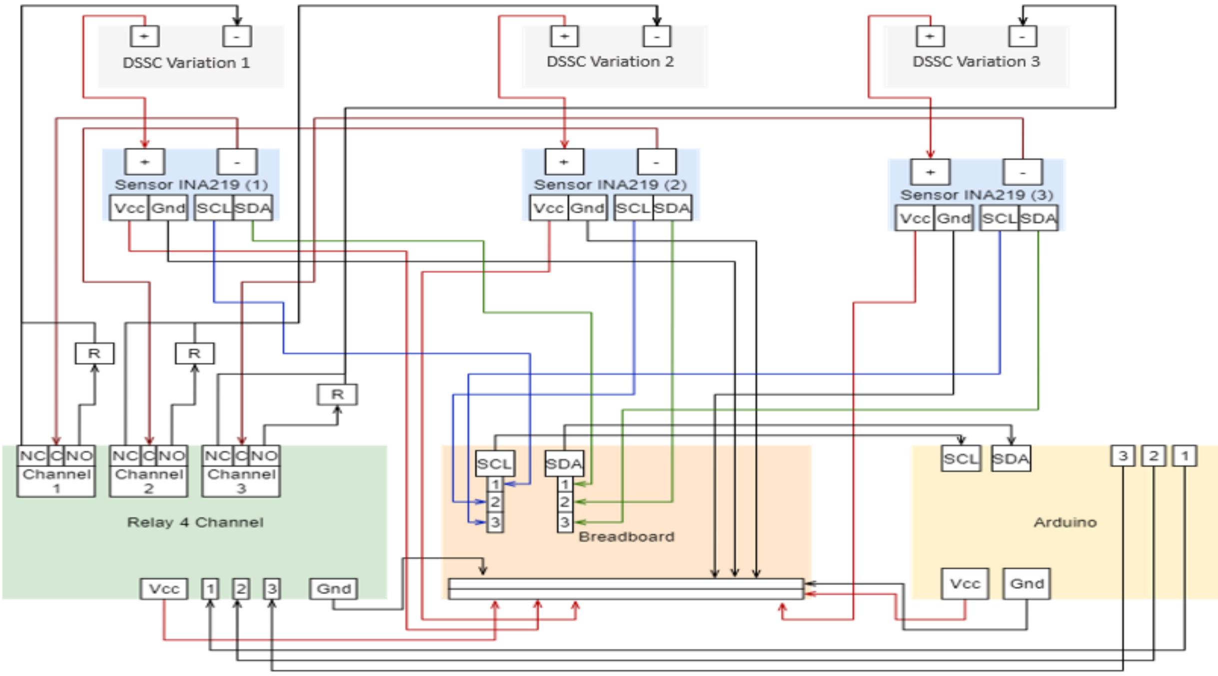

Fig. 2. DSSC measurement circuit schematics

When measuring the V_{oc} and I_{sc} values, the arduino kit will give a command to the relay to divert the flow of the electric current to the circuit having no resistance. Vice versa to measure the value of V_{mpp} and I_{mpp}. Then the data will be seen on the computer monitor in real time. Data recovery is carried out by data logging at intervals of 10 minutes for 4 hours from 09.30 to13.30 pm.

4. Results

4.1 Testing of the Red Dragon Fruit Dyed DSSC

In the DSSC study, titanium dioxide (TiO_2) dyed with red dragon fruit has three variations of thickness. The first variant uses one insulation layer, the second one uses two insulation layers, and the third one uses three insulation layers. The three thickness variants correspond to the thickness of the TiO_2 layers of 99 µm, 129 µm and 141 µm respectively. The DSSC performance is tested outdoors precisely in North Ulak Karang, Padang City, with sunny weather conditions from 9:30 am to 1:30 pm in July 2021.

4.2 Chart and Analysis
4.2.1 Time versus the intensity of solar radiation

The graph in Figure 3 shows the effect of time on the intensity of solar radiation (irradiance). The intensity of the solar radiation at 09.30 pm is about 611 W/m². This value continued to increase until reaching the value of 1009 W/m² at 12.30 p.m. According to previous research, this corresponds to the fact that the value of intensity of solar radiation continues to increase until noon [11,12]. From 12.40 pm, the intensity is 996 W/m² and continue to decrease at value of 850 W/m² by 13.30 pm.

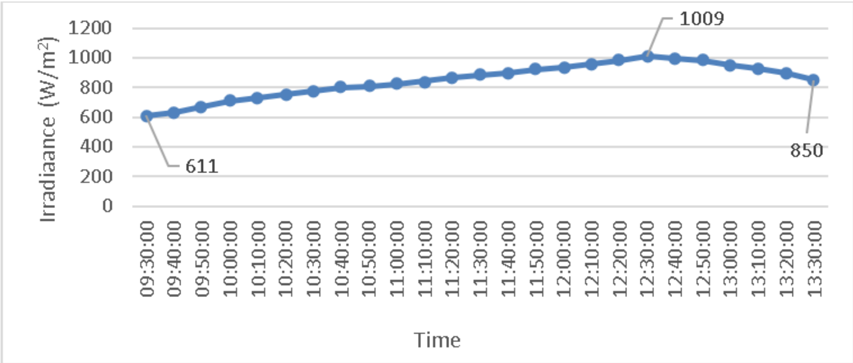

Fig. 3. Chart of the intensity of solar radiation versus time

4.2.2 Voltage, current and maximum power versus the intensity of solar radiation

The voltage, current and maximum power values obtained from the three variations of thickness of the DSSC solar cell versus the intensity of solar radiation is shown in Figure 4, 5 and 6. The voltage value obtained when measuring the DSSC solar cell operated at open circuit is the open-circuit voltage (V_{oc}), while the current value obtained when measuring the DSSC solar cell operated at short circuit is the short-circuit current (I_{sc}). The maximum power value of the DSSC solar cell is obtained through a calculation of the value of V_{oc}, I_{sc}, V_{mpp} and I_{mpp}. The V_{mpp} and I_{mpp} values are measured with a closed loop circuit which is with a load of a resistance of 20Ω.

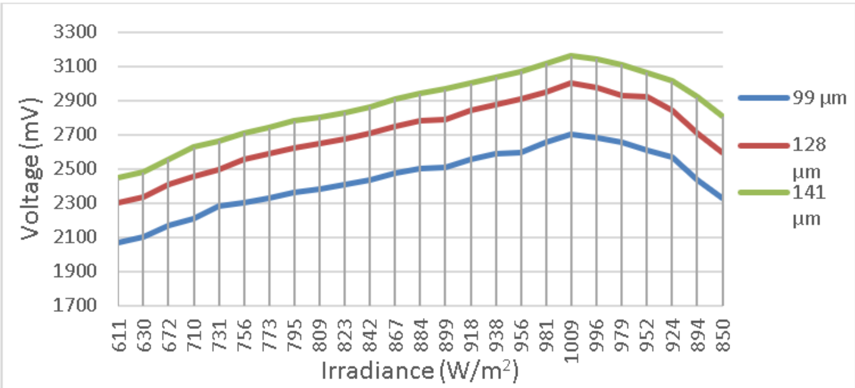

Fig. 4. voltage versus the intensity of solar radiation for the three variants thickness of the DSSC

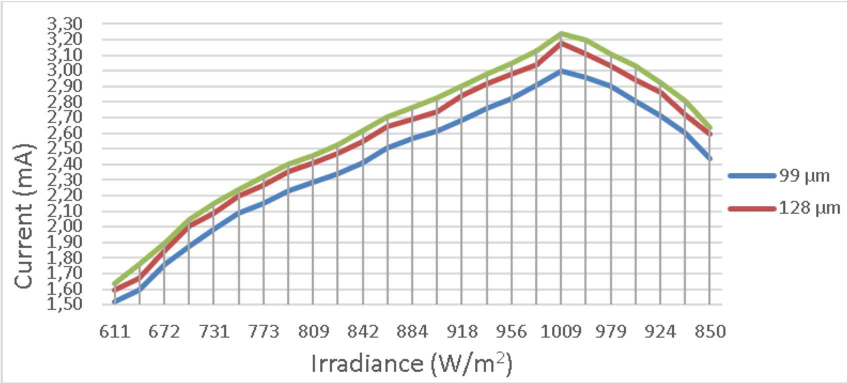

Fig. 5. Current versus the intensity of solar radiation for the three variants thickness of the DSSC

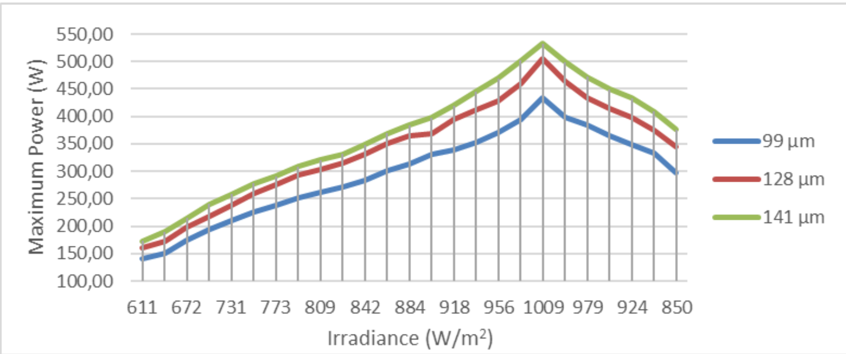

Fig. 6. Maximum power versus the intensity of solar radiation for the three variants thickness of the DSSC

For the three different thickness variations of the TiO_2 layers of the DSSC solar cell of 99 µm, 129 µm and 141 µm, if an irradiance of 611 W/m2, the DSSC voltage values obtained are 2071 mV, 2301 mV and 2446 mV respectively, the DSSC current values obtained are 1.52 mA, 1.59 mA and 1.64 mA respectively and the DSSC maximum power values obtained are 140.92 W, 162.50 W and 172.80 W respectively. Furthermore, the voltage, current and maximum power values of each DSSC increased to a maximum at 12.30 pm with an irradiance of 1009 W/m². The values of voltage of each variation of the DSSC solar cell at 1009 W/m² irradiance are 2701 mV, 3002 mV and 3159 mV respectively, the values of current are 3.00 mA, 3.17 mA and 3.24 mA respectively and the values of maximum power are 434.06 W, 506.27 W, and 532.26 W respectively. Once the peak value is reached, the DSSC voltage, current and maximum power continue to decrease until the test is complete.

From the data obtained, the voltage, the current and the maximum power are directly proportional to the intensity of the solar radiation. The higher the irradiance value, the higher the voltage, the current and the maximum power value.

4. Conclusions

This paper reports the use of red dragon fruit as a dye base for DSSC manufacture and shows the effect of TiO_2 thickness on DSSC performance by varying its thickness. Three variations in the thickness of the TiO_2 layer evenly positioned in the conductive area are tested using specially made of Arduino measurement kit. The thickness of the TiO_2 layer are 99 µm, 129 µm and 141 µm respectively. The DSSC having thickness of the TiO_2 layer of 141µm resulted in the highest maximum power value of 532.26 mW among the three thickness variations. From the three thickness variations, it can be concluded that the thicker the TiO_2 paste, the higher the maximum power value.

There are many DSSC components that affect the performance of DSSC solar cells such as TiO_2, dye influence and the use of electrolyte types. Further in-depth study is needed regarding the characteristics of the materials used.

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