Effect of Electrolytes on the Performance of Dye-Sensitized Solar Cells (DSSC) with Mulberry (*Morus*) Extract as Dye Sensitizer

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Abstract: A prototype of Dye Sensitized Solar Cell (DSSC) based TiO_2 nanoparticles and mulberry (morus) extract as dye sensitizer on the ITO glass substrate has been produced. The study aims to determine the difference between the use of gel electrolyte and liquid electrolyte on its influence on DSSC performance. Sandwich cells were made consisting of a working electrode in the form of a conductive glass ITO deposited with TiO_2 which was sensitized by a dye of mulberry extract, the opposite electrode in the form of a conductive glass ITO with carbon deposited, and the electrolyte in the middle of the two electrodes were liquid and one was gel. Irradiation was carried out on both samples by lighting halogen lamps. Tested the characteristics of voltage-time and current-time in both samples. The results obtained for higher voltage and current values in samples with liquid electrolytes, but for the period of stability, the samples with gel electrolytes showed better performance.

Keywords: gel electrolyte; liquid electrolyte; Mulberry (morus) extract; TiO_2 nanoparticles.

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I. INTRODUCTION

To overcome the scarcity of energy caused by the reduction in fossil fuels, various efforts to find alternative fossil energy, such as biogas, nuclear, wind, water, sun, and geothermal, are encouraged. Indonesia is one of the countries with a quite high sunlight intake because it is located on the equator, making it a potential country to apply the energy derived from sunlight as alternative energy, known as solar cells [1]. So far, solar cells have evolved in three generations (based on silicon crystals, thin films, and organic materials) [2]. Solar cell development is carried out to obtain the best value of efficiency and effectiveness in use. The third-generation solar cells, known as dye sensitized solar cells (DSSC), are more researched because the materials are highly available in nature, easy to fabricate, and inexpensive to manufacture [3]. This DSSC is a sandwich consisting of a working electrode in the form of a conductive glass coated with a semiconductor material, a natural coloring agent to improve the performance of the semiconductor material, a comparison electrode, a carbon-coated conductive glass, and an electrolyte in the middle of the two electrodes as a means of electron transport between the two electrodes [4]. There are two developments of electrolytes used in DSSC research (liquid electrolyte and gel electrolyte) [5]. In 2012, Zamroni conducted a DSSC research based on mangosteen peel extract dye and applied a liquid electrolyte. The results showed that the stability of the DSSC was still low. [6]. In 2013, Biaunik through her DSSC research, which was also based on mangosteen peel extract, applied a polymer-based electrolyte gel which was claimed to be more resistant to be used for a long time [7]. Recent research has shown that liquid electrolyte has the advantage of producing high efficiency in DSSC because of its high ionic conductivity, but the stability is low, resulting in reduced DSSC performance [8]. To anticipate the decline in DSSC performance due to low electrolyte stability, gel electrolyte was applied to improve DSSC performance [9], [10]. In this study, we analyze the difference between the uses of liquid and gel electrolytes in DSSC but based on mulberry extract dye (morus). Mulberry extract dye was chosen because the anthocyanin content is 1.993 mg/100 grams higher than the mangosteen peel extract, which contains only 59.3 mg/100 grams of anthocyanin so that it is hoped that the absorption of dye sensitizer to maximum lighting would affect the DSSC performance [11].

II. METHODOLOGY

Manufacture of working electrode

The working electrode consists of a conductive glass coated with a semiconductor material that has been sensitized by a dye. The semiconductor material used is TiO_2 (Titanium Dioxide), an order of nanometer with anatase phase with a

FIG. 1: Mulberry.

gap energy of 3.2 eV which has been proven to be able to produce good efficiency [12]. The smaller the particle size is, the greater the surface area of the particle binds with dye sensitizer [2]. The TiO_2 powder was produced by the co-precipitation method [7]. TiO_2 was sensitized with dyes so that the range of the area of light absorption is wider because, without the dye, the range of the area of light absorption is only 360-380 nm [2]. TiO_2 powder was converted into a solution form and then deposited on a conductive glass ITO (Indium Tin Oxide) measuring 2.5 x 2.5 cm which has good conductive properties for DSSC cells. This deposition was carried out by the spin coating method, which was dripped with a few drops of TiO_2 solution on the conductive side of the glass and then rotated on the spin coating device until all sides of the glass were covered with solution [13]. Glass deposited with TiO_2 solution was then dried for later immersion in a dye solution.

Manufacture of dye sensitizer

Dye sensitizer used is mulberry (morus) fruit extract. Mulberry was chosen because it has a higher anthocyanin content than mangosteen peel extract [1].

Mulberry was extracted with 50 ml of methanol (Sigma-Aldrich), 8 ml of acetic acid (Merck), and 42 ml of distilled water, and then the extracted solution was tested using a UV-Vis Spectrophotometer to determine its absorption capacity. The working electrodes that have been made were soaked in this solution for 24 hours [2].

Manufacture of opposite electrode

The opposite electrode used is ITO (Indium Tin Oxide) conductive glass measuring 2.5 x 2.5 cm coated with carbon solution. Carbon coated glass was heated at 350°C for 30 minutes. Then, the temperature was lowered to 70°C so that the carbon layer sticks perfectly to the glass [7].

Manufacture of electrolyte

First, the liquid electrolyte was made using a mixture of 3 grams of Potassium Iodide (Merck) and 3 ml of Iodine 10% solution (Nitra Kimia) that was stirred for 30 minutes [6]. The second was making gel electrolyte with the same procedure as making the liquid but with the addition of a polymer solution which is the result of mixing 2.5 grams of PEG 1000

(a) Liquid (b) Gel

FIG. 2: (a) liquid electrolyte (b) gel electrolyte.

FIG. 3: DSSC sandwich sample.

(Merck) with 5 ml of chloroform (Merck) which is stirred for 30 minutes; a liquid electrolyte mixed with polymer solution was stirred for 60 minutes at 85°C to thicken [7]. Therefore, two electrolytes were produced, namely liquid electrolytes and electrolytes, which are thicker liquid or gel.

Manufacture of DSSC Sandwiches and Testing

The first sandwich consists of a working electrode that was dripped with a liquid electrolyte and then affixed with the opposite electrode which leaves two blank sides without a 0.5 cm layer for testing. Then, the two electrodes that had been attached were clamped. The second sandwich is the same as the first sandwich, but the working electrodes are smeared with gel electrolytes [7].

The test circuit was created with the following mockup:

The light source for irradiation is 74,000 Lux halogen lamps with a distance of 2 cm above the Sandwich [7]. There are two types of tests carried out, voltage-time and current-time tests. Both tests were conducted to determine the stability level of DSSC. Each test was carried out for each sample.

III. RESULTS AND DISCUSSION

Nano order TiO_2

The results of the XRD (X-Ray Diffractometer) test for TiO_2 are as follows:

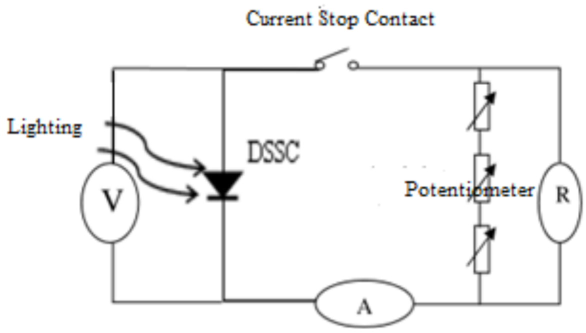

FIG. 4: DSSC circuit.

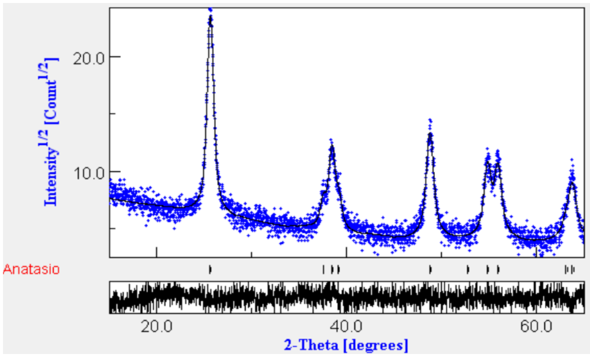

FIG. 5: XRD test results for TiO_2 size.

XRD test data were identified to determine the crystal size using Materials Analysis Using Diffraction (MAUD) software and the phase using Match software [7]. The size of TiO_2 crystal obtained is 10.9 nm with an error value of 1.43. The phase that best matches the TiO_2 that has been formed is anatase. The nano size of TiO_2 makes the surface area to bond with the dye better than the micro size [6]. The anatase phase is the best phase for TiO_2 because the energy gap is the widest compared to the rutile and brookite phases, which will support electron mobility [7].

Absorption capacity of dyes

The following are the absorbance test results of mulberry dyes using a UV-Vis Spectrophotometer with a wavelength range of 190 to 1000 nm:

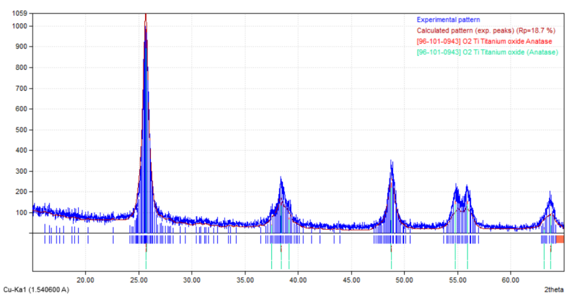

FIG. 6: XRD test results for TiO_2 phase.

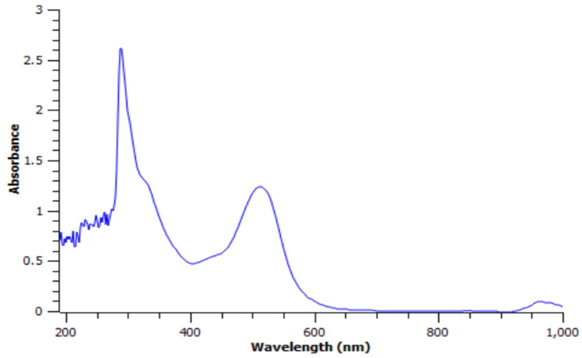

FIG. 7: Graph of mulberry dyes absorbance.

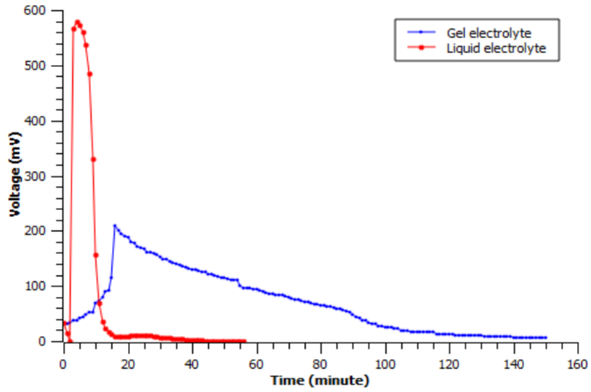

FIG. 8: Graph of the relationship of voltage & time.

The maximum absorption rate lies in the wavelength range of 270-388 nm and 392-614 nm Halogen lamps were chosen as the light source because the lighting intensity is constant while the source of the sunlight is not. Halogen lamps have a wavelength range of 360-500 nm which corresponds to a wavelength range where the dye absorption rate is maximum [14].

DSSC Sandwich Testing

Voltage-time

Tests were carried out on two DSSC sandwich cells (with gel electrolytes and with liquid electrolytes). The measurement results are shown in Fig. 8.

For gel electrolyte sandwiches, this test is carried out when the cell is first smeared with gel electrolyte under open-circuit conditions and lasts for 150 minutes or 2.5 hours. The measured voltage is generated every 1-minute interval. At the beginning of irradiation, the maximum measured voltage reaches 210 mV in the 16th minute and then decreases slowly until it reaches 5.4 mV in the 150th minute. The longer voltage drops more slowly because the gel electrolyte takes time to produce high stability.

For liquid electrolyte sandwiches, this test is also performed when the cell is first dropped with liquid electrolyte in an open circuit condition and lasts only for 58 minutes. The highest voltage is obtained at 580 mV in the 4th minute and

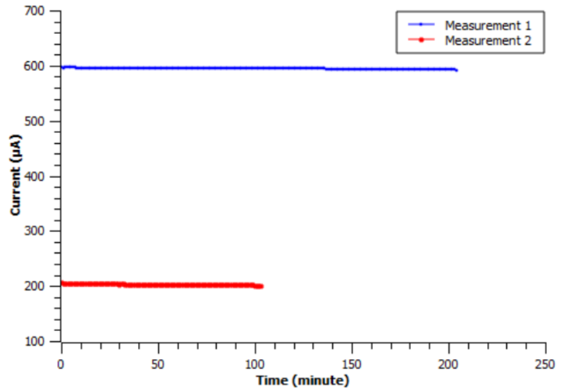

FIG. 9: Graphs of the relationship of current and time for gel electrolyte sandwiches.

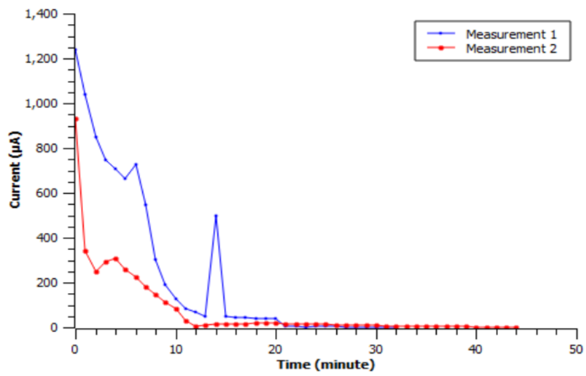

FIG. 10: Graph of the relationship of current and time for liquid electrolyte sandwich.

then stabilized for only 3 minutes. The value of the voltage produced is two times greater than that of a sandwich cell with a gel electrolyte, which is proportional to the current value. This is the same as the results of Zamronis research in 2012 [6]. In the 8th minute and after that, the voltage drops so drastically that only a very small voltage value below 5mV is obtained, and this value stays stable until it runs out for only 50 minutes. This shows that liquid electrolyte is unstable because the iodine liquid quickly evaporates so that the mobility of electrons is disturbed [6]. For periods of stability, gel electrolyte samples show better performance when compared to samples with liquid electrolytes although the voltage value is smaller than the sample with a liquid electrolyte which has high ionic conductivity. Both samples need time to reach the maximum voltage value from the first lighting. This shows the maximum absorbance of the dye sensitizer to absorb the halogen lamplight. When the maximum voltage is obtained, the two samples immediately reduce the voltage value with different levels of stability to show their performance. From the results of this voltage-time test, the maximum voltage value of DSSC with mulberry extract dye is 580 mV which is higher than the mangosteen peel extract dye which only produces a maximum voltage value below 550 mV for liquid electrolyte and only 398.3 mV for gel electrolyte [6, 7].

Current-time

The measurement of sandwich cells with gel electrolyte is shown in Fig. 9. The first measurement is done when the series is given a load of 0.4 kΩ and under the condition of new cells smeared with gel electrolyte. For this test, a very stable current was generated for 204 minutes or 3 hours more. After three days, a second measurement was made on the sandwich cell without the gel electrolyte being applied again with the second loading of 0.04 kΩ. It turned out that the current produced remained stable for 103 minutes or more than 1.5 hours. Both measurements show the stability of the DSSC produced. The gel electrolyte does not quickly run out or evaporate from the first to the second measurement which pauses 3 days. Thus, DSSC cell performance is quite good because it can produce very stable currents over a long period of time. By developing a polymer-based electrolyte, the electrolyte density will be higher while the porosity decreases; this causes smooth or undisturbed electron mobility because iodine does not rapidly shrink [10]. Sandwich cells with gel electrolytes also have a lower level of cell oxidation so that the cells do not easily corrode even though they are used for a long time, in the sense that the cell conditions are still quite good.

The DSSC performance of this mulberry extract is better than the research with mangosteen peel extract which applies both gel electrolyte and TiO_2 nanoparticles, which result in a maximum current of 600 μA lasting for 204 minutes, which is greater than the mangosteen peel extract which only produces a maximum current of 30.9 μA lasting for 180 minutes [7].

The results of sandwich cells with liquid electrolytes are shown in Fig. 10. Loading was given the same as when measuring cells with gel electrolyte. In measurement 1, when new cells were dropped with a liquid electrolyte, the maximum current reached 1238 μA in the first minute and then tended to decrease in the following minutes. However, the current was still large until the 15th minute and then dropped dramatically and was stable with very small current values. Then, it ran out in the 32nd minute. Measurement 2 was made on the same day, but electrolyte drops were needed again because, without electrolyte drops, the current value did not reappear. It was conducted on the same day as measurement 1 because, the next day, the sandwich cells would be oxidized or corroded so that the quality was not good for measurement. In liquid electrolyte test, the current generated is two times greater than the current produced by cells with gel electrolytes because, in a liquid medium, the ionic conductivity and capacity of the electrolyte to interact with TiO_2 particles are greater [5]. The high current value when first dropped by electrolyte decreases and only lasts to 44 minutes. Thus, the current stability is not as good as when using gel electrolytes. The oxidation levels are also high, which can reduce cell quality. Also, the longer temperature measurement of cells increases heat that causes rapid evaporation of electrolytes. It means that the iodine level has decreased so that ionic conductivity decreases. However, the current produced by the mulberry extract DSSC sandwich, which is 1238 μA, is the maximum compared to the research with mangosteen peel extract which produces no more than 200 μA for liquid electrolytes and only 30.9 μA for gel electrolytes [6,7].

IV. CONCLUSION

Dye Sensitized Solar Cell from TiO_2 measuring 10.9 nm with anatase phases with dye sensitizer in the form of mulberry fruit extract on the ITO glass substrate has been successfully made. Tests are carried out using two different electrolytes, namely gel and liquid electrolytes. Different characteristics are obtained between gel and liquid electrolyte samples. Liquid electrolyte samples produce higher voltage and current values compared to gel electrolyte samples, but the stability period of the liquid electrolyte samples is not so good as gel electrolyte samples that can last longer.

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