The Effect of Gel-Electrolyte on Dye Sensitized Solar Cell (DSSC) Prototype based on Nanosized-TiO₂ Using Mangosteen Pericarp as Absorber

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Abstracts

Dye Sensitized Solar Cell (DSSC) with Fluorine doped Tin Oxide (FTO) substrat and nanosize-TiO₂ layer sensitized by "dye" mangosteen pericarp extract, was succesfully fabricated. Gel-Electrolyte as electron regenerator was synthesized by adding Polyethylene Glycol (PEG) 1000 to electrolyte solution while nanosize-TiO₂ was synthesized by co-precipitation method from TiCl₃ solution. The crystal size of TiO₂ characterized by X-Ray Diffraction is 10.5 nm in size. The solar absorbance of "dye" mangosteen pericarp was measured using UV-Vis Spectrophotometer and it showed that the dye can absorb photon at Near Ultraviolet (NUV) to yellow visible light. Nanosize-TiO₂ based DSSC with gel-electrolyte successfully reached short circuit current up to 30.9 µA, open circuit voltage 398.3 mV and performed the long term stability. ©2017 JNSMR UIN Walisongo. All rights reserved

Key words: Dye-Sensitized Solar Cell (DSSC); Mangosteen Pericarp; Gel-Electrolyte; Nanosized-TiO₂

1. Introduction

Dye Sensitized Solar Cell (DSSC) was firstly fabricated by scientist from Switzerland, Michael Gratzel, in 1991 [1]. It was found to be the solution for low-cost solar power compared to silicon-based solar cell. DSSC generally consist of two electrodes (active electrode and counter electrode) and electrolyte for electron to transfer. Counter electrode was basically coated by Pt or carbon on its surface of substrate[2].

The mechanism of electron transfer of dye sensitized solar cell is described by Figure 1. The photon energy from the sun was absorbed by dye as a solar absorber to excite the electron from the ground state to excited state based on reaction : \( \text{S}_0^+ + e^- \rightarrow \text{S}^* \). The photoexcited dye transfers an electron to the semiconducting
TiO$_2$ layer via electron injection. The injected electron is then transported through the TiO$_2$ and collected by conductive glass. Within the electrolyte, the mediator (I$^-$/I$_3^-$) undergoes oxidation at the dye and regeneration at the catalyst-coated counter electrode as current flows through the electrical load [3]. DSSC as a low-cost solar cell device has achieved efficiency of 11% [1].

**Figure 1.** Mechanism of electron transfer within dye sensitized solar cell (DSSC)

DSSC has been attractive to be a substitute to previous silicon-based solar cell due to its higher efficiency and low-cost process. However, several issues such as electrolyte leakage in high temperature and short-term stability are main problems of liquid-electrolyte. This work is concerned to escalate DSSC performance by engagement of nanosize TiO$_2$ and gel-electrolyte to improve its stability.

2. **Experiments Procedure**

There are four general steps in fabricating DSSC, namely: synthesis of TiO$_2$, synthesis of dye solution, synthesis of gel-electrolyte and fabrication of DSSC device.

**Nanosize-TiO$_2$**

Nanosize-TiO$_2$ was synthesized by coprecipitation method of titanium trichloride, TiCl$_3$. Solution of HCl:DI water with the ratio of 2:5 was stirred for 15 minutes. The 20 ml of titanium trichloride was then gradually added to the solution and stirred for 30 minutes. 50 ml of ammonium hydroxide (NH$_4$OH) was gradually dropped to the solution and stirred for 1 hour. The suspension was further filtered and dried to gain nanosized powder of TiO$_2$.

**Dye solution**

Mangosteen pericarp was separated from its nut, cleaned and dried. It was then heated in oven at 60°C for 6 hours to remove the contained water. The dry mangosteen pericarp was crushed and further ground to obtain the powder and further dissolved in water to get dye solution. The dye solution was then characterized by UV-Vis Spectrophotometer to analyze the absorbance.

**Gel-electrolyte**

Electrolyte utilized in the experiment was redox solution of iodin and iodide (I$^-$/I$_3^-$) from Potassium Iodide (KI) and I$_2$ solution. 3 gram kalium iodide was dissolved in 3 ml Iodin e and stirred for 30 minutes. Furthermore, Polyethylene glicol (PEG) was employed to obtain gel electrolyte. The 2,5 gram of PEG was firstly dissolved in 5 ml chloroform and stirred for 30 minutes. The electrolyte solution was gradually added to it, stirred for minutes and maintained at 60°C.

**Fabrication of DSSC device**

There are two types of electrodes, namely: active electrode and counter electrode.

**Figure 2.** Active electrode consists of: TiO$_2$ layer, dye solution and gel-electrolyte

Thin TiO$_2$ layer was coated to FTO glass substrate by spin coater and it was further heated up to 450°C and slowly cooled to 70°C.
At that temperature, the layer was immersed in dye solution for 24 hours and further cleaned by DI water. Furthermore, the gel electrolyte was dropped to the cleaned pasta.

The counter electrode consists of FTO glass coated by carbon. The carbon layer gained by stretching the glass with carboneous pencil was heated up. The size of cell was (1 cm x 1 cm)

![Figure 3. Scratched FTO glass by carbonaceous pencil (left), heated carbon layer (right)](image)

Those two electrodes was then clipped to construct a prototype of DSSC device as described in Figure 4.

![Figure 4. Prototype of DSSC device](image)

The device was kept in dark room for 24 hours and further tested under yellow light illumination.

3. Result and Discussion

The EM absorption capability of dye synthesized from mangosteen pericarp extract was examined by UV-Vis Spectrophotometer. Figure 6 shows the absorbance range of dye was in the range of near Ultra-violet to blue-yellow visible light.

![Figure 5. IV-characterization process of DSSC under yellow light illumination](image)

![Figure 6. UV-Vis spectra of mangosteen pericarp extract](image)

The best dye absorber is the dye which is able to strongly absorb the long range of electromagnetic (EM) energy from the sun. Meanwhile, the visible light (390-700 nm) is the highest intensity of EM recieved by the earth. Figure 6 shows the dye is able to strongly absorb the EM energy in the range of Near-Ultraviolet to yellow visible light, i.e 300-550 nm. Therefore, it conclude that the dye was potential to be performed in the DSSC device.

The TiO₂ phase and crystal size was characterized by X-ray diffractometer (XRD).
The TiO$_2$ anatase phase is assigned to diffraction angle of $2\theta : 25.4^\circ$ determining the (101) crystalline plane while rutile phase is assigned to diffraction angle of $2\theta : 27.36^\circ$ determining the (110) crystalline plane [4][5]. Figure 7 shows that the (101) is assigned to $2\theta : 25.7^\circ$ and the rutile peak is undetectable. The anatase phase was observed at 450°C and that was apparently in agreement with previous work performed by Muneer and co-workers who analyzed the effect of heating temperature to TiO$_2$ phase formation. They stated that the rutile peak formation was observed at heating temperature of 500°C.

The crystalline size of TiO$_2$ referring to (110) crystalline plane identified by Materials Analysis Using Diffraction (MAUD) was 10.5 nm in size. Nanosize-TiO$_2$ possesses higher specific surface area compared to micrsize-TiO$_2$. The higher specific surface area of TiO$_2$, the more dye molecules embedded on TiO$_2$ surface.

The stability of the device was observed by screening for 180 minutes under yellow light illumination. The optimum performance of the device occurred after illumination about 8 minutes (Figure 8). It inferred that the electron required sometimes to transfer. The performance was gradually decreased and remained stable at the minute of 120th due to the leakage and evaporation of electrolyte. However, the stability of device was better than that of the previous work utilizing liquid electrolyte performed by Rofiah [6].
DSSC performance is well represented by the value of its efficiency and fill factor \[7\]. The efficiency of the photovoltaic cell is calculated from the maximum power of the cell divided by total power of illumination as described by Equation 1:

\[ 
\eta_{cell} = \frac{P_{max}}{P_{in}} 
\]  
(1)

which power maximum \( P_{max} \) is equal to short circuit current \( I_{sc} \) multiplied by open circuit voltage \( V_{oc} \), while the value of fill factor is described by Equation 2.

\[ 
\eta_{cell} = \frac{P_{max}}{V_{oc}I_{sc}} 
\]  
(2)

Maximum voltage of 70.3 mV and maximum current of 9.6 µA was reached by the cell. The fill factor reached the value of 0.2. This number is higher compared to the fill factor of previous work utilizing microsized-TiO\(_2\) which was performed by Rofiah \[6\]. Nanosize-TiO\(_2\) possesses higher specific surface area than that of microsize-TiO\(_2\). It affects the amount of dye molecules embedded on the TiO\(_2\) surface. The higher amount of dye molecules on the TiO\(_2\) surface is assumed to absorb higher amount of light source intensity which affect to the number of transferred electron within the cell.

4. Conclusion

In conclusion, these preliminary results suggest that Dye Sensitized Solar Cell (DSSC) based on nanosize-TiO\(_2\) and gel electrolyte using mangosteen pericarp as absorber was successfully fabricated. The long-term stability was achieved due to the utilization of gel-electrolyte which was able to minimize electrolyte leakage and evaporation. Furthermore, the engagement of nanosize-TiO\(_2\) was able to improve the efficiency if it was compared to work done by Rofiah\[6\] due to the higher surface specific area compared to microsize-TiO\(_2\).

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