Int. j. adv. multidisc. res. stud. 2024; 4(3):1021-1023

Received: 18-04-2024
Accepted: 28-05-2024

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Fabrication and Performance Test of Dye-Sensitized Solar Cell (DSSC) with Mango (*Mangifera Indica*) Leaf Extract as Sensitizer

[1] Arief Rahmatulloh, [2] Mutia Devi Hidayati
[1, 2] Department of Chemical Engineering, Politeknik Negeri Malang, Indonesia

Corresponding Author: **Arief Rahmatulloh**

Abstract
In this research, we reported the fabrication of a dye-sensitized solar cell (DSSC) with mango leaf extract as a sensitizer. TiO_2, which existed as a working electrode along with the sensitizer, has a role as a photocatalyst. TiO_2 preparation with Indium Tin Oxide (ITO) glass was carried out by the doctor blade method, followed by the submersion of the TiO_2–ITO glass at mango leaf extract. Carbon was added to act as the counter electrode. FTIR characterization is conducted to determine the interaction between dye sensitizer, TiO_2, and ITO glass. The appearance of a new absorption at wave number 1498.73 cm^{-1} shows the interaction between dye sensitizer and TiO_2–ITO glass. In addition, the emergence of absorption at wave numbers 580.59 and 420.57 cm^{-1} which stand for Ti–O and In–O respectively, strengthen the interaction existance between the dye and TiO_2–ITO glass. The performance of DSSC was tested using a multimeter digital. The highest photovoltaic efficiency values of DSSC are obtained from a 2.5% sensitizer of 0.2188% under the sunlight.

Keywords: Mango, Sensitizer, Photovoltaic Efficiency, Dye-sensitized Solar Cell

Introduction

Dye-sensitized solar cell (DSSC) is a solar cell that utilizes natural dyes as a sensitizer. DSSC converts energy using natural color pigments from plants as photosensitizers. The photosensitizer acts as an absorber of light energy. The requirements for a sensitizer utilized as a light harvester in DSSC must have an absorption spectrum covering a wide region of the visible light spectrum and retaining groups, such as hydroxyl or carboxyl groups, to bind to the semiconductor film [1]. Further, the dye's lowest unoccupied molecular orbital (LUMO) should be higher in energy than the semiconductor's conduction band as a consequence, upon excitation, the dye can introduce electrons into the TiO_2 conduction band [2]. The absorption spectrum of the sensitizer and its functional group improves the injection of exciting electrons into the nanoporous semiconductor layer which enhances the efficiency of DSSC [3]. A good photosensitizer must meet several fundamental fabrication criteria, such as (i) strong dye adsorption particles onto the semiconductor surface; (ii) large visible light harvesting capacity; (iii) ability to inject the electron into the conduction band of the semiconductors; and (iv) =O or ─H groups capable of anchoring on the semiconductor surface to ensure high rates of electron transfer [4]. Extract dyes or plant pigments that can be used as photosensitizers can be extracts of chlorophyll, carotene, anthocyanins, etc. Chlorophyll attracts the attention of numerous researchers compared to others. This is because chlorophylls can absorb visible light in a wide range. Chlorophylls belong to a natural group that provides color to the leaves of plants. Chlorophyll molecules are attached to the surface of the semiconductor with carbonyl and hydroxyl groups, which stimulates the transfer of electrons from the sensitizer to the conduction band of the porous semiconductor layer. Ludin *et al*, who fabricated dye-sensitized solar cells with chlorophyll derivative, disclosed that the chlorophyll could enhance the performance of DSSC. They also said that chlorophyll-based DSSC should have higher efficiency and a longer lifetime. One of the plants that contain chlorophyll is the mango leaf [5].

Mango leaf was used in this study which was extracted as a dye sensitizer. It has a Latin name *Mangivera Indica L.* Further, it has numerous advantages such as abundant amount, easy to find, and cheap. Chlorophyll contained in mango leaf absorbs sunlight in the region of blue, green, and yellow color with a wavelength of 480-618 nm. In addition, the extract of sensitizer coated on the transparent conductive oxide (TCO) glass and acted as a photoanode. The TCO glass type that is commonly used is Indium Tin Oxide (ITO). Further, besides the dye sensitizer which is coated on the TCO, semiconductor such as Titanium Dioxide (TiO_2) was also coated on the TCO. TiO_2 gained the most popularity among the others because of its high surface area, higher chemical stability, less toxicity, significantly high catalyst band edge, very low charge recombination, etc. Moreover, the other advantages of utilization of TiO_2 namely easy to find and fabrication, and has high oxidative properties [6]. This study aims to disclose the performance increment of the dye-sensitized solar cell (DSSC) employing the natural pigment extracted from mango leaf and blended with TiO_2 as a photoanode.

Experimental

Chemicals and Materials

DSSC used in this study were fabricated from Indium Thin Oxide (ITO) glass (Sigma Aldrich, Singapore), charcoal (96% purity degree, Merck, Singapore), mango leaf, titanium dioxide (96% purity degree, Merck, Singapore), potassium iodide (96%, Merck, Singapore), iodine (95% purity degree, Merck, Singapore). Other chemicals with pro-analysis purity were ethanol (96% purity degree, Merck, Singapore), monoethanolamine (MEA) (95% purity degree, Sigma Aldrich, Singapore), demineralized aqua.

Instrumentals

This study used several tools to do some experiments such as an electric heater, beaker glass, thermometer, spatula, scale, a hundred mesh sieve, magnetic stirrer, ultrasonic cleaner, multimeter, ultraviolet lamps, rotary evaporator IKA RV 8 basic, spectrophotometer UV-Visible of Varian Cary 50 Conc.

Dye extraction

Dye extraction from mango leaf was carried out with Ultrasound Assisted Extraction (UAE) method. The concentration of mango leaf was varied by 2.5; 5 and 7.5% (w/v). The power of UAE also varied from 35 and 50 watts. Those samples were soaked in ethanol solvent with a ratio of 1:15. The UAE process was conducted for 2 hours. Next, the filtrates were collected using a mesh sieve. Further, the extract liquid dyes were treated with a rotary vacuum evaporator to evaporate the solvent. As a result, the condensed extract has been obtained [7].

Photoanode preparation

The photoanode was prepared from 3.5 grams of titanium dioxide which was soaked on 7 ml demineralized aqua and stirred for 30 minutes at 60˚C. During stirring, the monoethanolamine (MEA) with the amount of 15 mL was added. Next, it was left until it reached room temperature. The following step was the mixture transferred onto ITO glass which was conducted with the doctor blade method and the thickness was 1.1 mm. Further, the TiO_2-coated ITO glass was left at room temperature. Next, TiO_2-coated ITO glass was soaked in dye extract for 24 hours. Then, it was rinsed with demineralized aqua. The photoanode was dried at room temperature. Moreover, carbon as a counter electrode was added to another part of TiO_2-coated ITO glass [3, 8].

TiO_2-based DSSC fabrication

TiO_2-based DSSC was formed from dye-sensitized photoanode, carbon as counter electrode and electrolyte. The electrolyte was evenly dripped on the counter electrode. Then two dye-sensitized photoanodes were placed face to face. The installation of dye-sensitized photoanodes was fixed by two binder clips to hold the device tenderly.

Characterization

The performance of DSSC was measured using a multimeter appliance. Further, the band gap values of TiO2 and TiO2-Dye sensitizer were calculated using the Tauc Plot Method.

Results and Discussion

Dye extraction

The dye extraction process of mango leaf for each mass concentration was conducted for 2 hours. The duration of extraction was chosen because the color of the dye changed from green to biru after 2 hours. It indicates that all of the chlorophyll pigment of mango leaf extract has already been extracted. Next, the liquid extract was treated with a rotary vacuum evaporator to evaporate the solvent at 50ºC. When the concentration is increased then the yield extract is decreased. This condition is because of the saturated solution. Further, the yield extract is directly proportional to the potency of the dye extract as a sensitizer. The bigger of yield extract then the better the potency of the dye extract to be utilized as a sensitizer.

Photoanode preparation

The preparation of the photoanode began with sterilizing the ITO glass. Meanwhile, the TiO2 was dissolved and added with MEA. The presence of MEA in this process becomes important because it makes the TiO2 more viscous and reduces the drying process. Further, the existence of MEA can ensure colloidal stability for electrosteric purposes. Further, the TiO2 was cast on the ITO glass and dried at room temperature with the doctor blade method. The purpose of this method is to form the transport layers that have no aggregation of the transport active molecule in the solid film. As a consequence, the layers can sustain the motion of electrons regardless of loss to deep traps.

Next, it was soaked in the dye extract and dried at room temperature as well to evaporate the residual solvent. At last, the counter electrode was added to the photoanode. The photoanode can be seen in Fig 1.

Fig 1: Photoanode with dye extracted from mango leaf

Characterization

Band Gap Energy (Eg) Calculation

The Spectrophotometry UV-visible spectra of mango leaf extract can be seen in Fig 3. It shows that the dyes absorb light at the visible spectrum region. Consequently, the dye is appropriate to act as a sensitizer in DSSC. The band gap energy was calculated using the Tauc Plot method. The result of these calculations show that the value of the band gap energy of TiO2 is 5.515 eV, while the value of the band gap energy of the dye – TiO2 is 2.976 eV. This result indicated that the presence of the dye on the photoanode decreases the band gap energy of TiO2 due to the incorporation of the dye into the TiO2 which interacts chemically with each other [9].

DSSC Performance

The photovoltaic performance of the DSSC device with various mass concentrations of dye extract has been investigated in two conditions namely: Indoors at room temperature, and outdoors with UV irradiation. The dye extracted from mango leaves was used as photosensitizers. The intensity of the light in these conditions has been measured using a lux meter. Further, the photovoltaic efficiency (η) has been calculated as well. The relation between mango leaf concentration, UAE power, and photovoltaic efficiency parameter can be seen in Figures 2 and 3.

In this study, a different situation was conducted to find out the role of dye as a sensitizer on the DSSC performance. From the table 2 & 3, it can be seen that the efficiency of DSSC rose consequentially when it irradiated with UV. This condition is due to the existence of a dye sensitizer on the DSSC. The photoanode with dye extracted from 2.5% mango leaf has the highest power conversion efficiency (PCE) among the others. The figures also illustrated when the power of the UAE is increased then the efficiency is decreased. This condition is due to the degradation of mango leaf pigment which is caused by the mechanical treatment of the UAE [10].

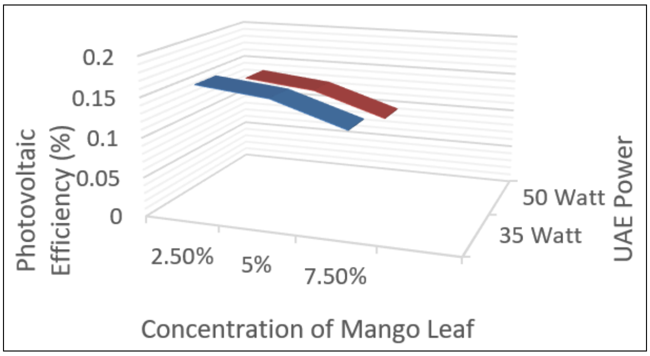

Fig 2: DSSC Performance in Indoor Investigation

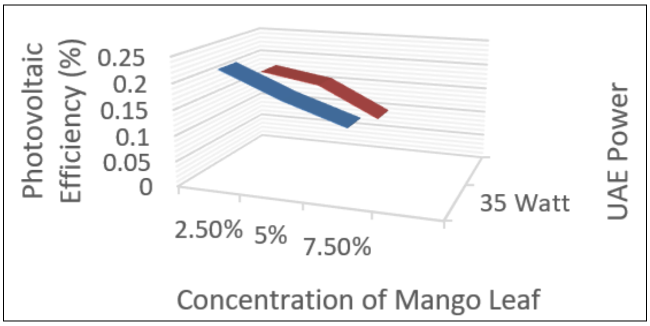

Fig 3: DSSC Performance in Outdoor Investigation

Conclusion

In summary, natural dye sensitizers were extracted from mango leaves and used in dye-sensitized solar cells. The maximum photovoltaic conversion efficiency of 0.22% was achieved for DSSC fabricated with dye extracted from 2.5% mango leaf in outdoor conditions with UV irradiation. In addition in the indoor condition at room temperature, the highest efficiency of 0.16% was obtained for the same DSSC. From the result, it could be concluded that the dye has a greater influence on the device's performance. The band gap analysis UV-visible spectra revealed that the presence of the dye shortens the band gap energy.

Acknowledgements

The author would like to express their gratitude to the Chemical Engineering Department of Politeknik Negeri Malang for extending their support and providing the infrastructure to carry out the research work.

References

1. Giribabu L, Singh VK, Vijay Kumar C, Soujanya Y, Gopal Reddy V, Yella Reddy P. Adv. Optoelectron, 2011. Doi: http://dx.doi.org/10.1155/2011/294353
2. Hemmatzadeh R, Mohammadi A, Theor J. Appl. Phys. 2013; 7:1-7. Doi: http://dx.doi.org/10.1186/2251-7235-7-57
3. Prakash P, Janarthanan B, Ubaidullah M, Al-Enizi AM, Shaikh SF, Alanazi NB, *et al*. J. King Saud Univ. - Sci. 2023; 35:102625. Doi: http://dx.doi.org/10.1016/j.jksus.2023.102625
4. Ludin NA, Al-Alwani Mahmoud AM, Bakar Mohamad A, Kadhum AAH, Sopian K, Abdul Karim NS. Renew. Sustain. Energy Rev. 2014; 31:386-396. Doi: http://dx.doi.org/10.1016/j.rser.2013.12.001
5. Ludin NA, Al-Alwani MAM, Mohamad AB, Kadhum AAH, Hamid NH, Ibrahim MA, *et al*. Int. J. Electrochem. Sci. 2018; 13:7451-7465. Doi: http://dx.doi.org/10.20964/2018.08.04
6. Ananthakumar S, Ramkumar J, Babu SM. Renew. Sustain. Energy Rev. 2016; 57:1307-1321. Doi: http://dx.doi.org/10.1016/j.rser.2015.12.129
7. Vidana Gamage GC, Choo WS. Food Chem. Adv. 2023; 2:100209. Doi: http://dx.doi.org/10.1016/j.focha.2023.100209
8. Nang Dinh N, Minh Quyen N, Chung DN, Zikova M, Van Truong V. Sol. Energy Mater. Sol. Cells. 2011; 95:618-623. Doi: http://dx.doi.org/10.1016/j.solmat.2010.09.028
9. Nnorom OO, Onuegbu GC, Etus C. Results Opt. 2022; 9:100311. Doi: http://dx.doi.org/10.1016/j.rio.2022.100311
10. Rakhman dkk. J. Mhs. TEUB. 2014; 2:1-9.