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journal or publication title	IOP Conference Series: Materials Science and Engineering
volume	619
number	1
page range	012049-1-012049-6
year	2019-10-01
URL	http://hdl.handle.net/10228/00007677

doi: info:doi/10.1088/1757-899X/619/1/012049

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IOP Conf. Series: Materials Science and Engineering **619** (2019) 012049 doi:10.1088/1757-899X/619/1/012049

Clitoria ternatea flower as natural dyes for Dye-sensitized solar cells

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Abstract. *Clitoria ternatea* flowers have been investigated as a natural sensitizer in Dye-sensitized solar cell (DSSC). Dried *C. ternatea* flowers ware immersed in ethanol for 48 hours in dark room to obtain anthocyanin pigments. We compared the photovoltaic performance of the sensitizers with Titanium dioxide (TiO_2) only and TiO_2 with *scattering layers*. *C. ternatea* dyes have higher Power Conversion Efficiency (PCE) when applied in TiO_2 with *scattering layers* compared to standard TiO_2 semiconductors. *Scattering layer* (SL) has increased the light path inside the photo-anode film that doubled the short-circuit current (Jsc) and enhanced the open circuit voltage (Voc) compared to TiO_2 based cell without the SL. In conclusion, from the result, higher electron injections can be achieved by light management on photo-anode film with *scattering layers* as one of strategy to enhance the efficiency for further low cost and environment-friendly solar cell.

1. Introduction

Dye-sensitized solar cells (DSSCs) are gaining more attention due to their relatively lower cost of production [1]. DSSCs consist of two electrodes sandwich together filled with electrolyte. Both working and counter electrode are supported with conductive glass mainly made of Fluorine doped Tin Oxide (FTO). The Working electrode is made of FTO glass coated with thin layer of semiconductor materials such as Titanium dioxide (TiO_2), Tin dioxide (SnO_2), Zinc oxide (ZnO), etc [2-7]. Thin layer of semiconductor is covered with dye as electrons generator [8]. Counter electrode is made of FTO glass coated with thin layer of carbon, Graphene or platinum [9-11]. In order to maintain the electron regeneration, Electrolyte is employed between working and counter electrode. It is made of redox couple such as iodide/tri-iodide [12], Co(II)/Co(III)[13], etc. In DSSCs, one of the main components to increase the efficiency is dye sensitizer. Ruthenium-based sensitizer is the most widely used in DSSCs research area now. Ruthenium-based as well as metal free dyes have been reported having photon harvesting area mainly in the visible region of solar spectrum [14]. The difficulties of synthesize and higher price of ruthenium dyes made researcher effort to find out organic or inorganic dyes as co-sensitizer to fill the gap in ruthenium dye [15-18]. Ruthenium dyes are manufactured in sophisticated ways that raise the cost of the DSSC. Most of the sensitized dyes need anchoring groups in order to attach in nanoporous surface. In order to attach dyes on TiO_2 semiconductor surface, it could be accomplished by several types of bonding, for example, hydrophobic and covalent bonding [19]. Natural dye has been used for decades in industries. In DSSC, dyes from the plant as sensitizer

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are getting more attention due to lower cost production and easier in preparation [20-25]. In this works, the extracts of *Clitoria ternatea* flowers as dye sensitizer in DSSC. *C. ternatea* dye solution in ethanol was measured with UV-Vis Spectrophotometer. The DSSC was made using two configurations of TiO_2 semiconductors which are TiO_2 only and TiO_2 with scattering layers. The Incident photon-to-current Efficiency (IPCE) and current-voltage (I-V) characteristics were measured to define the photo-conversion efficiency (PCE).

2. Experimental

2.1. Plant material

Scientific classification of *Clitoria teratea is*
Kingdom: Plantae
Order: Fabales
Family: Fabaceae
Genus: *Cltoria*
Species: *C. ternatea*
Local name: Blue Pea, Bunga Telang, Butterfly Pea.

Clitoria ternatea is plant species belongings to Fabaceae Family. It is a native plant to Africa and introduced to lowlands of Asia, Central and South America. *C. ternatea* flowers are widely used as herb tea and coloring for food in Southeast Asia. Other than that, It is used as traditional Ayurvedic medicine in India[26] and traditional Chinese medicine [27]

2.2. Dye preparation

Clitoria ternatea flowers used in this study were cleaned with water and dried at room temperature in shaded places for more than three weeks. It were cut into small pieces and then crushed into powder with Food Grinder (FTC-Z100). Powdered flowers have 20-180 mesh fineness. Prior to usage, it was diluted in ethanol solvent with the composition of 10 gram of *C. ternatea* powder and 100 ml of ethanol. The mixture was sonicated for 60 minutes and then kept in dark place for 72 hours. In order to separate the remained powder, it was filtered with a vacuum pump and stored in a dark glass container. The dark container was used to protect the dye solution from direct light exposure.

2.3. Preparation of dye-sensitized solar cell

Fluorine doped Tin Oxide (FTO) glass was cut into 15 x 20 mm. It was cleaned in an ultrasonic cleaner with distilled water, Isopropanol, acetone sequentially 15 minutes for each process. After dried, the glass was coated with Titanium Dioxide (TiO_2) using blade coating method. The configuration of working electrode for this study were two types, which are TiO_2 only (smaller particle size, 30NRD) and TiO_2 with Scattering layers (Smaller and larger particle size, 30NRD and 400NR). Photoanode TiO_2 only was prepared by coated cleaned FTO glass with TiO_2 with small particle size for dye adsorption. TiO_2 film with scattering layer was prepared by coated FTO glass sequentially with two types of TiO_2 paste which are large (400nm) particle size serve as scattering layer and then sintered $450^{O}C$ for 30 minutes. After that, the second layer was made by screen printing the smaller (30nm) particle size of TiO_2 on the top of the first layer of 400nm particle size TiO_2, and then sintered $450^{O}C$ for 30 minutes. The average thickness after sintering process for TiO_2 only was 7 µM, TiO_2 with scattering layer was 10 µM (SURFCOM130A). The cell area was 0.25 cm^2. Baked working electrode then immersed in the dye solution for 24 hours until dye attached in semiconductor indicated from color changes. Counter electrode using Platinum (Pt) sputtered on FTO glass. Both working and counter electrode assembled in sandwich structure separated with 25 µm (Solaronix Spacer) thickness of the spacer used to create a gap for electrolyte injection. Electrolyte containing of 500 mM of Lithium Iodide (LiI), 50 mM Iodine (I_2), 600 mM Ethylmethylimidazolium dicyanoimide (MeEtIm-DCA), and 580 mM *tert*-butylpyridine (TBP) in Acetonitrile was used to fabricate the DSSCs.

Photovoltaic characterization the DSSCs were made using a solar simulator (Bunko-Keiki Co. Ltd., Model Solar Simulator CEP-2000SRR). The photovoltaic measurement used a black metal mask to avoid the effect of optical reflection from the light source to the cell from the side of the glass.

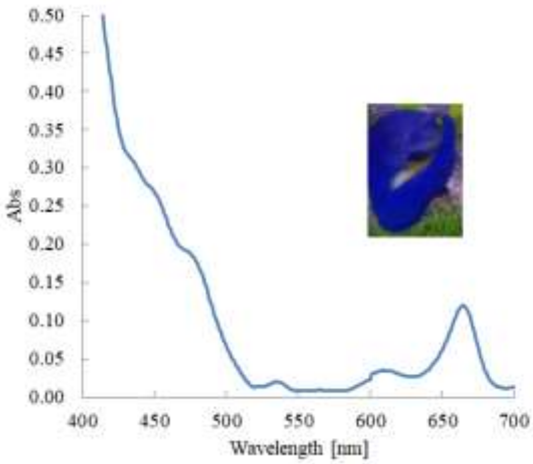

Figure 1. UV-Vis Absorption spectra of Natural dyes: *C. ternatea* in ethanol.

3. Results and Discussions

The Natural dyes from C. ternatea flowers extract have been utilized as sensitizers in this study. UV-Vis spectrophotometer (Jusco V-670) was used to characterize the light absorption spectra of dye. The absorption spectra of *C. ternatea* in ethanol solution are shown in figure 1. The maximum peak was recorded at 665 nm. It was found that *C. ternatea* flowers have lower solubility in ethanol that required immersing the powdered flowers for 72 hours before suitable usage in DSSC fabrication.

The Current-Voltage (I-V) characteristics of DSSC fabricated with TiO_2 only and TiO_2 with scattering layers were shown in figure 2. The main aspects adjusting the Photoconversion efficiency (PCE) are the short circuit density (Jsc) since open circuit voltage (Voc) and fill factors (FF). It can be seen that PCE of a device fabricated using TiO_2 with scattering layers has increased dramatically from 0.069% to 0.182%. This result was contributed to the enhancement of Jsc parameters. The dramatic boost in Jsc was increased more than twice from 0.203 mA/cm^2 to 0.481 mA/cm^2. This effect was donated by an increase of light path and better light management caused by scattering layers [28]. However, fill factors and Voc were not improved so much.

Table 1. I-V Characteristic of DSSCs with *C. ternatea* dye.

	TiO_2 Only	TiO_2 + SL
Efficiency [%]	0.069	0.182
FF	0.678	0.700
Voc [V]	0.501	0.539
Jsc [mA/cm^2]	0.203	0.481
Mask Area [cm^2]	0.214	0.214

Table 1 shows result of TiO_2 only have Jsc of 0.203 mA/cm^2, Voc 0.501 V, FF 0.678 and PCE 0.069% and TiO_2 with SL have Jsc of 0.481 mA/cm^2, Voc 0.539 V, FF 0.700 and PCE 0.182% for device with TiO_2 semiconductor. IPCE graph in figure 3 shown that photon to current density on TiO_2 with scattering layer was higher than TiO_2 only configuration. Higher electron injection was confirmed from wider IPCE in 300 to 500 nm wavelength.

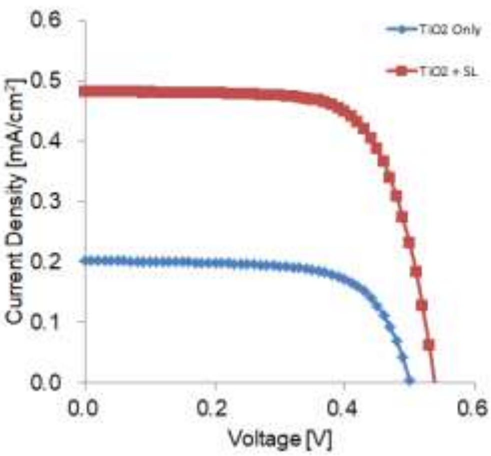

Figure 2. I-V Characteristic of DSSCs

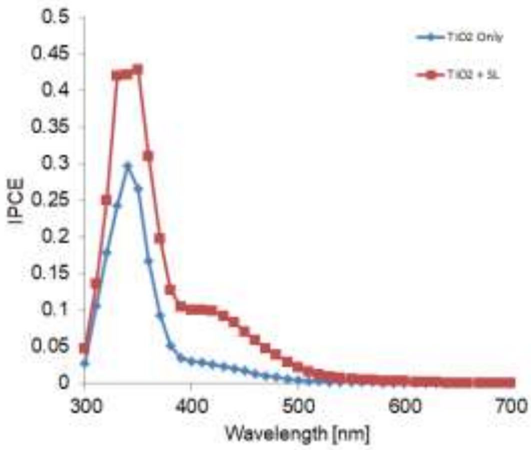

Figure 3. IPCE Spectra of DSSCs

4. Conclusions

DSSC with Natural dye, *Clitoria ternatea* flowers, was fabricated with two configurations of TiO_2 semiconductors which are TiO_2 only and TiO_2 with scattering layer (SL). Cell fabricated with TiO_2 + SL configuration produced higher PCE than a cell with TiO_2 only configuration. Longer light diffusion path on TiO_2 with SL lead to higher electron injection due to a greater probability of light interact with dye in TiO_2 film. IPCE graph confirmed that photon to current density on TiO_2 film with SL was higher. In conclusion, from the result, higher electron injections can be achieved by appropriate light management as one of strategy to enhance the efficiency for further low cost and environment-friendly solar cell.

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Acknowledgment.
The work was part of Grand “PDUPT 2018” from Indonesia Directorate General of Higher Education.