A Study on the Extraction Process and Optical Properties of Mangosteen Pericarp for Dye Sensitized Solar Cell (DSSC) Application

M. A. S. Suri, N. A. Yahaya, and K. Hamzah*
Faculty of Mechanical Engineering
Universiti Teknologi MARA
Shah Alam, Malaysia

**afifah@salam.uitm.edu.my*

ABSTRACT

Dye Sensitized Solar Cell (DSSC) is the third generation of photovoltaic solar cell that provides an alternative concept of organic or inorganic components in photovoltaic solar cells. The use of natural pigments as sensitizers from organic gives the advantages as it is easy to obtain, low cost and environmentally friendly compared to the inorganic components of this alternative form of solar energy conversion. There are many natural dye extracts that can be used as photosensitizer such as from flowers, fruits, leaf plant etc. which results vary for solar to electric conversion efficiencies. One of the good candidates for the dye used in DSSC is mangosteen pericarp which is expected to contribute to the high light absorption. This is because high light absorption would give high efficiency in DSSC. Therefore in this study, the investigation on the extraction process of the mangosteen pericarp was studied and compared. The preparation of the natural dye by extraction affected the conversion efficiency. The optical properties of mangosteen pericarp dye were also evaluated as high absorption leads to high efficiency of solar cell. The absorption spectrum of mangosteen pericarp dye with acetone extraction gave higher maximum wavelength that ranged between 200 – 490 nm. The DSSC sensitized by mangosteen pericarp dye with acetone also had higher current flow and voltage which are 0.027 mA and 1.6 mV respectively.

Keywords: *dye sensitized solar cell, mangosteen pericarp, extraction process, optical properties.*

Introduction

Solar energy is capable to improve the air quality by producing non-polluting electricity and reduce toxic carbon emission. Various technologies have been developed to harvest solar energy. Before 1974, Melvin Calvin developed his

---

ISSN 1823- 5514, eISSN 2550-164X
© 2016 Faculty of Mechanical Engineering,
Universiti Teknologi MARA (UiTM), Malaysia.
Received for review: 2017-04-30
Accepted for publication: 2017-10-10
Published: 2018-04-15

concept of using the reactions of photosynthesis to convert sunlight into electrical power.

Basically, the developments of solar cells were classified into three generations based on the technologies used. The first generation solar cell was larger and the model was a photo-electrochemical cell based on a synthetic membrane where carotenoids were used as a wire inside the membrane. The absorption of a light by a sensitizer molecule was localised at one side and diffused through the membrane to the other side where it was captured by an electron acceptor [1]. However, this first generation solar cell was expensive due to purity of silicon, which required high manufacturing technology and higher photons are wasted as heat [2].

A model for photochemical hydrogen production, also known as thin-film solar cells, was suggested by Melvin Calvin. The model was based on the photosynthetic electron transport system. Later it was directly shown that illumination electrons are transferred from canthaxanthin, an accessory carotenoid of the photosynthetic system, to chlorophyll, the electron collector system. This second generation solar cell is cheaper than the previous generation solar cell but has lower efficiency [1, 3].

A comparative methodology has been taken in parallel to physical and chemical sciences. Sunlight is utilised to energise electrons of pigments, generally metal complexes, into a higher vitality level which are then exchanged to the conduction band of a wide band gap semiconductor. Compared to the well-known silicon devices, such dye-sensitized solar cells (DSSCs) have a place with the developing third-era photovoltaic idea and use natural dyes as light harvesting pigments. They are likewise called Grätzel cells named after their publication in 1991 [1].

In the Laboratory of Photonics and Interfaces in Ecole Polytechnique Federale de Lausanne, Switzerland, Grätzel with his co-workers developed a successful combination of nanostructure electrodes and efficient charge injection dyes to their solar cell. Hence, this solar cell was called the dye sensitized nanostructure solar cell [3]. The use of sintered mesoporous titanium dioxide (TiO_2) was the breakthrough that established DSSC technology and raised its efficiency, η from 1% (for cells having a non-porous TiO_2 surface) to 7 %.

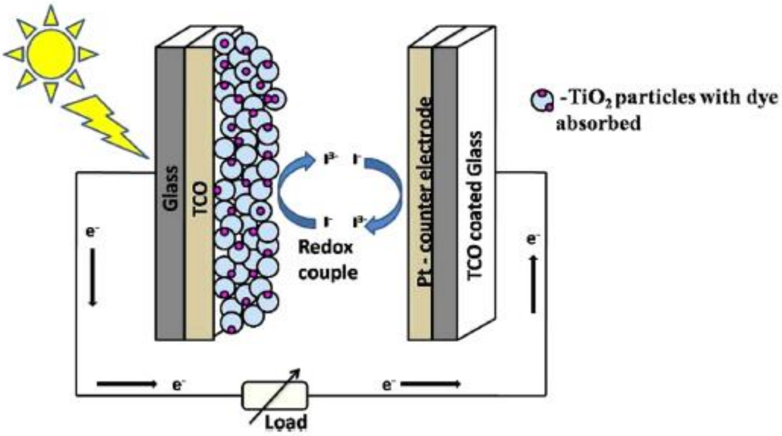

Figure 1: Schematic setup of DSSC [4].

Dye Sensitized Solar Cell (DSSC) has become a topic of significant research in the last two decades because of their fundamental and scientific importance in the area of energy conversion. The ease of fabrication, low cost solar cells, and broadly available materials coupled with reasonable efficiency made DSSC capable to go further for its research and development [4].

Recently, most of the researchers in this field use Ruthenium complex as dye in the DSSC which provides high power conversion efficiencies and durability. However, Ruthenium is a rare metal that results to higher cost, tendency to undergo degradation and should be regarded as highly toxic material [5]. These limitations have opened up for alternate sensitizers that are biocompatible natural sensitizers. Natural dyes as photosensitizers for DSSCs are very attractive because of the low cost, abundant in supply, easy attainability, and no environment threat [3].

High open circuit voltage and high conversion efficiency were obtained from the natural dye extracted from mangosteen pericarp sensitizer [6]. The result is very promising because mangosteen is widely grown in Asian countries especially in Malaysia. Malaysian government must find a way on how to develop this solar energy to become among the most utilized renewable energy in Malaysia since the potential to establish large scale solar power installation is very convincing with practical average solar radiation per month.

Therefore, this research is done to study the extraction process and optical properties of mangosteen pericarp. From this study, it can determine which extraction process will give the highest conversion efficiency and can be further developed for commercial purpose.

Methodology

Before carrying out the experiment, the materials and equipment were prepared. The procedures to prepare the natural dyes, TiO_2 suspension, electrolyte solution, and fabrication of DSSC were explained.

Preparing the natural dye

Mangosteen pericarp powder was bought from the online market. The anthocyanin of mangosteen pericarp powder is extracted by ethanol (2 mL concentrated acetic acid in 95% ethanol) solutions at room temperature with solid/solvent ratio of 10 g/100 mL [4]. For the fresh mangosteen pericarp, the anthocyanin is extracted at room temperature. The natural dye is blended for 10 minutes until it shows homogeneous in colour while 10 g sample of mangosteen pericarp dye is soaked in 100 mL acetone (1:10) and stirred for 12 hours at room temperature. The crude solution is filtered using Whatman No. 41 filter paper to remove solid residue. Finally, the two concentrated dye solutions are protected from direct light exposure and stored in refrigerator at 5 °C [2, 7].

Preparing the TiO_2 suspension

The first step of the procedure starts with 6 g of TiO_2 powder being added with 1 mL of acetic acid into mortar and pestle. To accomplish this step, it must be conducted in a well ventilated area. Mix the solution well and the process should take 30 minutes until it results into a very white milky paint-like solution. After that, add one drop of clear dishwashing detergent without grinding it into the TiO2 solution as a surfactant as the substance tends to reduce the surface tension of the solution in which it dissolves. The solution is kept into a small bottle by pouring it through the filter funnel.

Preparing the electrolyte solution

The redox electrolyte with (I_3^-/I^-) 1:9 was prepared by dissolving 0.5 M of Potassium Iodide (KI) and 0.05 M of iodine (I_2) in acetonitrile solvent.

Fabrication of DSSC

The fabrication started by cutting the FTO glass into 30 mm by 30 mm square using diamond glass cutter. Then, identify the conducting side of the slide by using multimeter to measure the resistance. The conducting side will have resistance value while the other side of the glass results in 0 ohm. A glass surface is cleaned using distilled water and ethanol to remove any contaminant and dried at room temperature.

With the conducting side up, tape one side down on the table on every edge of the slide. Then, drop the TiO_2 paste onto the surface side and a glass rod is used to spread the TiO_2 paste evenly over the side. The glass is annealed at 450 °C for 30 minutes.

To prepare the sample, the dried glass coated with TiO_2 is immersed into dye solution for 10 minutes until the colour of film changes to bright purple. If any white TiO_2 paste remains on the film after 10 minutes, immerse it the glass again into the mixture for another 5 minutes. Rinse gently with distilled water to remove any excess dye and then with ethanol to remove water from the porous TiO_2 and dry the sample at room temperature.

The carbon coating of the counter electrode is prepared with another piece of 30 mm by 30 mm square of FTO glass. Determine the conducting side of the slide by using multimeter to measure the resistance. The small amount of graphite from pencil lead is scratched onto the surface conducting side. Graphite acts as a catalyst to keep the reaction from moving. Hence, the counter electrode is prepared and ready for final assembly of DSSC.

At the final stage of fabrication, TiO_2 coated slide and carbon coated slide are sandwiched together by making sure it is 4 mm offset of the edges and uses binder clips to hold the slides together. Drop the electrolyte solution at one edge of the slides and alternately open and close each side of solar cells by releasing and retaining the binder clips. The electrolyte solution is drowned into the space between the electrodes by capillary action and let the solution covers all the coated area.

Results and Discussion

Absorption of Mangosteen Pericarp Dyes

Optical absorptions of two different methods of extraction of mangosteen pericarp dyes which are sample A mixture with the ethanol and sample B mixture with the acetone were carried out by using JASCO V-670 UV-Vis/NIR Spectrophotometer.

<u>Sample A (Mangosteen pericarp dye with ethanol)</u>

The wavelength range of sample A spectrum lays between 200 – 550 nm as shown in Figure 3. It shows that sample A has maximum absorbance of 10 and starts to decline steadily after the maximum absorption. Then, when it reaches 1130 nm, it starts to increase at peak 0.9 absorbance at 1190 nm and starts to decline again.

<u>Sample B (Mangosteen pericarp dye with acetone)</u>

The absorbance spectra of concentrated dye of sample B extended all the way from 200 – 450 nm as shown in Figure 4. The graph below shows that sample B starts to increase the maximum absorbance at 280 nm. The maximum absorbance also occurs at wavelength range between 310 – 380 nm and starts to decrease rapidly after the maximum absorption.

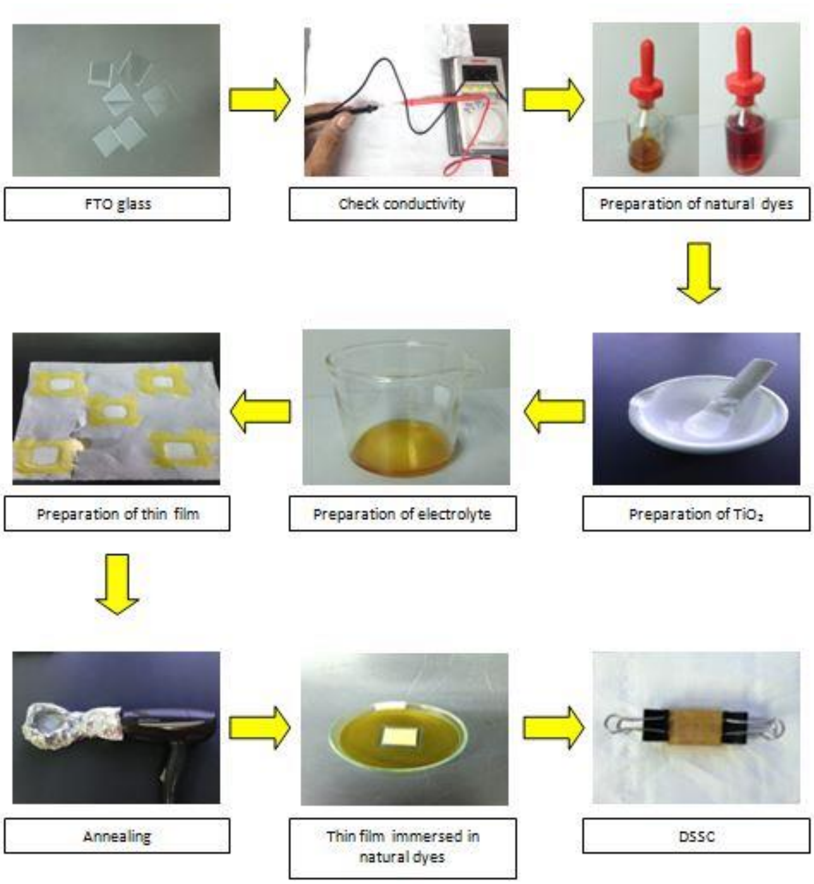

Figure 2: Fabrication process of the DSSC.

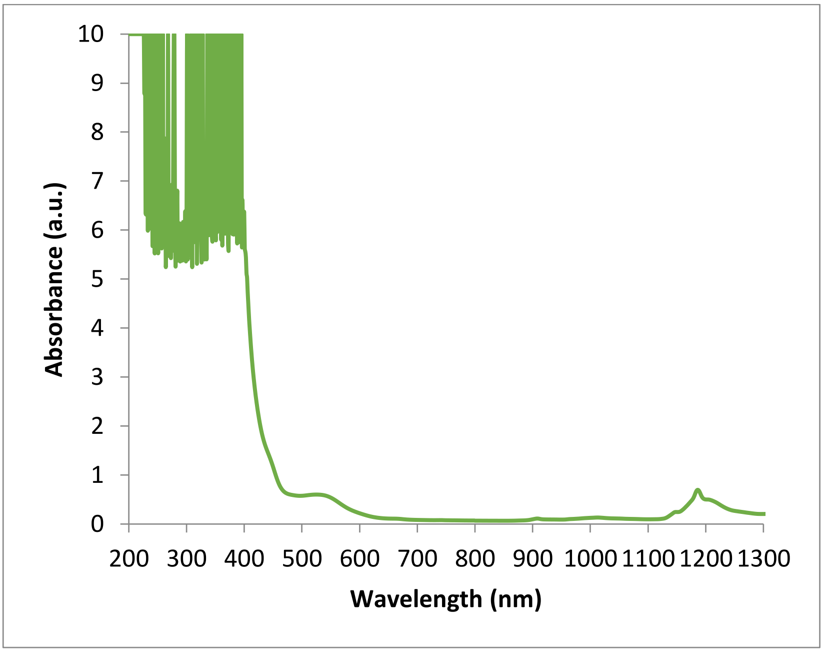

Figure 3**:** The absorption of mangosteen pericarp dye with ethanol.

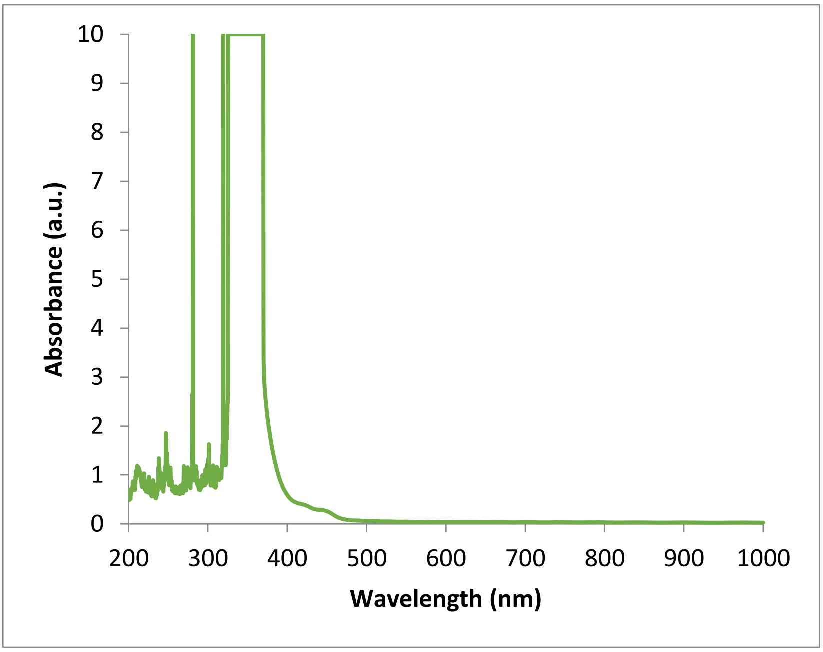

Figure 4: The absorption of mangosteen pericarp dye with acetone.

Absorption of TiO_2 Layer

The optical absorption of the TiO_2 layer was measured using Varian Cary 5000 UV-Vis-NIR Spectrophotometer. Based on Figure 5, the wavelength of the TiO_2 film lays between 200 – 480 nm.

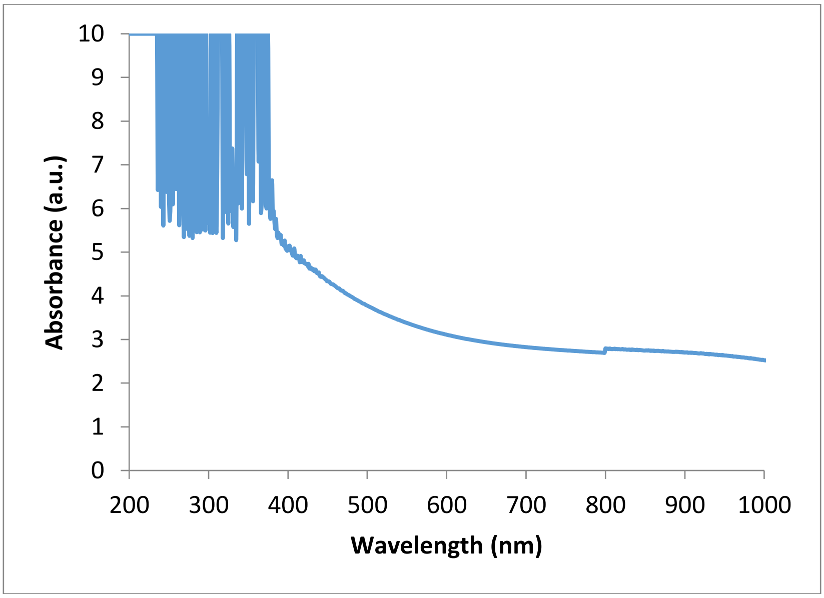

Figure 5: The absorption spectrum of TiO_2 film.

Absorption of Mangosteen Pericarp Dyes on TiO_2 Layer

The absorption spectrum of mangosteen pericarp dyes (sample A) on TiO_2 layer and sample B on TiO_2 layer were obtained using Varian Cary 5000 UV-Vis-NIR Spectrophotometer. Both samples show that the dye extracts have the same level of absorbance of 10 but sample B on TiO_2 has higher maximum wavelength range which is between 200 – 490 nm as shown in

Figure 6 compared to sample A on TiO_2 with wavelength range only between 200 – 280 nm as shown in Figure 7.

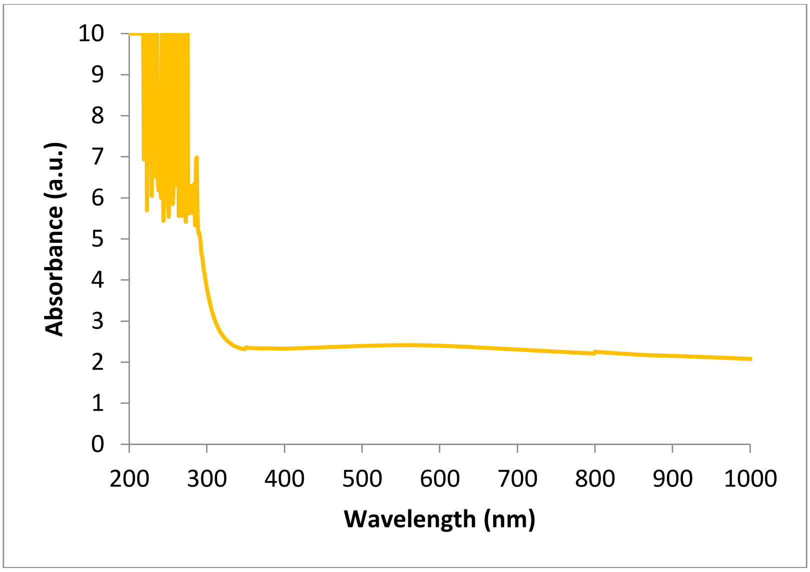

Figure 6: The absorption of mangosteen dye with ethanol on TiO_2 layer.

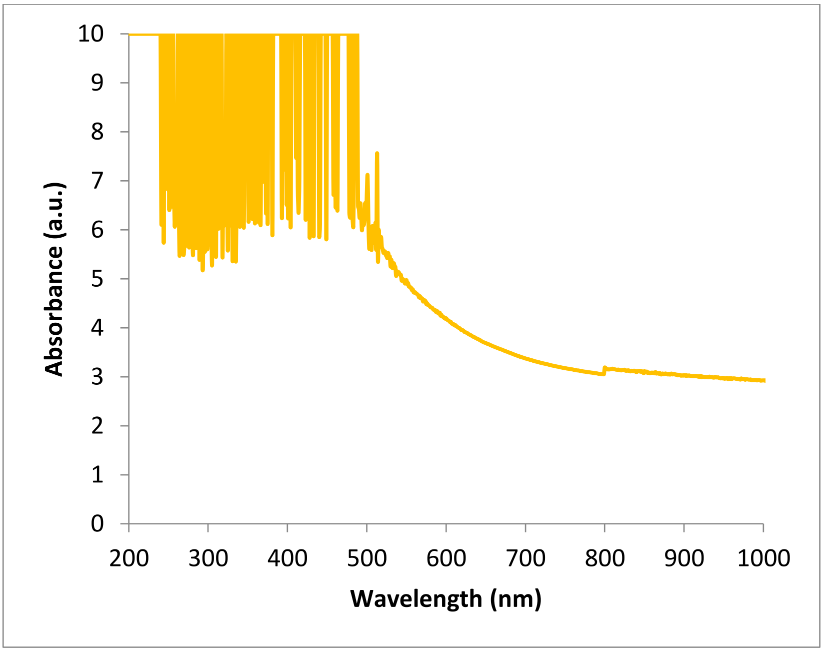

Figure 7: The absorption of mangosteen dye with acetone on TiO_2 layer.

Current Flow and Voltage

After the fabrication of DSSCs, each sample was measured on its current flow and voltage using a digital multimeter. The DSSCs was tested under cool white fluorescent with light intensity of 0.293 mW/cm^2.

Table 1: The comparison of current flow and voltage between two DSSCs under the same light intensity.

DSSC	Current, I (mA)	Voltage, V (mV)
Sample A + TiO_2	0.022	1.2
Sample B + TiO_2	0.027	1.6

From the table above, it shows that sample B on TiO_2 gave higher current flow and voltage compared to sample A on TiO_2. These results were expected based on the area under the graph of the absorbance spectrum of sample B, mangosteen dye with ecetone on TiO_2 (Figure 7), which was larger compared to absorption spectrum of sample A, mangosteen dye with ethanol on TiO_2 (Figure 6).

Table 2: Specific wavelength for region of light

Region	**Wavelength**
Fear ultraviolet	10-200
Near ultraviolet	200-380
Visible	380-780
Middle infrared	780-3000
Near infrared	3000-30,000
Far infrared	30,000-300,000
Microwave	300,000-1,000,000,000

Mangosteen as good light Absorbance

It was found that the mangosteen dye has peak absorption at 300nm-500nm. This result shows the same absorption of dragon fruit which is 450 nm to 600 nm wavelength[4]. Table 2 shows that the region of absorbance for dye of mangosteen pericarp is visible light. It means that it is really good for absorbance of sunlight. It is found that anthocyanins from mangosteen pericarp has good light absorption to be used in DSSC fabrication.

Conclusion

In this research, two methods of extraction process of mangosteen pericarp were used as photosensitizer in DSSC. From that, the performances were described and compared to their optical properties based on absorbance spectrum. The dyes extracted from mangosteen pericarp contained anthocyanins that absorbed sunlight to change from photons to electrons. The mangosteen pericarp dye with acetone extraction gave higher maximum wavelength as compared to the mangosteen pericarp dye with ethanol. The DSSC sensitized by mangosteen pericarp dye with acetone also had a higher current flow and voltage with a difference of 0.005 mA and 0.4 mV respectively. In general, the mangosteen pericarp dye as photosensitizer in DSSC is a promising dye to be used in the future, since they are easy to attain and extract, low cost and environmental friendly.

Acknowledgment

I would like to thanks University Technology Mara (UITM) and Ministry of Higher Education (MOHE), Malaysia for supporting this research. This work was funded by MOHE, under fundamental research grant scheme (FRGS) with reference code FRGS/1/2015/TK10/UITM/03/3. Special thanks to NANO-SciTech Centre (NST), Institute of Science (IOS) and NANO-ElecTronic Centre (NET), Faculty of Electrical Engineering (FKE), UiTM, for permitting to conduct this experiment in there.

References

[1] H. Hug, M. Bader, P. Mair and T. Glatzel, “Biophotovoltaics: Natural pigments in dye-sensitized solar cells,” Applied Energy 115, 216 – 225 (2014).

[2] M. Mazalan, M. M. Noh, Y. Wahab, M. N. Norizan and I. S. Mohamad, “Development of Dye-Sensitized Solar Cell (DSSC) using patterned Indium Tin Oxide (ITO) glass: Fabrication and testing of DSSC,” Conference on Clean Energy and Technology (CEAT), 187 – 191 (2013).

[3] M. R. Narayan, “Review: Dye sensitized solar cells based on natural photosensitizers,” Renewable and Sustainable Energy Reviews 16 (1), 208 – 215 (2012).

[4] Riyaz Ahamad Mohamed Ali and Nafrizal Nayan, "Fabrication and analysis of dye-sensitized solar," *International Journal of Integrated Engineering*, pp. 55-62, 2015

[5] S. Shalini, R B. Prabhu, S. Prasanna, T. K. Mallick and S. Senthilarasu, “Review on natural dye sensitized solar cells: Operation, materials and methods,” Renewable and Sustainable Energy Reviews, 51, 1306 – 1325 (2015).

[6] C. Sangsubun, K. Kunmuak, P. Nutongkaew, N. Choosiril, V. Amomkitbamrung and J. Waewsak, “Synthesis Dye Sensitized Solar

Cells from red sandal wood, mangosteen and lac," Energy Procedia, 52, 567 – 571 (2014).
[7] H. Zhou, L. Wu, Y. Gao and T. Ma, "Dye-sensitized solar cells using 20 natural dyes as sensitizers," Journal of Photochemistry and Photobiology A: Chemistry, 219 (2 – 3), 188 – 194 (2011).
[8] W. Maiaugree, S. Lowpa, M. Towannang, P. Rutphonsan, A. Tangtrakam, S. Pimanpang, P. Maiaugree, N. Ratchapolthavisin, W. Sang-aroon, W. Jaremboon and V. Amomkitbamrung, "A Dye Sensitized Solar Cells using natural counter electrode and natural dye derived from mangosteen peel waste," Scientific Reports, 5:15230, 1 – 12 (2015).