FABRICATION OF TWO CELLS, THREE CELLS AND FOUR CELLS MEANDER TYPE DYE-SENSITIZED SOLAR CELL MODULES

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Abstract

Two cells, three cells and four cells meander type dye-sensitized solar cell modules have been fabricated by using natural dyes extracted from teak leaves as sensitizer. These solar cell modules were assembled with two 20-30 ohms conductive glasses (TEC 15, Dyesol) (one for TiO_2 coated electrode and another for carbon coated electrode), TiO_2 nano-powder (Degussa-P25 powder), iodide electrolyte solution and soft graphite pencil for carbon coating. The silver lines were drawn for series and meander connections. The silicone was drawn as a protective barrier on both sides of the silver line. The performance of all fabricated DSSC modules was evaluated by the open circuit voltage V_{oc}, the short circuit current I_{sc} and the fill factor (FF). The energy conversion efficiency (η) was obtained under the air mass (AM) 1.5 radiation.

Keywords: Meander type DSSC modules, Natural dyes, TiO_2 nano-powder, Electrolyte, Silver line

Introduction

A photovoltaic module refers to an array of identical solar cells which are all interconnected in series or in parallel. Module design can be classified into two categories: strip module design and interdigital meander type module design. A new interdigital meander module design requires fewer holes in the glass substrate for electrolyte filling than the conventional strip design. Furthermore, to achieve a high utilizable current, cells can be connected in series by overlapping the silver grids on the boundary of the cells. This research focuses on the fabrication of a serial interconnected, meander type dye-sensitized solar cell module, one of the categories of third generation solar cells, using dye extracted from teak leaves as sensitizer.

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A meander type dye-sensitized solar cell module can be designed as shown in Figure 1(a). The module consists of six cells. Each cell has a width of about 5 cm. Front and counter electrode of a module with meander shaped cells is shown in Figure 1(b). The silver grid of the front electrode is shifted with respect to the silver grid of the counter electrode. The silver grid results in a meander shaped cell area, allowing an easy coloration and filling process via 2 holes per cell. When front and counter electrodes are aligned on top of each other, the silver grids of front and counter electrode only overlap on the boundary of two neighbouring cells as shown in Figure 1(c), thus forming an electrical series connection. The TCO layer of the substrate is structured accordingly. The silicone was drawn as a protective barrier on both sides of the silver line.

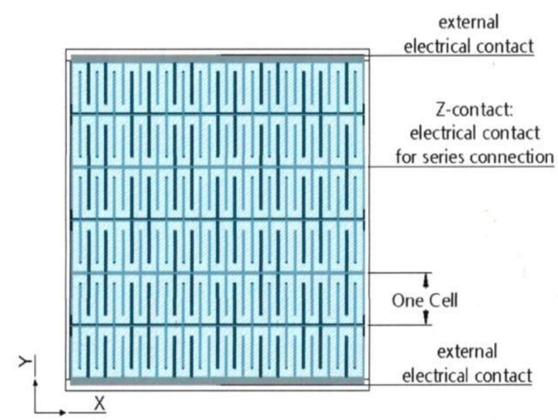


Figure 1(a) A meander type dye-sensitized solar cell module design

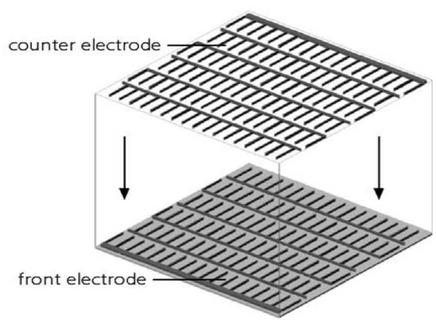


Figure1(b). Front and counter electrode of a meander type DSSC module

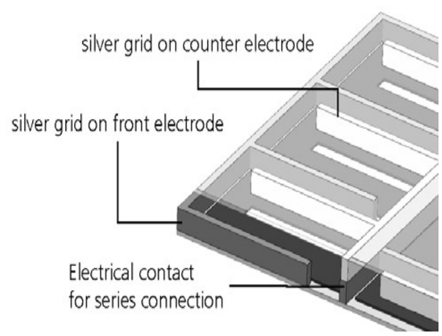


Figure 1(c). Aligning front and counter electrode on top of each other

Experimental Procedures

Figure 2. shows the flow chart for experimental procedures of meander type DSSC modules.

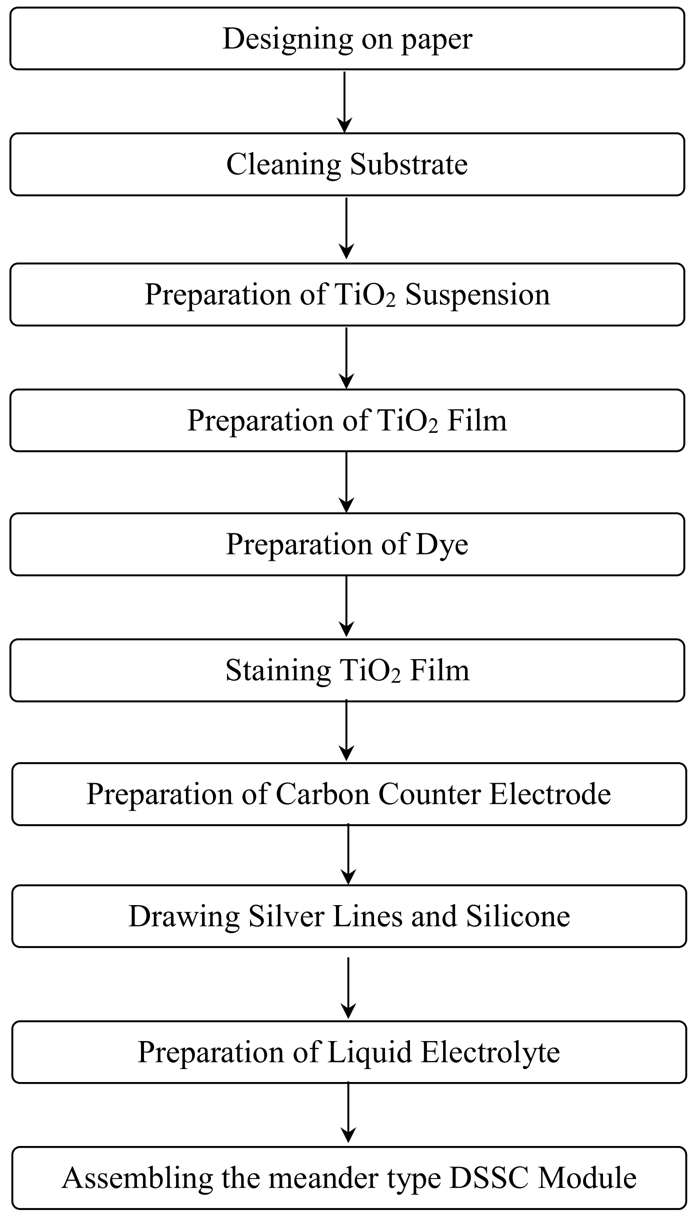


Figure 2. Flow chart for experimental procedures of meander type DSSC modules

Designing on Paper

First the designs of TiO_2 electrode for the two cells, three cells and four cells were drawn on the paper as shown in Figure 3(a), (b) and (c).

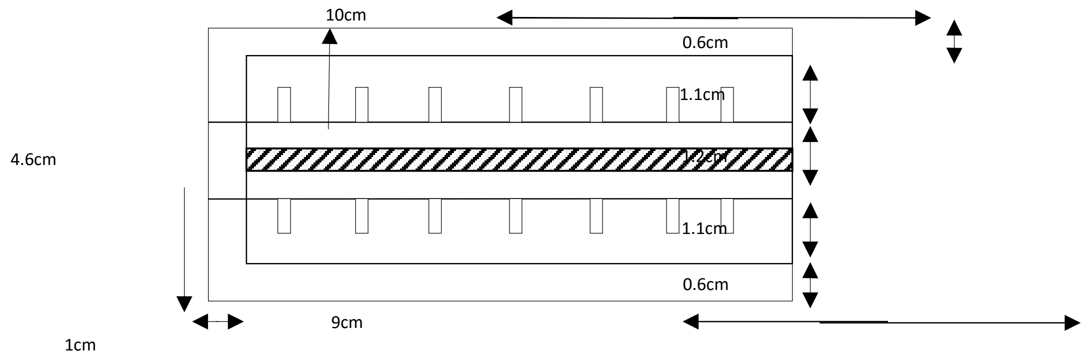


Figure 3(a) The design of TiO_2 electrode for two cells

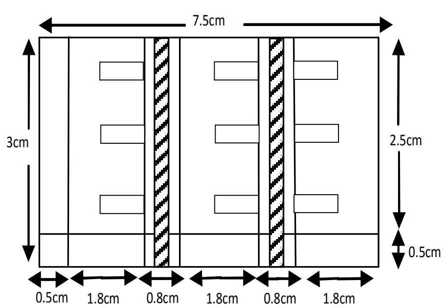


Figure 3(b). The design of TiO_2 electrode for three cells

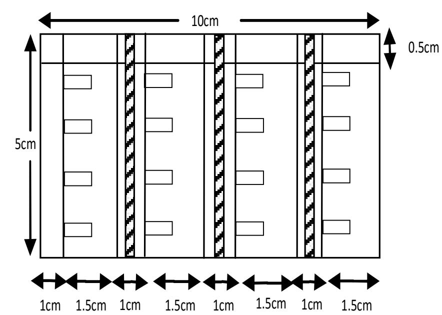


Figure 3(c). The design of TiO_2 electrode for four cells

Cleaning Substrate

The substrates were first dipped into acetone for at least 5 minutes to dissolve unwanted organic materials and to remove dust and contamination material. Another 5 minutes in methanol was followed in order to remove the acetone and materials that are not cleaned or dissolved by acetone. Finally, 5 minutes in isopropyl alcohol (IPA) was needed to further remove the residual particles on the substrates. The cleaned substrates were then put inside the 90°C oven and baked for at least 15 minutes to ensure that the solvents were vaporized and that the remaining particles were removed.

Preparation of TiO_2 Suspension

To fabricate two cells, three cells and four cells meander type DSSC modules, the 5g of TiO_2 nano powder was needed to be used. The TiO_2 nano-powder was put in the mortar and then 1mL nitric acid solution (pH 3 - 4) was added to it while grinding with a pestle until a colloidal suspension with a smooth constancy was obtained. Some clear dishwashing detergent was then added. The mixture was kept to equilibrate at room temperature for about 15 minutes.

Figure 4 (a). Weighing TiO_2 nano-powder

Figure 4(b). TiO_2 suspension

Preparation of TiO_2 Film for Two Cells, Three Cells and Four Cells Meander Type DSSC Modules

Using a multimeter, the conducting side was identified. According to the designs, TiO_2 paste was put on the glass. The transparent conducting oxide (TCO) layer on the glass substrate was structured.

For two cells, by placing the conducting side of tin oxide coated glass plate up, the two edges which are 0.6 cm wide of the plate were taped with Scotch tape. At the left side of the plate, 1 cm wide was taped and 1.2 cm wide in the middle of the plate was masked by the tape. Moreover, the gaps (0.2 cm x 0.6cm) on the substrate were taped to draw the silver lines.

For three cells, at the bottom, 0.5cm wide of the plate was taped with Scotch tape. At the left side of the plate, 0.5 cm wide was taped and 0.8 cm wide between the cells was masked by the tape. Moreover, the gaps (0.2 cm x 1cm) on the substrate were taped to draw the silver lines.

For four cells, on the top of the glass plate, 0.5cm wide was masked by Scotch tape. At the left side of the plate, 1cm wide was taped. Then, 1.5cm wide between the cells was taped. Moreover, the gaps (0.2 cm x 0.8 cm) on the substrate were taped to draw the silver lines.

Then, some titanium dioxide (TiO_2) suspension was put on the one glass and quickly spread it over the surface using a glass rod (doctor-blade method). The tape was then carefully removed without scratching the TiO_2 coating. The coated plate was dried for 1 minute in a covered Petri dish. The glass plate was heated on the hotplate about 30 minutes until a white titanium dioxide coating was formed. The glass plate was then slowly cool by turning off the hotplate. TiO_2 coated plates for two cells, three cells and four cells were shown in Figure 5(a) and (b).

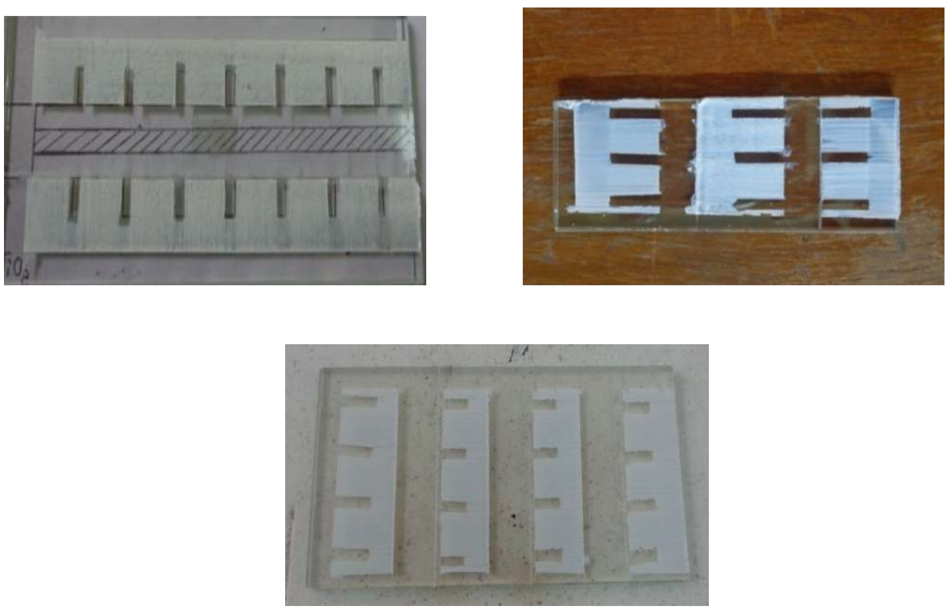


Figure 5(a) TiO_2 coated plates for two cells, three cells and four cells

Figure 5(b). Heating the TiO_2 coated glass plate

Extracting Dye

To extract dyes from teak leaves, the leaves were cut and ground with the mortar and pestle and then 3-5 mL of acetone was added. Then it was squeezed into the Petri dish as shown in Figure 6(a) and (b).

Figure 6(a) Grinding teak leaves with mortar and pestle

Figure 6(b) Squeezing into the Petri dish

Staining TiO_2 Film

The dye solution extracted from teak leaves was poured into a Petri dish. The TiO_2 electrode was dipped into the dye solution with the coated side down for 24 hours until no white TiO_2 can be seen on either side of the glass. The TiO_2 electrodes were dipped into the dye solution for two cells, three cells and four cells as shown in Figure 7. The glass plate then appeared as brownish red color. It was first washed in H_2O and then in ethanol in order to remove water from the porous TiO_2. Any residue was wiped off with a tissue, blotting gently to dry.

Figure 7. Staining TiO_2 films

Preparation of Carbon-Coated Counter Electrode

Firstly, the design for carbon-coated counter electrode was drawn on the paper as the design of TiO_2 electrode. Then, the glass plate was first washed with ethanol. Using a multimeter the conducting side was identified. By scratching thoroughly with a soft graphite pencil, a thin carbon coating was put on the conductive side of the glass plate. The thin carbon coated plates for two cells, three cells and four cells were shown in Figure 8(a), (b) and (c).

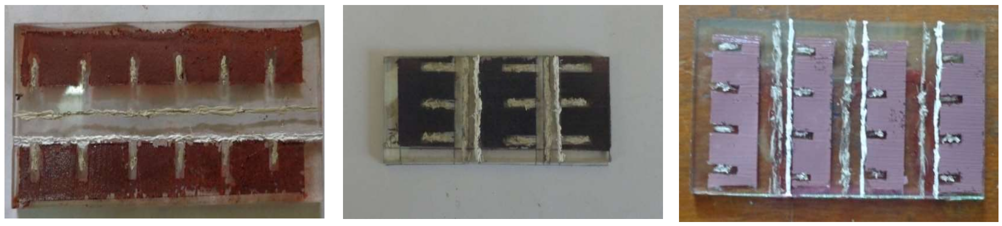
(a) (b) (c)

Figure 8. Carbon-coated counter electrodes for two cells, three cells and four cells

Drawing the Silver Lines and Silicone for Two Cells, Three Cells and Four Cells

For series connection, the silver line was drawn in the middle of the substrate. For meander type connection, the silver lines were drawn on the surface of TiO_2 glass substrate and thin carbon coated plate as shown in

Figure 9(a), (b) and (c). The silicone was drawn as a protective barrier on both sides of the silver line. The silver lines of the carbon-coated electrode were shifted with respect to the silver lines of the TiO_2 electrode. These silver lines result in a meander shaped cell area.



(a) (b) (c)

Figure 9. Drawing the silver lines and silicone on the TiO_2 substrate for two cells, three cells and four cells

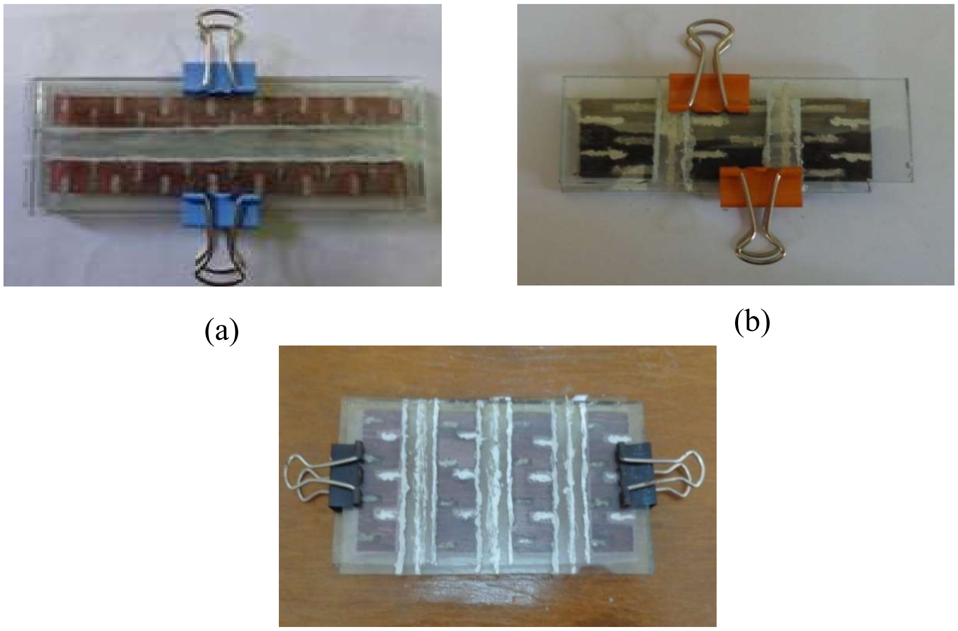
Preparation of Liquid Electrolyte

0.5 M potassium iodide was mixed with 0.05 M iodine in water-free ethylene glycol. 10 mL of ethylene glycol was put in a container. Then, 0.127 g of I_2 (Iodine) and 0.83 g of KI (Potassium Iodide) was added to it. They were mixed together stirring with a clean glass rod. All the bottles and the containers were kept tightly capped when not in use.

Assembling the Two Cells, Three Cells and Four Cells Meander Type DSSC Modules

The carbon-coated glass plate was placed with the coated-face down on the TiO_2 coated glass plate. The two glass plates were stacked slightly off set. The plates were bound together with the binder clips on each side of the longer edges. Then, two to three drops of iodide electrolyte solution was put on one edge of the plates. Each side of solar cell was then made slightly open and closed alternately so that the electrolyte solution was drawn in and wet the TiO_2 film, thus making all the stained area to be in contact with the electrolyte solution.

Figure 10(a), (b) and (c) illustrate assembling the two cells, three cells and four cells meander type DSSC modules.



(a) (b)

(c)

Figure 10. Assembling the two, three and four cells meander type DSSC modules

Results and Discussions

XRD, pH and UV-Vis Measurements

Titanium dioxide (TiO_2) powder was characterized by using RIGAKU-RINT 2000 X-ray Diffractometer. The X-ray diffraction pattern was recorded to different diffraction peaks corresponding to different plane. The resulting XRD pattern was found to be exactly coincide with the reference (78-2486) TiO_2 pattern. This shows that the used TiO_2 nano-powder was pure with no other chemical impurities. By using Scherrer equation, the average crystallite size of TiO_2 powder was found to be 40.81 nm and anatase phase was observed. Figure 11 shows the XRD pattern of TiO_2 nano-powder.

Figure 12 shows the measuring pH for teak leaves dye solution with pH meter. It was found that the pH of teak leaves dye was 5.67.

The UV-Vis absorption spectrum in the wavelength range between 300 nm and 700 nm of liquid dye extracting with acetone from teak leaves was shown in Figure 13. The absorbance peaks appeared at 413 nm and 663 nm and maximum absorbance A_{max} was 1.081 at 413 nm.

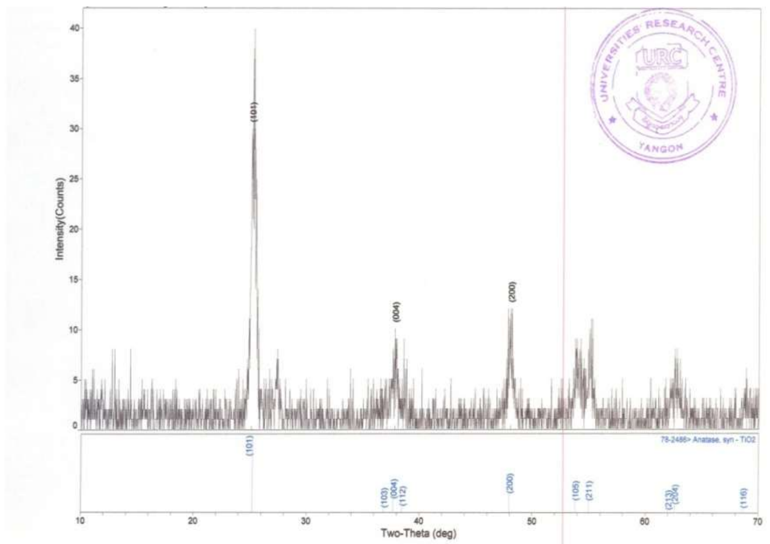


Figure 11. XRD pattern of TiO_2 nano-powder

Figure 12. Measuring pH for teak leaves dye solution with pH meter

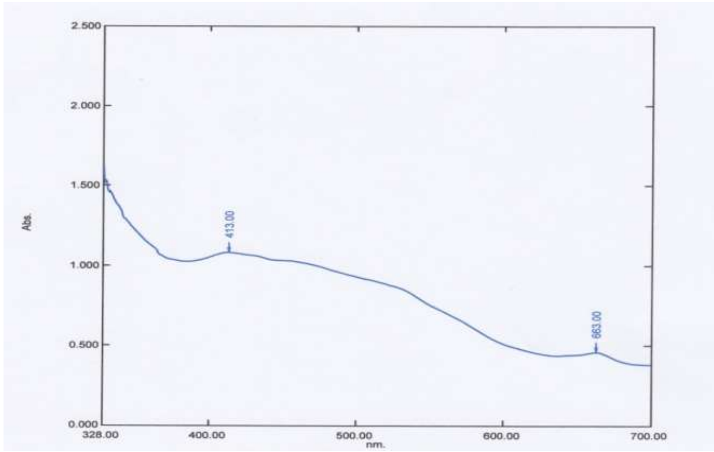


Figure 13. UV-Vis absorption spectra of liquid dye extracting with acetone from teak leaves

The Performance of Meander Type Dye- Sensitized Solar Cell Modules
Two Cells Meander Type Dye- Sensitized Solar Cell Module

The open circuit voltage V_{oc} and the short circuit current I_{sc} of two cells meander type DSSC module which connected in series sealing with silicone were measured with the multimeter as shown in Figure 14(a) and (b), giving the results 0.276 V and 0.026 mA respectively.

The extent to which a measured cell deviates from this ideal situation is determined by calculating the cell's 'Fill Factor' (FF) using the following equation:

$$FF = \frac{I_{max} V_{max}}{I_{sc} V_{oc}}$$

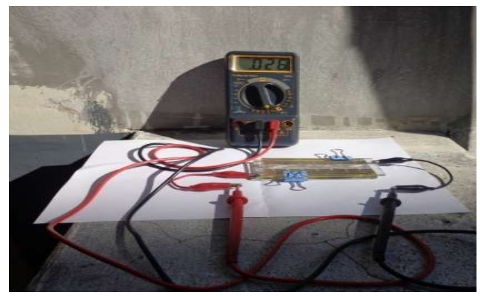
where I_{max} and V_{max} are the values of current and voltage measured at the inflection point of the curve shown in Figure 15 and where the 'perfect' cell would have FF = 1.

The efficiency of conversion of sunlight to electricity (η) by the tested cell can be determined by the following formula:

$$\eta = \frac{I_{max} V_{max}}{P_{in}}$$

where P_{in} is the power of light incident on the tested cell, which is about 100 $mWcm^{-2}$ for sunlight.

For two cells meander type DSSC module, the fill factor (FF) was obtained 0.659 and the energy conversion efficiency (η) was 0.0048%. The photoelectrochemical parameters of two cells meander type DSSC module are listed in Table 1. From Table 1, the value of Fill Factor (FF) 0.659 was agreed with the typical Fill Factor range from 0.6 to 0.9.



(a) (b)

Figure 14 (a) The open circuit voltage V_{oc} (b) The short circuit current I_{sc} for two cells meander type DSSC module

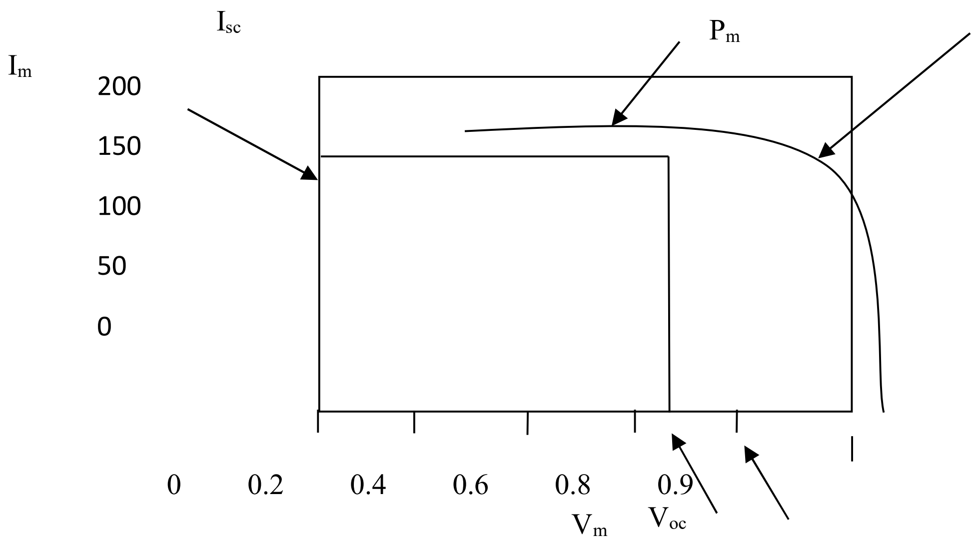


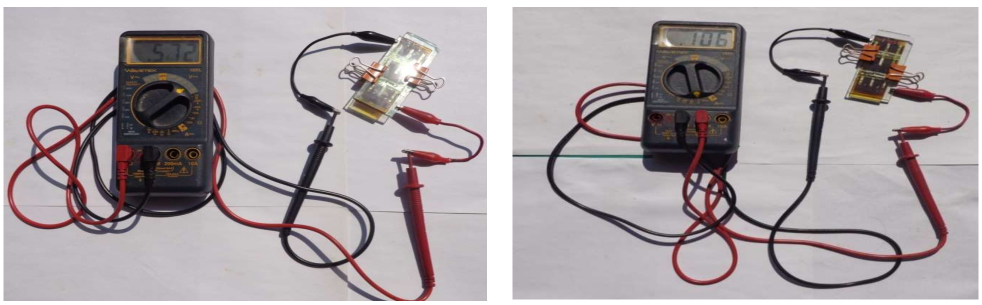
Figure 15. Current-voltage curve of a typical solar cell

Table 1. I-V Characteristics of Two Cells Meander Type DSSC Module

V_{MP} (V)	I_{MP} (mA)	V_{oc} (V)	I_{sc} (mA)	FF	Efficiency(%)
0.2	0.0238	0.28	0.026	0.659	0.0048

Three Cells Meander Type Dye- Sensitized Solar Cell Module

The measuring for the open circuit voltage V_{oc} and the short circuit current I_{sc} of three cells meander type DSSC module were shown in Figure 16(a) and (b). The open circuit voltage V_{oc} was found 0.572 V and the short circuit current I_{sc} was found 0.106 mA. The fill factor (FF) and the energy conversion efficiency (η) were 0.759 and 0.046% respectively. The photoelectrochemical parameters of three cells meander type DSSC module are listed in Table 2.



(a) (b)

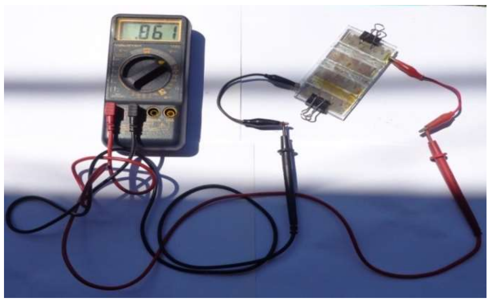
Figure 16 (a) The open circuit voltage V_{oc} (b) The short circuit current I_{sc} for three cells meander type DSSC module

Table 2. I-V Characteristics of Three Cells Meander Type DSSC Module

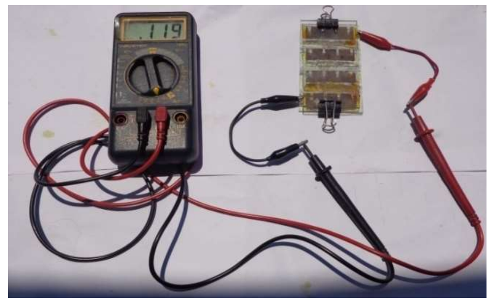
V_{MP} (V)	I_{MP} (mA)	V_{oc} (V)	I_{sc} (mA)	FF	Efficiency(%)
0.500	0.092	0.572	0.106	0.759	0.046

Four Cells Meander Type Dye- Sensitized Solar Cell Module

The open circuit voltage V_{oc} and the short circuit current I_{sc} of four cells meander type DSSC module were measured with the multimeter as shown in Figure 17(a) and (b), giving the results 0.861 V and 0.119 mA respectively. The fill factor (FF) and the energy conversion efficiency (η) were obtained 0.724 and 0.074%. The photoelectrochemical parameters of four cells meander type DSSC module are listed in Table 3.



(a)



(b)

Figure 17 (a) The open circuit voltage V_{oc} (b) The short circuit current I_{sc} for four cells meander type DSSC module

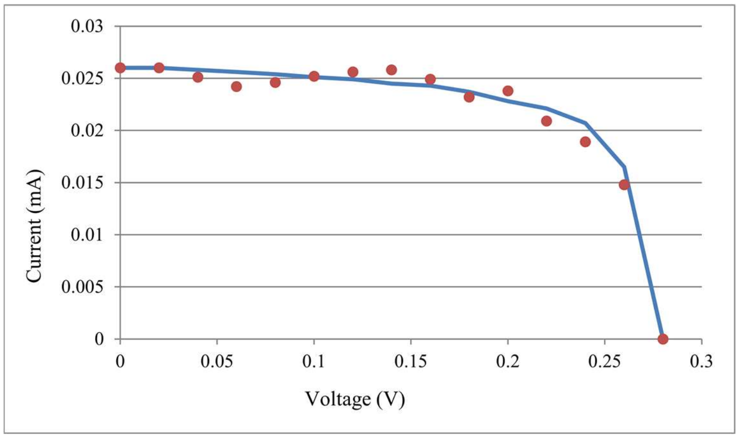
Table 3. I-V Characteristics of Four Cells Meander Type DSSC Module

V_{MP} (V)	I_{MP} (mA)	V_{oc} (V)	I_{sc} (mA)	FF	Efficiency(%)
0.700	0.106	0.861	0.119	0.724	0.074

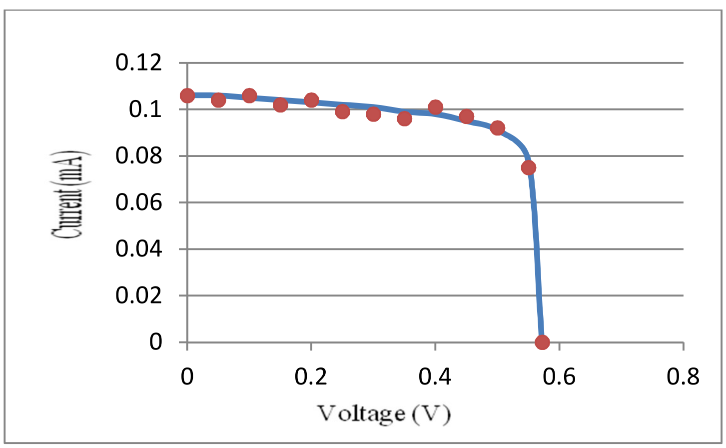
Table 4 shows comparison of I-V characteristics of meander type DSSC module for different number of cells with interconnection. From these comparison results, it was found that the open circuit voltage V_{oc} , the short circuit current I_{sc} and the efficiency of four cells meander type DSSC module were increased than the two cells and three cells meander type DSSC module.

Table 4. Comparison of I-V Characteristics of Meander Type DSSC Module for Different number of Cells

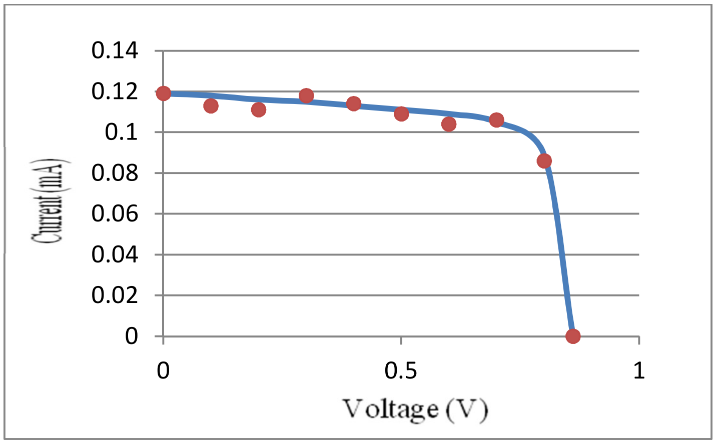
	V_{oc} (V)	I_{sc} (mA)	FF	Efficiency (%)
2 cells module	0.28	0.026	0.659	0.0048
cells module	0.572	0.106	0.759	0.046
4 cells module	0.861	0.119	0.724	0.074



(a)



(b)



(c)

Figure 18. Current-Voltage (I-V) curves for two cells, three cells and four cells meander type DSSC module

Current-Voltage (I-V) curves for two cells, three cells and four cells meander type DSSC modules were shown in Figure 18 (a), (b) and (c) and their I-V characteristics were shown in Table 5, 6 and 7.

Table 5. I-V Characteristic of Two Cells Meander Type DSSC Module

Voltage (V)	Current (mA)	Power (mW)
0.00	0.026	0.0000
0.02	0.026	0.0005
0.04	0.0251	0.0010
0.06	0.0242	0.0014
0.08	0.0246	0.0020
0.10	0.0252	0.0025
0.12	0.0256	0.0031
0.14	0.0258	0.0036
0.16	0.0249	0.0040
0.18	0.0232	0.0042
0.20	0.0238	0.0048
0.22	0.0209	0.0046
0.24	0.0189	0.0045
0.26	0.0148	0.0038
0.28	0.0000	0.0000

Table 6. I-V Characteristic of Three Cells Meander Type DSSC Module

Voltage (V)	Current (mA)	Power (mW)
0.000	0.106	0.000
0.050	0.104	0.005
0.100	0.106	0.011
0.150	0.102	0.015
0.200	0.104	0.021
0.250	0.099	0.025
0.300	0.098	0.030
0.350	0.096	0.034
0.400	0.101	0.040
0.450	0.097	0.044
0.500	0.092	0.046
0.550	0.075	0.041
0.572	0.000	0.000

Table 7. I-V characteristic of Four Cells Meander Type DSSC Module

Voltage (V)	Current (mA)	Power (mW)
0.000	0.119	0.000
0.100	0.113	0.011
0.200	0.111	0.022
0.300	0.118	0.035
0.400	0.114	0.046
0.500	0.109	0.055
0.600	0.104	0.062
0.700	0.106	0.074
0.800	0.086	0.069
0.861	0.000	0.000

Conclusion

Two cells, three cells and four cells meander type dye-sensitized solar cell modules have been fabricated by the use of nano crystalline titanium dioxide TiO_2 photo electrode, carbon counter electrode, dye extracted from teak leaves, redox electrolyte.

The photovoltaic (PV) performance of two cells meander type DSSC module was found that the open circuit voltage (V_{oc}) 0.28 V, the short circuit current (I_{sc}) 0.026 mA, the fill factor (FF) 0.659 and the energy conversion efficiency (η) 0.0048%, respectively.

For three cells meander type DSSC module, it was found that the open circuit voltage (V_{oc}) 0.572 V, the short circuit current (I_{sc}) 0.106 mA, the fill factor (FF) 0.759 and the energy conversion efficiency (η) 0.046%, respectively.

The performance of four cells meander type DSSC module was found that the open circuit voltage (V_{oc}) 0.861V, the short circuit current (I_{sc}) 0.119mA, the fill factor (FF) 0.724 and the energy conversion efficiency (η) 0.074%, respectively.

From the measurement of meander type DSSC modules, the open circuit voltage V_{oc}, the short circuit current I_{sc} and the efficiency of the four cells meander type DSSC module were higher than the two cells and three cells meander type DSSC modules. Therefore, the values of the open circuit voltage V_{oc} and the short circuit current I_{sc} were increased depending on the number of cells. This research shows that natural herbal extract dyes from teak leaves can be used as low cost sensitizer in fabrication of dye-sensitized solar cell module.

Future Prospective

The dye-sensitized solar cell is at present the only serious competitor to solid state junction devices for the conversion of solar energy into electricity. The use of natural herbal extract dyes as sensitizers for these devices could lead to achieve dye solar cells with higher efficiencies holding great potential for further cost reduction and simplification of the manufacturing.

Acknowledgement

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