Fabrication of Monolithic Dye-Sensitized Solar Cell

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Abstract

A monolithic dye-sensitized solar cell has been fabricated by using natural dyes extracted from teak leaves as sensitizer. This solar cell was assembled with one glass between 20 to 30 ohms fluorine doped tin oxide (FTO) glass for titanium dioxide (TiO_2) working electrode and another typical glass for graphite counter electrode. The other materials were TiO_2 nano-powder (Degussa-P25 powder), zirconium dioxide (ZrO_2) powder, carboxymethyl celloulose (CMC) powder, iodide electrolyte solution and graphite paste for graphite coating. The performance of a monolithic dye-sensitized solar cell was evaluated by the open circuit voltage V_{oc}, the short circuit current I_{sc}, the fill factor (FF) and the energy conversion efficiency (η).

Keywords: A monolithic dye-sensitized solar cell, TiO_2 nano-powder, Natural dyes,V_{oc} , I_{sc}, η

Introduction

DSSC is a type of photoelectrochemical cell. Photoelectrochemical cells, including dye-sensitized solar cell and organic solar cells are utilized in the photochemical reaction to generate electricity. This type of cell has many advantages such as low mass production cost, good alterability in material structure, and wide range in visible light absorption (Chen, 2010). Some materials used for this type of cells are said to be reproducible. Furthermore, the cells are much less sensitive to the semiconductor defects than the conventional crystalline cells. The structure of the cell is normally in sandwich structure, with transparent substrates at the top and bottom layer and transparent conductive oxide (TCO) layers as conductor. However, the fabrication of monolithic dye-sensitized solar cell doesn't require transparent conducting oxide substrate for the counter electrode (Jasim, 2011). In this cell, the oxide semiconductor material, typically TiO_2, is used for light absorption and electron transfer. But, due to the fact that the material is a wide band gap semiconductor, much shorter wavelength (UV range) is required for electron excitation. Therefore, light sensitive dye material is used to coat the semiconductor material for electron excitation within visible wavelength range (Kay and Gratzel, 1993). The liquid electrolyte is used to regenerate electrons for dye material and long stability purpose. The cathode layer, usually a thin Pt coating, is used to transfer the electrons from the load to the liquid electrolyte for oxidation-reduction process (REDOX) (Ngamsinlapasathian *et al.*, 2000).

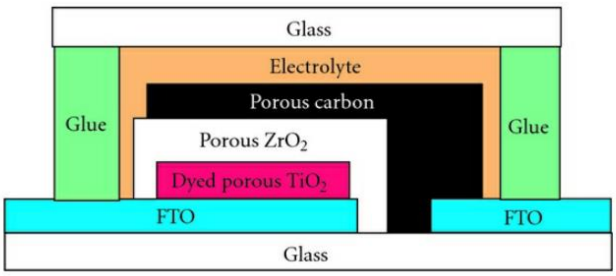

Figure (1) The monolithic setup of DSSC.

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Experimental Procedures

Substrate cleaning

The substrate was first dipped into acetone for at least 5 minutes to dissolve unwanted organic materials and to remove the dusts and contamination materials that were left on the substrates. Another 5 minutes in methanol was followed in order to remove the acetone and materials that were not cleansed or dissolved by acetone. Finally, 5 minutes in isopropyl alcohol (IPA) were needed to further remove the residual particles on the substrates. The cleansed substrate was 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

The 3 g of TiO_2 nanopowder P25 was put in the mortar and then 1 mL nitric acid solution (pH 3-4) was incrementally added to it five times 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 15 minutes.

Preparation of TiO_2 film

Using a multimeter, the conducting side was identified. By placing the conducting side of tin oxide coated glass plate up, the glass was taped with 3M Scotch tape, with a 0.25 cm wide strip along both edges of the plate and with a 1.5 cm wide strip along top of plate to be coated. Some titanium dioxide (TiO_2) suspensions were put on the glass and quickly spread it over the surface using a glass rod. 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 hot plate about 30 minutes until a white titanium dioxide coating was formed. The glass plate was then slowly cool by turning off the hot plate.

Preparation of Dye Extracted from Teak Leaves

In the fabrication of dye-sensitized solar cell, the natural herbal extracted dyes from teak leaves have been used as sensitizer. To extract dyes from the leaves, four or five leaves were cut and ground in a mortar and pestle and then 2-3 mL of acetone was added. Then it was squeezed into the 100 mL beaker using the paper towel and filtered with a filter paper. The colour of dyes was brownish red for teak leaves.

Staining TiO_2 film

The dye solution was then 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 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.

Preparation of ZrO_2 Paste

The 2 g of carboxymethyl celcullose (CMC) powder was firstly put in the beaker and then 20 mL terpineol solution was added to it and put it on the magnetic stirrer and stirred about 1 hour. Some ice was then added and stirred with glass rod for 20 minutes. The mixture was kept to equilibrate at room temperature for 5 minutes. The 1.5g of ZrO_2 powder was put in the mortar and then 3mL of the mixture was added to it while grinding with a pestle until a suspension with a smooth constancy was obtained.

Preparation of ZrO_2 Film on the Stained TiO_2 Coated Glass

The hand operated screen printing was used for ZrO_2 layer fabrication on the stained TiO_2 coated glass. The coated plate was dried for 5 minutes in a covered Petri dish. The glass plate was heated on the hot plate 25 minutes until a dry ZrO_2 coating was formed.

Preparation of Graphite Paste

The 2 g of carboxymethyl celcullose (CMC) powder was firstly put in the beaker and then 20 mL terpineol solution was added to it and put it on the magnetic stirrer and stirred about 2 hours. Some ice was then added and stirred with glass rod for 20 minutes. The mixture was kept to equilibrate at room temperature for 5 minutes. The 1g of graphite powder was put in the mortar and then 3mL of the mixture was added to it while grinding with a pestle until a suspension with a smooth constancy was obtained.

Preparation of Graphite Counter Electrode

Before printing non-conductive glass plate was carefully cleaned. Non-conductive glass plate was first washed with ethanol. The graphite paste has been printed on non-conductive glass. The coated plate was dried for 5 minute in a covered Petri dish. The glass plate was heated on the hot plate for 20 minutes until a dry graphite coating was formed. The glass plate was then slowly cool by turning off the hot plate.

Preparation of Liquid Electrolyte

10 mL of water-free Ethylene Glycol was put in a container. Then, 0.127 g of Iodine, and 0.83 g of Potassium Iodide were added to it. They were mixed together, stirring with a clean glass rod. All the bottles and the container were kept tightly capped when not in use.

Assembling the solar cell

The graphite-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 were 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.

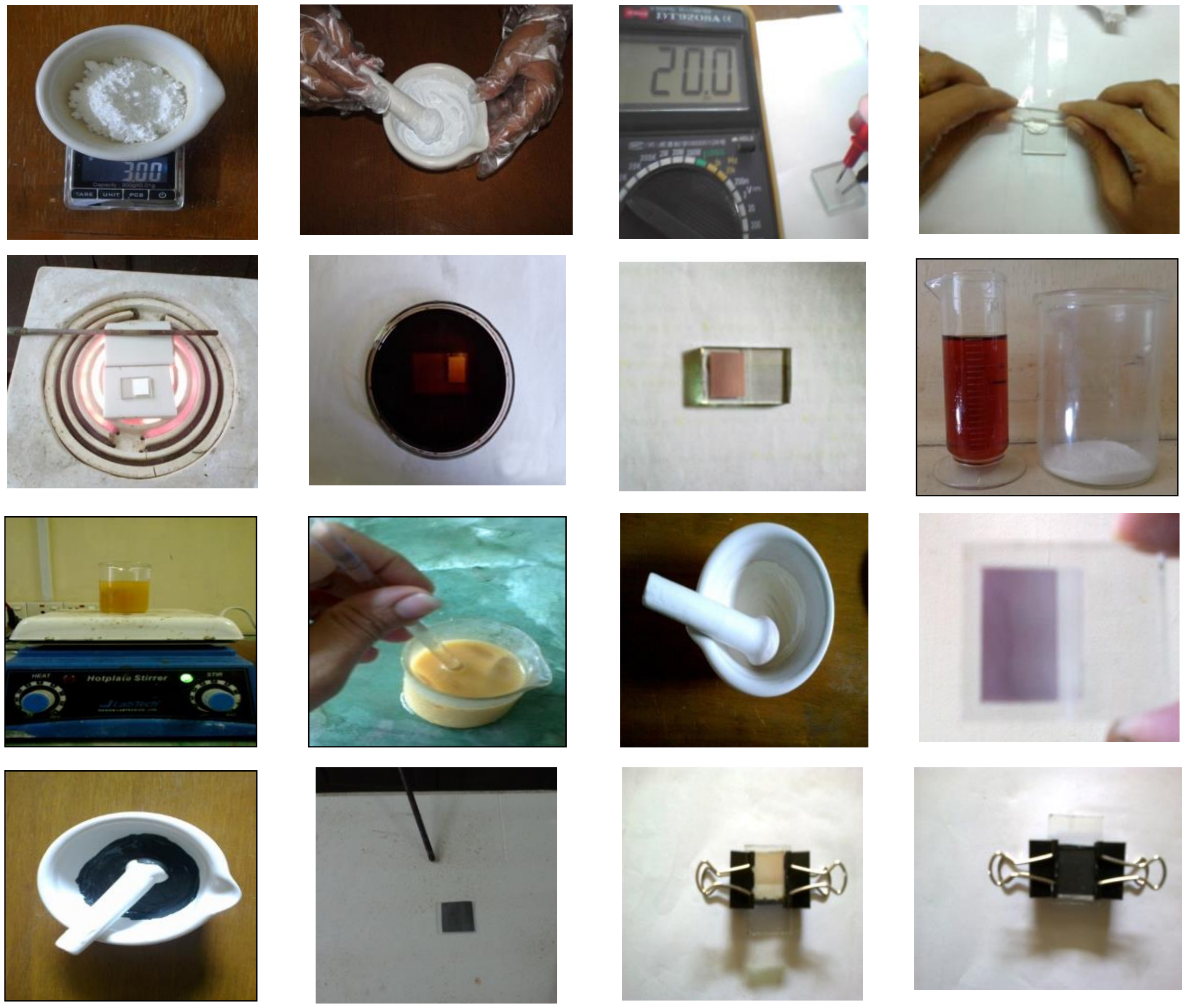

Figure (2) Experimental procedures of monolithic DSSC.

Results and Discussion

The crystalline phase and particle size of carboxymethyl cellulose, zirconium dioxide and carbon powder were analyzed by using powder X- ray diffraction (XRD) with CuK_{α} radiation (λ = 1.54059 Å). The structural properties of carboxymethyl cellulose (CMC) were examined using RIGAKU-RINT 2000 X-ray Diffractometer. XRD pattern of carboxymethyl cellulose was shown in figure (3). By using Scherrer equation, the particle size of carboxymethyl cellulose was found to be 50 nm.

The properties of zirconium dioxide (ZrO_2) and carbon powder were also examined, using RIGAKU-RINT 2000 X-ray Diffractometer. By using Scherrer equation, the particle size of (ZrO_2) and carbon powder were found 56.995 nm and 78.615 nm respectively. Figure (4) and (5) show XRD patterns of (ZrO_2) and carbon powder.

Nanosized titanium dioxide (TiO_2) semiconductor was also analyzed by XRD pattern. 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. The average crystallite size of TiO_2 was about 40.81 nm and anatase phase was observed. Figure (6) shows XRD pattern of TiO_2 nano-powder.

Figure (7) 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 ranging between 300 nm and 700 nm of liquid dye extracting with acetone from teak leaves was shown in figure (8). The absorbance peaks appeared at 413 nm and 663 nm and maximum absorbance A_{max} was 1.081 at 413 nm.

For a monolithic dye-sensitized solar cell, the open circuit voltage V_{oc} was found 0.318V and the short circuit current I_{sc} was found 0.031 mA shown in figure (9a and 9b) respectively.

The photoelectrochemical parameters such as the Fill Factor (FF) and the overall photoconversion efficiency (η) of the DSSC sensitized with natural dyes are listed in Table 1. These parameters were calculated by using the following equations:

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

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

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

P_{in} is the power of light incident on the tested cell, which is about 100 mW for sunlight.

The Fill Factor (FF) and the overall photoconversion efficiency determined from the measured I-V curve were summarized in table (1). The voltage V_{MP} and I_{MP} were obtained at maximum power point from curve.

From table (1), the value of Fill Factor (FF) 0.794 was agreed with the typical Fill Factor ranging from 0.6 to 0.9 but the overall photo conversion efficiency of 0.0078 shows to make further attempt to get better efficiency.

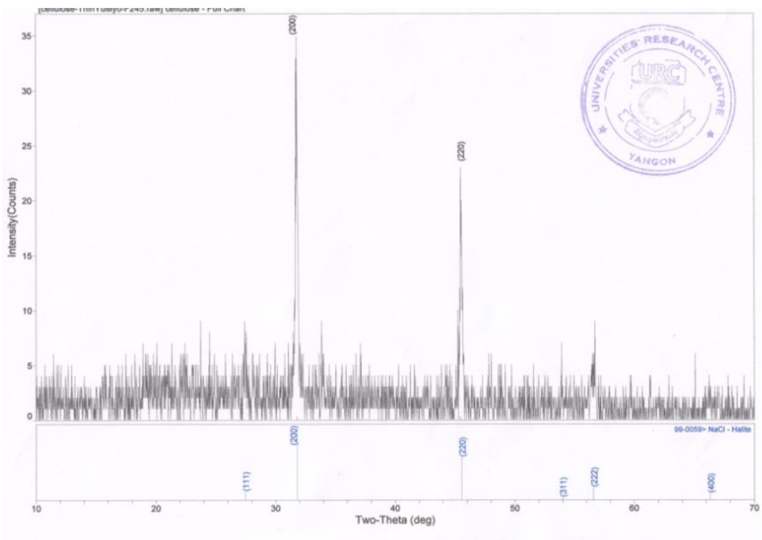

Figure (3) XRD patterns of carboxymethyl cellulose (CMC) powder.

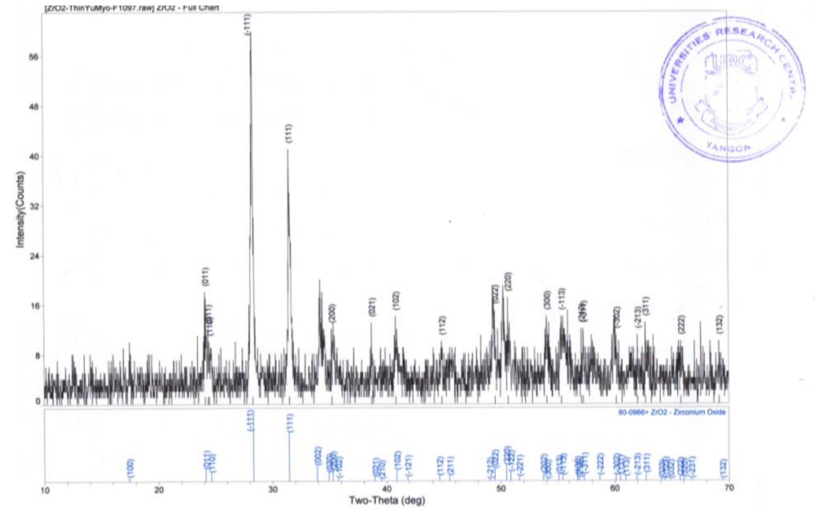

Figure (4) XRD patterns of zirconium dioxide (ZrO_2) powder.

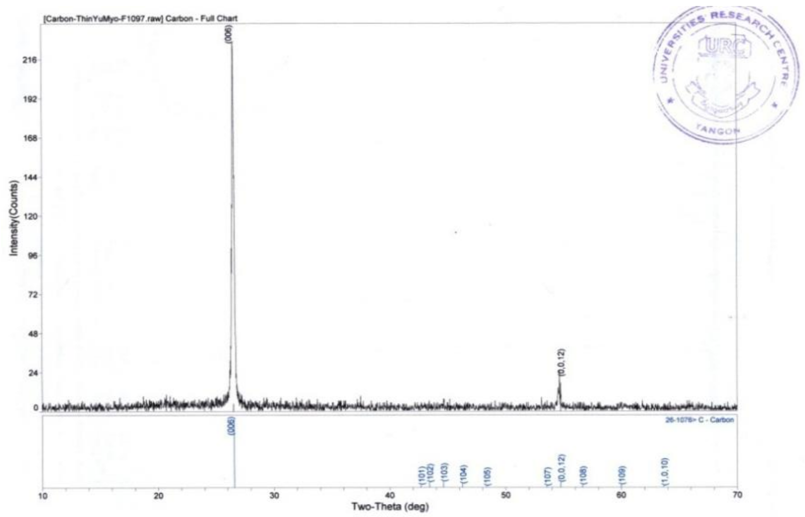

Figure (5) XRD patterns of carbon powder.

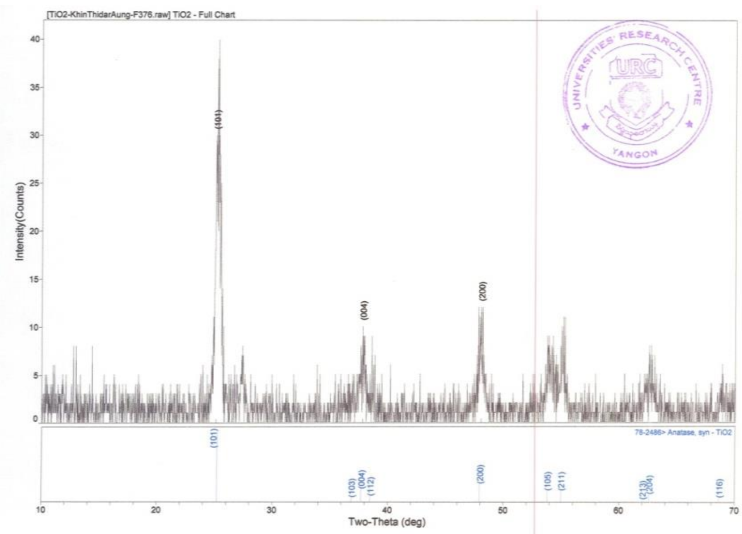

Figure (6) XRD patterns of TiO_2 nano-powder.

Figure (7) Measuring pH for teak leaves dye solution with pH meter.

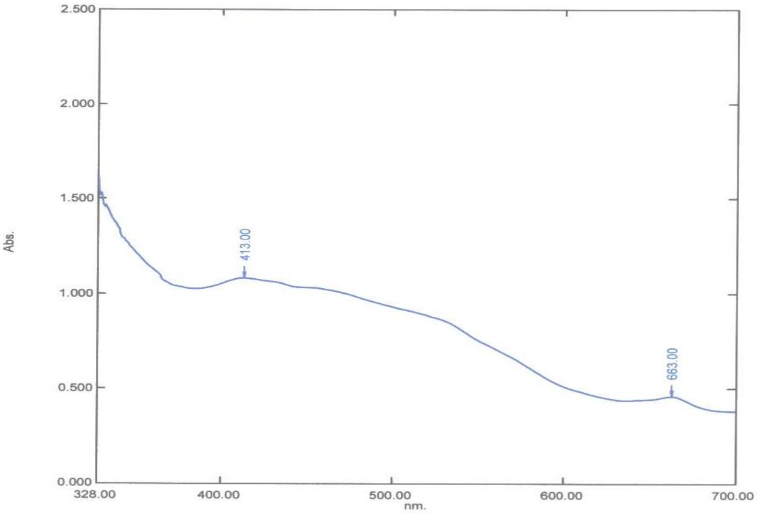

Figure (8) UV-Vis absorption spectra of liquid dye extracting with acetone from teak leaves.

(a) (b)

Figure (9) Measuring the electrical output of a monolithic dye-sensitized solar cell (a) for open circuit voltage (b) for short circuit current.

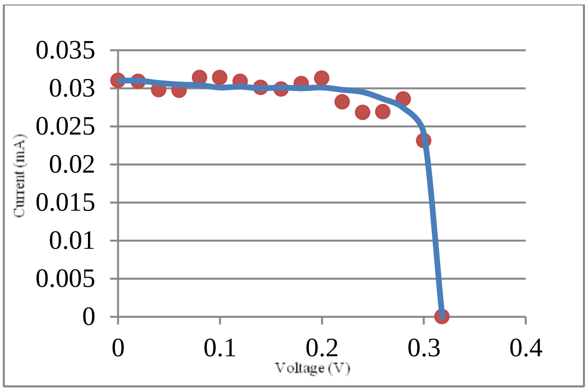

Figure (10) Current-voltage (I-V) curve of monolithic DSSC.

Table (1) I-V Characteristics of Monolithic Dye-Sensitized Solar Cell.

V_{oc}(V)	I_{sc} (mA)	V_{max} (V)	I_{max} (mA)	FF	Efficiency (%)
0.318	0.031	0.27	0.029	0.794	0.0078

Conclusion

The research on dye-sensitized solar cell started in 1991 by discovering sensitizing titanium dioxide photoelectrode covered with organometallic dye can be useful for fabrication of photoelectrochemical cells. Main factors that limit the device dissemination are costs and performance. New material concepts and cell setup are still needed.

New monolithic set-up of DSSC is one of the interesting low cost technologies of fabrication photovoltaic devices. In this research, the high V_{oc} of DSSC was obtained from natural herbal extract dyes from teak leaves. So, teak leaves dyes can be used as low cost sensitizer in fabrication of dye-sensitized solar cell. It was found that output voltage of monolithic solar cell using one TCO glass was the same as that of the cell using two TCO glasses. Therefore, a monolithic dye-sensitized solar cell has been fabricated successfully with low cost by using only one TCO glass.

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