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FABRICATION OF LOW COST SENSITIZED SOLAR CELL USING NATURAL PLANT PIGMENT DYES

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ABSTRACT

Looking for the green sources of energy have been the subject for research activities for last decade. For years studies have been using various kinds of energy sources to fulfill energy requirement. In order to reduce further accumulation of greenhouse gases (GHGs), green generator or converter of energy has been designed to replace the conventional (fossil) energy sources. A new technology had been developed that is known as Natural Dye Sensitized Solar Cells (NDSSC) which consists of a group of photovoltaic cells that produces green energy at low cost of sensitization material production since no vacuum systems or low cost equipment are usedin fabrication process. This paper reviews the structure and working principles of dye sensitized solar cell DSCC. Discussing preparation procedures, optical and electrical characterization of the types of natural dyes, namely, raspberry, blueberry, tumeric (curcuma longa), henna (lawsonia inermis), dragon fruit (hylocereuscostaricensis) and senduduk (melastoma malabathricum). Dye sensitized solar cell with dimension 2.5 cm x 2.5 cm is fabricated by using screen printing method with thickness 10μm of titanium dioxide (TiO_2) by putting it on indium tin oxide (ITO) coated glass.Then, the solar cell is tested under sunlight. Dye extracted from raspberry with TiO_2 viscosity 1.0 g is the most desired natural dye within the selected range of natural dye, with a value of Isc (0.0367 mA), Voc (474mV) , FF (0.818), Pmax (0.0000142) and η(0.0568).

Keywords: natural dyes, dye – sensitized solar cell, photoelectrochemical cell.

INTRODUCTION

Solar cells have gone through a number of years and a number of phases. Their development can be described according to their construction principles (Hara & Arakawa, 2005). A solar cell is a photonic device that changes photons together with particular wavelengths to electricity (Torchani *et al*., 2015). Alexandre Edmond Becquerel, a French physicist discovered this photo electrochemical or also known as photovoltaic impact in 1839 while investigating and analyzing the effect of light on metal electrodes absorbed through electrolyte. Analysis in this area extended as well as technologies produces many different types and also structures of the materials presently used in photovoltaic (PV) technology. Most of photovoltaic industry uses wafer of single crystal and poly-crystal silicon as material for photovoltaic (PV) modules. However, the cost of these modules is high due to material and processing cost (Hara & Arakawa, 2005).

The first and the second generations of photovoltaic cells are generally mainly made of semiconductors which include crystalline silicon, III-V compounds, cadmium telluride, and copper indium selenide/sulfide (Zhao *et al*., 1999).However, solar energy produces a limited application that directly relates to its expensive cost to generate electricity per watt. At present, technology of solar cells determined by crystalline silicon is usually coping with a problem involving silicon-based raw materials (Jasim & Hassan, 2009). Consequently, low cost alternatives and new varieties of low cost solar cells is surely an urgent issue and have absolutely recently been the subject of the research work for the last three decade.

The name DSSC stands for “dye sensitized solar cell". A dye-sensitized solar cell (DSSC) is the latest technology of solar cells. It belongs to the group of thin film solar cell that has attracted considerable attention because of their low cost of production along with the environmental friendliness. Dye sensitized solar cell (DSCC) is a group in the third generation of solar cell that was found by O'Regan and Gratzel in 1991.

The simple assemble of solar cell (also referred to as photovoltaic device) operates by renovating affordable photon from solar energy to electrical energy according to sensitization of wide bandgap semiconductor, dyes and also electrolyte (Jasim & Hassan, 2009) . The performance of dye absorption in DSSC is dependent on the sensitizer dye and wide bandgap material such as TiO_2, ZnO and Nb_2O_5 (Tennakone *et al*., 1996). TiO_2 $_{is}$ always chosen because its ability to the surface and to avoid the move of electron which take place under illumination solar photon. One of the ways to determine the efficiency of solar cell depends on the performance of dye absorption spectrum that is coated on the surface of TiO_2 (Bisquert *et al*., 2004). The most efficient sensitizer, ruthenium polypyridyl complex can be created from heavy transition metal coordination compound. This type of this sensitizer used widely because great charge - transfer (CT) absorption in the visible light spectrum and good absorption (Hau *et al*., 2006) .On the other hand, high cost of ruthenium and hard to prepare highlights the need to identify low-cost, efficient sensitizers. Natural dyes are well known for their high absorption coefficient, cheap and easy availability, non-toxic and renewable reservoir to materials for many applications. Narayan (2012) in her review stated that a number of natural dyes have been extracted as to facilitate dye-sensitized solar cells. Besides that, natural dyes compare to semiconductor solar cell are promising alternative sensitizers for DSSC because they are only available, easy to prepare, cheap and eco-friendly (Narayan, 2012).

In this study, six types of extracts, namely raspberry, blueberry, turmeric, henna, dragon fruit and melastoma were used and characterized.

METHODOLOGY

The fabrication process of Dye-sensitized solar cells involved different type of components in order to accomplish the whole assembly. The key point of DSSC mechanism included identifying the suitable indium tin oxide (ITO), preparation of TiO_2 paste, staining the organic dye and preparation of counter electrode (Ahmad *et al*., 2010). Figure-1 below showed the fabrication steps in general.

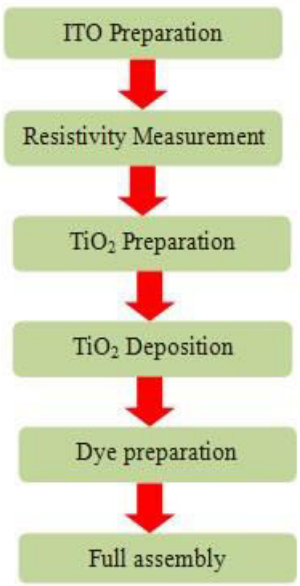

Figure-1. The fabrication steps of DSSC.

ITO Preparation

In this experiment, indium tin oxide (ITO) has been used as substrate. It started with cutting ITO glass with 5cm by 5cm square into 2.5cm by 2.5cm square.After cutting process, the substrates chemically cleaned by using Acetone and Ethanol. Then the substrates were place in ultrasonic bath to remove any contaminant on the ITO surface.

Resistivity Measurement

The next step is measuring the resistivity of the substrate. Digital multimeter is used to measure the resistance. The conductive side usually has a much lower resistance compare with non-conductive side.

TiO_2 Preparation

To prepare the TiO_2, 1g and 2.5g of TiO_2 powder were used. Then the TiO_2 were mixed with 2ml of vinegar and a drop of detergent until it has the consistency of thin paint or liquid corrector fluid.TiO_2were deposited on the ITO glass by using screen printing technique. Screen printing technique is a low cost technique and easy to carried out.

Dye Preparation

The sample is then heated on the hot plate under temperature 200 ^{0}C for 20 minutes. This process will remove the water and improve the electrical contact between the substrate and TiO_2 paste. In this experiment six difference dyes were used. The dyes were extracted from henna, dragon fruit, raspberry, blueberry, turmeric and shrub (melastoma malabathricum). Mortar and pestle is used to crush the samples until the juice is squeezed out. Then a few drops of each dye were dropped onto the cooled titanium slide.

Assembly

The counter electrode (cathode) was prepared by taking another ITO glass, and pass the conductive side through a candle flame several times. The redox shuttle and electrolyte were prepared by mixing 127mg of iodine crystal with 830mg of potassium iodide and 10 ml of ethylene glycol. At the final assembly, a few drops of redox shuttle and electrolyte were poured onto the stained sample and place over it with the soot covered slide. The coated sides must be facing each other. Alligator clips are used to contact the exposed sides so that electricity from the test cell can be measured.

Characterization and Measurements

Fill factor is one of the important parameters in order to achieve high efficiency. Fill factor (FF) can be calculated using equation where V_{max} and I_{max} are the current and voltage at the maximum power (Chu, 2011). Fill factor also called as "FF" is a parameter which is in conjunction with Voc and Isc. Fill factor can be defined as the ratio of the maximum power from the solar cell to the product of Voc and Isc. Fill factor can be defined as:

$$\text{Fill factor} = \frac{I_{max} \times V_{max}}{I_{sc} \times V_{oc}}$$

The energy conversion of a solar cell is defined as the ratio of the output power of the cell and incident irradiance. Maximum efficiency is reached when power delivered to the load is P_{max}. Incident optical power is normally specified as the solar power on the surface of the earth which is approximately 1mW/mm^2. The power conversion efficiency η, which is the key parameter of a DSC, was calculated from the power incident Pin = 0.1W/cm^2 and the surface area of the conductive glass is 0.5 cm x 0.5 cm. It is defined as:

$$\text{Efficiency}, \eta = \frac{P_{max}}{P_{in} \times \text{Area}}$$

RESULTS AND DISCUSSIONS

In this study, the dye-sensitized solar cells (DSSC) are made of six extracted dyes with different chemical reactions and anthocyanin molecules. Therefore, 24 samples were recorded by using different number of

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mesh and the viscosity of titanium dioxide mixture. Table-1 shows the measured value of electrical characteristic for each sample.

From Table-1, it is evident that raspberry has the highest efficiency compared to other dyes. Dye extracted from raspberry with TiO_2 viscosity 1.0 g exhibits a value of J_{sc} (0.0367 mA), V_{oc} (474mV), FF (0.818), P_{max} (0.0000142) and η(0.0570). It can be seen that for other dyes, the efficiency do not exceeds 0.005%.

According to Narayan (2012), the low efficiency of natural dye sensitized solar cells are due to the structure of pigments of the dye. In cases where there are interference which hinders for the dye pigments to form bond with the oxide surface of the TiO2. This will then prevents the molecule from arraying on the TiO2 film effectively (Narayan, 2012)

The low value of efficiency in the cell in this study may be due to the fast charge recombination rate, loss resulting from the increase traffic of the electron or incompatibility between the energy of the excited state of the absorbed dye and the conduction band edge of TiO_2.
Figure-2 shows seven scanning electron microscope (SEM) images of titanium dioxide (TiO_2). SEM images were taken at 15KeV beam voltage. Each and one of the images have different micro windows and different magnification factor. Figure-2(a) shows the coating of 1μm micro window with the magnification factor x 10,000 compared with Figure-2(b) with same micro window but different magnification factor of x 5,000. Figure-2(c) shows the surface of TiO_2 coating at 2μm micro window and the magnification x 3,000. Meanwhile Figure-2(d) shows different images of the surface at the magnification of x 1,000 with the 10μm micro window. With same micro window, the surface in Figure-2(e) look quite similar except for the image more clearly as the magnification factor equals 500. The TiO_2 coating in Figure-2(f) is at 100μm of micro window with the magnification equals to 100. Figure-2(g) has low magnification factor of 30 and the micro window equals to 200μm where the image almost similar as the actual TiO_2 coating but with the closer look.

Table-1. Parameters characteristic for dragon fruit, henna, turmeric, shrub, blueberry and raspberry.

Dyes	Mesh size (POL)	TiO2 viscosity (g)	Voc (mV)	Jsc (mA/cm^2)	Fill factor	Efficiency, η (%)
Dragon fruit	100	1	233	0.0043	0.93	0.00300
Dragon fruit	100	2.5	191	0.0007	0.88	0.00050
Dragon fruit	200	1	337	0.0044	0.86	0.00500
Dragon fruit	200	2.5	103	0.0067	0.89	0.00200
Henna	100	1	207	0.0027	0.87	0.00200
Henna	100	2.5	65	0.0001	0.87	0.00030
Henna	200	1	393	0.0002	0.87	0.00002
Henna	200	2.5	105	0.0005	0.86	0.00020
Turmeric	100	1	103	0.0003	0.86	0.00011
Turmeric	100	2.5	238	0.0013	0.85	0.00011
Turmeric	200	1	337	0.0214	0.85	0.02457
Turmeric	200	2.5	102	0.0063	0.85	0.00220
Shrub	100	1	274	0.0019	0.87	0.00180
Shrub	100	2.5	212	0.0017	0.80	0.00110
Shrub	200	1	408	0.0002	0.88	0.00029
Shrub	200	2.5	400	0.0005	0.85	0.00068
Blueberry	100	1	7	0.0007	0.85	0.00002
Blueberry	100	2.5	317	0.0225	0.78	0.00250
Blueberry	200	1	3	0.0013	0.53	0.00001
Blueberry	200	2.5	16	0.0009	0.87	0.00005
Raspberry	100	1	474	0.0367	0.82	0.05700
Raspberry	100	2.5	148	0.0001	0.83	0.00005
Raspberry	200	1	267	0.0001	0.81	0.00008
Raspberry	200	2.5	4	0.0063	0.87	0.00090

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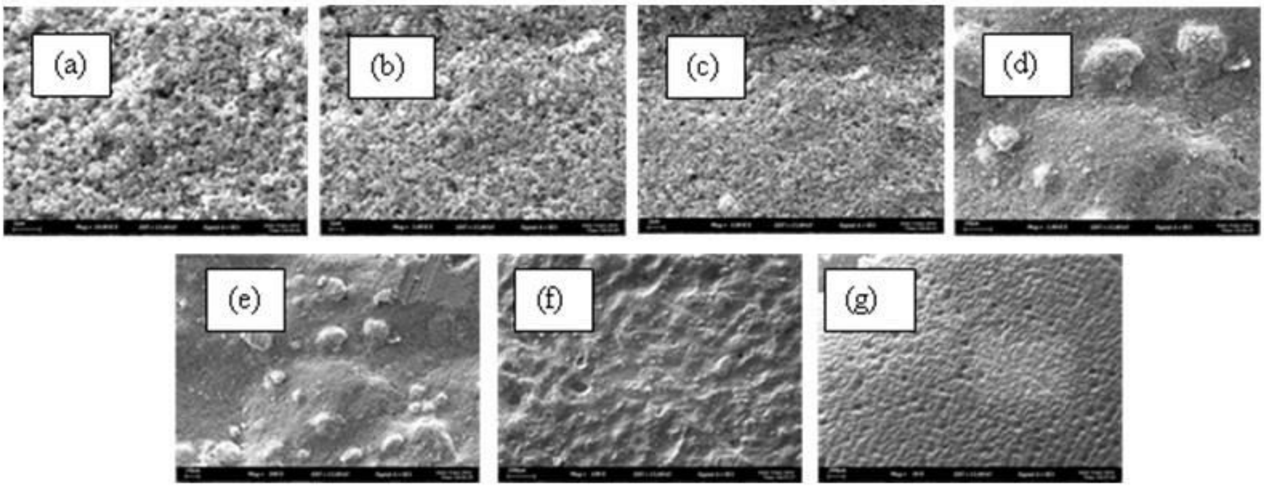

Figure-2. SEM images (a)1μm micro window; mag =10KX (b) 1μm micro window; mag =5KX (c) 2μm micro window; mag =3KX (d) 10μm micro window; mag =1KX (e) 10μm micro window; mag =500X (f) 100μm micro window; mag =100X (g) 200μm micro window; mag =30X.

CONCLUSIONS

The objectives of the experiments were to study the fabrication and the characterization of the dye sensitized solar cell using natural dyes. The electrical parameter of the DSSC was the main focus of attention in this experiment. The characterization also included titanium dioxide past and dyes, photo electrode, counter electrode different parts of the cell were separately characterized and also the benefits used in this work. The natural dyes were extracted from six types of plants and fruits. In this experiment, an investigation on six types of pigments as natural photosensitizers, describing and comparing their sensitization. In this study DSSC ability to mimic photosynthesis investigated using anthocyanin extract from plants and fruits as a sensitizer. Besides that, it also showed the possibility of using natural plant dyes that contain high concentration of anthocyanin (such as raspberry) as a good organic dye compared to blueberry. After done this project, DSSCs can work effectively with the natural dyes and efficiency of DSSC varies with dye solution used. Raspberry sensitized DSSC achieved the highest energy conversion efficiency of 0.0568%. The best performance was obtained for DSSC sensitized with raspberry with parameter Isc = 0.0367 mA, Voc = 474 mV and FF= 0.818. Compared with traditional solar cells, the dye-sensitized solar cells have less efficiency but if the project continues, maybe one day the dye-sensitized solar cells can achieve high efficiency as similar with silicon-based solar cells. This dye-sensitized solar cell can be the replacement of the silicon-based solar cell because of the low cost production as the dyes is easy to find and it only use screen printing method. Plus, dye-sensitized solar cell has the advantage in term of flexibility of the solar cell where people can carry the solar cells wherever they go.

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