THE PHOTOVOLTAIC PERFORMANCE OF DYE-SENSITIZED SOLAR CELL BASED ON CHLORIN LOCAL DYE

J. O. OZUOMBA^{a*}, A. J. EKPUNOBI^b, P. I. EKWO^b

^aDepartment of Physics, Madonna University, Elele, Nigeria ^bDepartment of Physics and Industrial Physics, Nnamdi Azikiwe University, Awka, Nigeria

The paper reports on the fabrication and characterisation of a dye sensitized solar cells using *chlorin* (Ch)-stained titanium (iv) oxide (TiO_2). A second bare or plain cell which serves as a control was fabricated using unstained TiO₂. The chlorine dye was extracted from bahama grass. Thin films of Ch-strained TiO₂ and unstained TiO₂ were deposited on transparent conducting oxide glass using the blade method. The Ch-stained electrode was found to absorb solar radiation both in the UV and VIS region. The photoelectric energy conversion efficiency was found to be 1.00% and 0.03% for Ch-stained and bare electrodes respectively. The diurnal variation of output power for both cells was carried out for three days. The efficiency of the stained cell can be compared with 1.43% obtained by Suri et al and 1.5% recorded by Law et al. Results of the hourly output power obtained for the three days revealed that the local dye can make a good photo sensitizer but would require further treatment to improve on its optical absorbance and stability under exposure to solar irradiation.

(Received February 8, 2011; accepted February 22, 2011)

Keywords: Dye sensitized solar cell, local dye, bahama grass, ruthenium complexes, photovoltaic performance

1. Introduction

Since the pioneering work of Regan Gratzel[1], a great attention has been paid to dye sensitized solar cells (DSSCs) as cheap, effective and environmentally benign candidates for a new generation solar devices [2]. DSSC is a photoelectrochemical device which effectively utilizes a property of nanocrystalline wide band gap metal oxide semiconductor porous electrode. Generally, a DSSC consists of an indium-tin oxide (ITO) or fluorine-doped tin oxide (FTO), dve modified electrode, electrolyte and a counter electrode. Unlike standard silicon-based solar cells, DSSCs are photoelectrochemical in nature, making the manner by which they convert solar energy into electrical energy resemble photosynthesis. The reaction taking place within the cells closely mirrors that of the photosynthesis reaction in plants. Like chlorophyll in plants, the light absorbing dyes used in thin-film based solar cells absorb incoming sunlight and use that energy to perform chemical reactions. The process is written as follows:

i. Dye^* hv + Dve

 $Dye^* + TiO_2$ e^{-} (TiO₂) + Dye⁺ ii.

 e^{-} (TiO₂) + FTO \longrightarrow TiO₂ + e^{-} (FTO) (Electron goes into FTO and through the load) iii.

 $3I^{-} + 2Dye^{+}$ • $I_3^- + 2Dye$ iv. $3I^{-} + (C.E.)$

V. $I_3^{-} + 2e^{-}(C.E.)$ -

^{*}Corresponding author: okanandu@yahoo.com

Photons enter enough energy into the system to excite the dye. The dye then donates an electron to the titanium dioxide, which then sends an electron through the load to the counter electrode (carbon or platinum in a FTO substrate) and to the electrolyte causing reduction/oxidation to occur. The electrons from the redox system are then returned back to the TiO₂/FTO electrode (photo electrode). The process can then be repeated as long as light input occurs. Although various dye molecules have been investigated as photo-sensitizers in the last decade, ruthenium (Ru) complexes remain the best sensitizers for TiO₂ [3]. In 2007, Suri *et al*[4] achieved a conversion efficiency of 1.43% using undoped ZnO as photoanode and Eosin-Y as an organic dye. Law *et al*[5] fabricated DSSC with TiO₂ sensitized with Ru(DobpyH)₂ (NCS)₂ and obtained photo-conversion efficiency of 1.5% under a full sun intensity of 100 mW/cm². Particle size and shape, porosity, film thickness, distance between electrodes, electrolyte composition, dye molecule and illumination direction are significant factors in DSSC. The need to explore cheaper materials in DSSC fabrication is essential, thus, it is necessary to compare various materials for fundamental understanding of the behaviour of DSSC.

In this paper, we report on the photovoltaic properties of a DSSC fabricated with *chlorin* local dye. The properties of another cell fabricated with unstained photo-electrode was measured to ascertain the effectiveness of the local dye as a photo-sensitizer.

2. Experimental details

2.1 Electrode preparation

In this work nanocrystalline titanium (iv) oxide (Ti-nanoxide T/sp, Solaronix SA, Rue de e duriette 128) was used as photo electrode. The active area of a 2.5cm x 2.5cm FTO was identified and covered on each of the two parallel edges with a triple layer of masking tape to control the thickness of the TiO_2 film.



Fig. 1. Preparation of the FTO for electrode deposition.

The covered part of the FTO measuring 2.5cm x 8mm will provide the electrical contact area. Before deposition, the glass substrate was cleaned with acetone, then methanol and etched through plasma treatment for 1min. The $nc - TiO_2$ which was in form of paste was applied at one of the edges of the conducting glass and distributed with a squeegee sliding over the tape-covered edges. Allow the film to dry naturally without blowing. Remove the adhesive tapes and clean the

edges with ethanol. The electrode was sintered for 30 min at 400 °C using carbolite 201tubular furnace.

A well blended mixture of powdered activated carbon (PAC) and natural graphite powder (NGP) formed as a paste through sol-gel technique was used as counter electrode. The same blade method used in TiO_2 deposition was adopted in depositing the carbon electrode. In this case the electrode was blown with hot air dryer for about 3 minutes before removing the adhesive tapes. Sintering was done for 15 minutes at 150 °C.

2.2 Dye sensitization

The mesoporous TiO₂ film was immersed into a solution of the *chlorin* local dye overnight [5]. The electrode was preheated at 80 °C for 15 minutes before it was dipped into the dye solution. This process helps in the prevention of rehydration of the TiO₂ surface or capillary condensation of water vapours from ambient air inside the nanopores of the film [6]. The presence of water in the pores decreases the injection efficiency of the dye. This local dye was extracted from the popular bahama grass. The grass was pounded and the green pigment extracted with 90% ethyl alcohol. The extract was purified by chromatography and some copper ions were added. After dye sensitization, dye-coated electrode was rinsed in ethanol, dried using hot-air blower and kept in dark in an air tight case till the assembly of the cell.

2.3 Characterisation of electrode

The thickness of both electrodes was measured using Dektak stylus 7.0 surface profiler. The sheet resistance of the counter electrode was measured using dual-pro 301 (auto calculating 4.pt. probe resistivity test system). Avaspec 2.1 spectrophotometer was used to measure the optical absorbance of the semi-synthetic chlorin dye adsorbed on TiO_2 thin films.

2.4 Solar cell assembly

Sealing gasket (SX 1170 – 60 PF, Solaronix SA) brings the ease of using a 60μ m thick hot melt foil for sealing the cells.



Fig. 2. The sealing gasket.

The sealing gasket was cleaned in ethanol before placing it on top of the dyed working electrode. The counter electrode was gently placed on top of the frame and held in position with a clamp with the conducting carbonized side towards the working electrode. The set up was held

over a hot plate for 1 min at 150 °C before allowing it to cool for a few minutes. A few drops of the electrolyte (Iodolyte R-150, BN408/071008SN, solaronix SA) were introduced through one of the 3mm holes by capillary action. The holes were then sealed using Amosil 4R sealant (BN011008SN, Solaronix SA). Electrical contacts were made by applying silver paint along the /AC/conducting side of each electrode. Both cells have active area of 1.8cm².

2.5 Solar cell characterization

The current-voltage (I-V) measurements were done using an oriel class A solar simulator while data acquisition was computerised. Measurements were done at a solar intensity of 100mW/cm². Outdoor diurnal measurements were carried out using a thermocouple and Mastech MY64 digital multi-meter. The diurnal measurement was done on top of a zinc roof measuring 6.5m from ground for three days within a space of three weeks.

3. Results and discussion

We obtained 6.2µm and 4.2 µm as the thickness of the photo-electrode and counter electrode respectively. The sheet resistance of the counter electrode was 15.4Ω/ . Figure 4 shows the absorption spectrum of semi-synthetic chlorin dye adsorbed on TiO₂ electrode. Thus *chlorin* dye can absorb solar radiation in the range of 297nm – 558nm with two outstanding peaks at 313nm and 504nm. Hence the Ch-dye can absorb light of appropriate wavelength and so can be used as photo sensitizer for wide-band gap semiconductors such as TiO₂ which alone cannot absorb visible light.



Fig. 3. Optical absorbance of Ch-stained TiO₂

Fig.4 and Fig. 5 show the photocurrent-voltage characteristics of the solar cells based on the Ch-dyed and unstained electrodes under solar illumination (100 mW/cm²). The energy conversion efficiency (n) and fill factor (FF) were evaluated using the following relations:

$$n = \max \operatorname{maximum power output} = I_m V_m$$

$$maximum power input \qquad A \ge E$$

$$FF = I_m V_m$$

$$\overline{A \ge E}$$

$$2$$

A is the active surface area of the solar cell while E is the illumination intensity. The short circuit photocurrent (I_{sc}), the open circuit voltage (V_{oc}), FF, and *n* for the Ch-stained solar cell were found to be 3.9mA/cm², 0.44V, 0.59 and 1.00% respectively. I_{sc} , V_{oc} , FF, and *n* for the plain solar cell were found to be 0.20mA/cm², 0.24V, 0.63 and 0.03% respectively. The lower absorption of light by the unstained electrode reduces the injection efficiency of carriers and the energy conversion efficiency.



Figs. 6, 7 and 8 are the outdoor power-temperature curves are the outdoor power-time curves for the three days.



Fig. 7. Power-temperature curves for the *chlorin*-dyed and plain cells (Day 2).



Fig. 8. Power-temperature curves for the *chlorin*-dyed and plain cells (Day 3)

There was a high instability in the power output of the Ch-dyed cell while the un-dyed cell was relatively stable. The high value of power obtained on the first day in the Ch-dyed cell shows that the local dye can perform even better than the Ru but would require further treatment to improve on its stability under solar illumination. The high performance of the dyed cell as compared to the bare cell is a proof that the local dye was effective in improving the optical absorbance of the TiO_2 electrode.

4. Conclusions

Dye sensitized solar cells using *chlorin*-stained and unstained electrodes have been successfully fabricated. The incident solar light to electric energy conversion efficiency was found to be 1.00% and 0.03% for Ch-dyed and un-dyed solar cells respectively. The efficiency of the cells depend on the optical absorption of the TiO₂ layer. The local dye extracted from chlorophyll has the viability of being a good alternative to the ruthenium complexes.

References

- B. O'Regan, M. Gratzel, A Low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO₂ films, Nature 353, 737 (1991).
- [2] A. Hagfeldt, M. Gratzel, Acc. Chem. Res. 33, 269 (2000).
- [3] M. K. Nazeeruddin, A. Kay, I. Rodicio, R. Humphry-Baker, E. Muller, P. Liska, N. Vlachopoulos, M. Gratzel, J. AM. Chem. Soc., 115, 6382 (1993).
- [4] P. Suri, M. Panwar, R. M. Wehra, Photovoltaic performance of dye-sensitized ZnO Solar Cell based on Eosin-Y photosensitizer, Materials Science Poland, 25, (1) 137 (2007).
- [5] M. Law, L. E. Green, J. C. Johnson, R. Saykally, P. Yang, Nature Mater, 4, 455 (2005).