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THE VIABILITY OF *PROPHYRIN* LOCAL DYE IN THE FABRICATION OF DYE SENSITIZED SOLAR CELLS

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This work is an analytical report on the performance of *prophyrin* local dye, which is a pigment extracted from carica papaya leaves. We compared the characteristics of dye-sensitized solar cell fabricated with *prophyrin* stained titanium dioxide electrode with those of a bare solar cell. The stained electrode showed considerable optical absorbance both at the ultraviolet and visible region. The overall conversion efficiency of the cells were 0.11% and 0.03% for the dyed and un-dyed solar cells respectively. The photoelectric energy conversion efficiency obtained for the stained cell can be compared with 0.04% to 1.6% recorded by Sirimanne et al (2008). Results of the hourly variation of photoelectric power also revealed that the dyed working electrode performed better than the plain electrode.

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Keywords: Gratzel, Solar cell, Carica papaya, Local dye, Titanium dioxide

1. Introduction

Dye-sensitized solar cells (DSSCs) have drawn great attention since O'Regan and Gratzel announced the first high-performance DSSC in 1991 [1]. Since then, not only the overall conversion efficiencies of the DSSCs have been improved to over 10% [2-4], but other aspects that limit the use of the cells like lifetime of dyes, ease of operation, and material have been pushed further. High performance organic dyes have been designed and synthesized to lower the cost, while quasi-solid-state electrolytes have been used to replace the inconvenient liquid electrolytes [5-7]. However, the conversion efficiency is yet the bottleneck for the DSSCs to become the low-cost alternative of the conventional inorganic cells [8].

A DSSC is composed of a dye-sensitized nanocrystalline titanium dioxide (TiO_2) electrode, a counter electrode, and a redox electrolyte in between [9]. Figure 1 shows the cell structure and the principle of operation for the DSSC. The light incident on the transparent electrode (photo-electrode) excites the dye in the cell from the ground state to an excited state, whereby an electron (e^-) is formed. The e^- passes through TiO_2 to reach the transparent electrode, and flows into the external circuit. Meanwhile, the loss of e^- in the dye is supplemented with iodine ions ($3I^-$) in the electrolyte. At this point, $3I^-$ are oxidized into iodine and then return to $3I^-$ (reduction) by receiving e^- that is supplied from the counter electrode.

A dye-sensitized solar cell was recently developed by sandwiching a natural pigment in between n-type and p-type semiconductor by a Sri Lankan research group [10]. The efficiency of this cell was less than 1%. Several natural pigments [10-13] have been identified as suitable sensitizers for wide band gap semiconducting oxides. Sirimanne et al, 2008 [14] obtained photoconversion efficiency ranging from 0.04% to 1.67% using three different dyes. Suri et al, 2007 [15] obtained photoconversion efficiency of 1.43% using undoped ZnO as photo-electrode and Eosin-Y as an organic dye. Hence, this work studies the photovoltaic performance of a DSSC

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fabricated with local dye extracted from carica papaya leaves by comparing its characteristics with those of un-dyed solar cell.

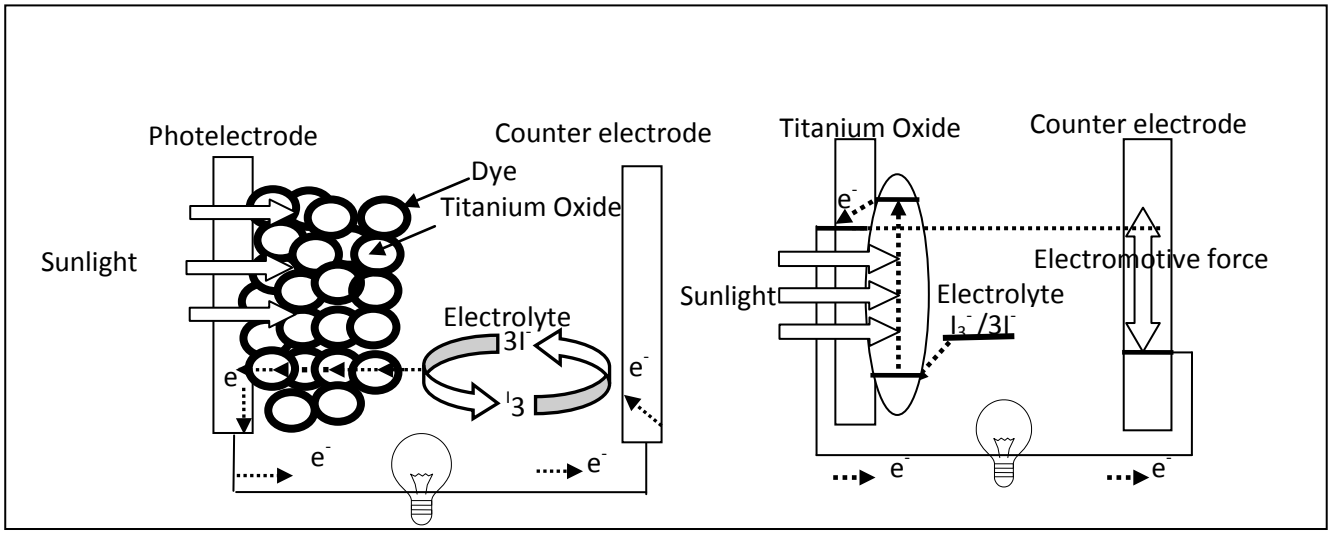

Fig. 1. The structure (left) and principle of operation (right) of dye-sensitized solar cell

2. Experiment

2.1 Electrode preparation

In this work, an equal amount of well blended powdered activated carbon (PAC) and a kind of natural graphite powder (NGP) were used as counter electrode for both cells. The deposition of our counter electrode on fluorine-doped tin oxide (FTO) glass substrate was enabled through the sol-gel process and blading method. The conducting side of a 2.5cm x 2.5cm FTO was identified and covered on each of the two parallel edges with a double layer of masking tape to control the thickness of the TiO_2 film (Fig. 2). The covered FTO edge 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 carbon paste which was prepared through sol-gel technique was applied at one of the edges of the conducting glass and distributed with a squeegee sliding over the tape-covered edges. A hot air blower was used to dry the electrode for about 3 minutes before removing the adhesive tapes. The edges were cleaned with ethanol. The carbon electrode was sintered at 150^0C in furnace (carbolite 201 tubular furnace) for about 15 m

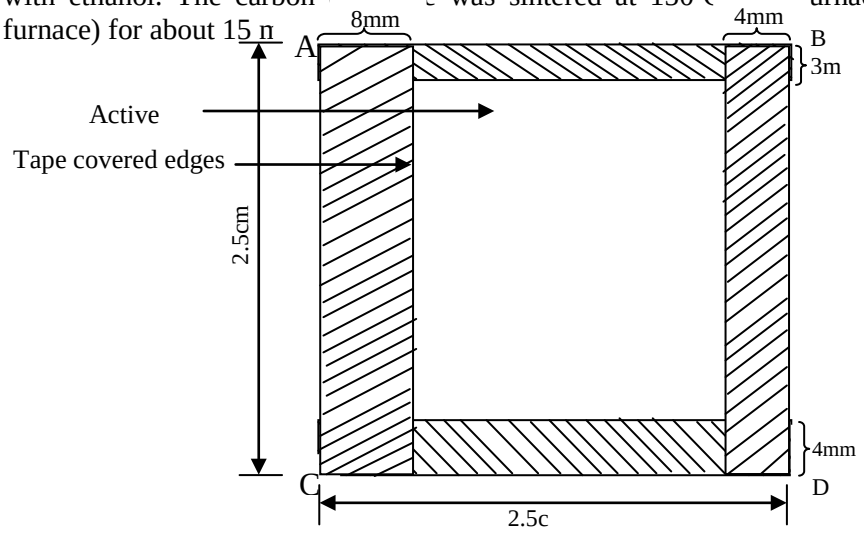

Fig. 2. Preparation of the FTO for electrode deposition.

Nanocrystalline titanium (iv) oxide (Ti-nanoxide T/sp) was used as photo-electrode. The same blade method was adopted in depositing the TiO_2 layer and the film was allowed to dry naturally without blowing before removing the adhesive tapes. The edges were also cleaned with ethanol. The electrode was sintered for 30 min at 400 ^oC using the same carbolite 201tubular furnace.

2.2 Dye sensitization

The *prophyrin* dye used in sensitizing the nanocrystalline TiO_2 film was extracted from carica papaya leaves. The carica papaya leaves were well blended and the pigment which forms our local dye was extracted using 90% ethanol. The TiO_2 photo-electrode was immersed into a solution of the *prophyrin* dye overnight. The electrode was preheated at 80 ^oC for 15 minutes before it was dipped into the dye solution.

2.3 Cell fabrication

Sealing gasket (SX 1170 – 60 PF) brings the ease of using a 60µm thick hot melt foil for sealing the cells (Fig 3). The sealing gasket was cleaned in ethanol before it was rightly placed on 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 ^oC before allowing it to cool for a few minutes. We introduced few drops of the electrolyte (Iodolyte R-150) through one of the 3mm holes by capillary action. The holes were then sealed using Amosil 4R sealant. Electrical contacts were made by applying silver paint along the /AC/ conducting side of each electrode. A second cell was assembled using un-dyed TiO_2 electrode to obtain our plain cell. The active surface area of the *prophyrin*-dyed cell was 1.63cm^2 and that of the plain cell was 2.25cm^2.

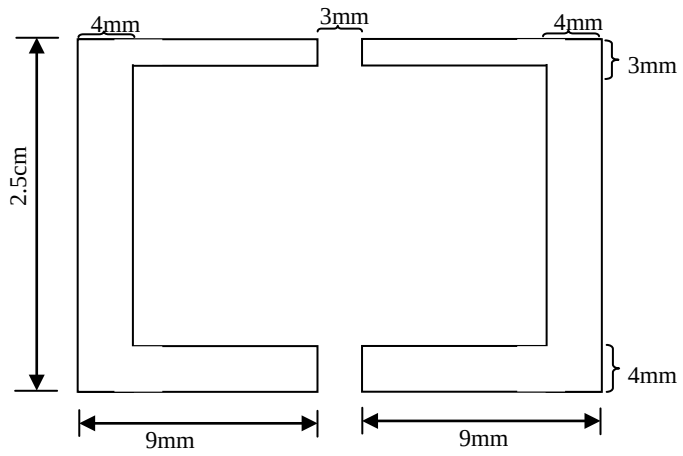

Fig. 3. The sealing gasket

2.4 Solar cell characterization

The thickness of both electrodes was measured using Dektak stylus 7.0 surface profiler. The sheet resistance of the carbon counter electrode was measured using dual-Pro 301 (auto calculating 4 pt. Probe resistivity test system). The optical absorbance of the *prophyrin*-stained TiO_2 was measured using Avaspec 2.1 spectrophotometer. The current-voltage (I-V) characteristics were measured using an Oriel class A solar simulator (AM 1.5, 100mW/cm^2). Outdoor output power measurements were carried out using a copper/constantan thermocouple and Mastech MY64 digital multi-meter. This diurnal measurement was carried out on top of a zinc roof measuring 6.5m from ground, for three non-consecutive days within a space of three weeks.

3. Results and discussion

The thickness and sheet resistance of the carbon counter electrode were 4.2µm and 15.4Ω/square respectively. The thickness of the photo-electrode deposited using the same blade method was 6.2µm. The *prophyrin*-stained TiO_2 has good optical absorbance over a wide wavelength range (310nm - 631nm) both in the UV and visible region. A peak absorbance of 2.00A.U. was recorded in the UV region at the wavelength of about 351nm (Fig. 4). Optical absorbance of 1.6 A.U. and 1.4A.U. were also recorded in the visible region at the wavelengths of 516nm and 600nm respectively. Meanwhile, Lee and Kang, 2010 [16] studied an unstained nanoporous TiO_2 and obtained optical absorbance of 1.3A.U. and 1.2A.U. at 200nm and 350nm respectively but no optical absorption was recorded beyond UV region. Also, a bare TiO_2 nanowire studied by Meng et al, 2008 [17] showed no optical absorbance beyond 400nm. Hence, the *prophyrin* dye greatly improved the optical absorbance of the TiO_2 electrode.

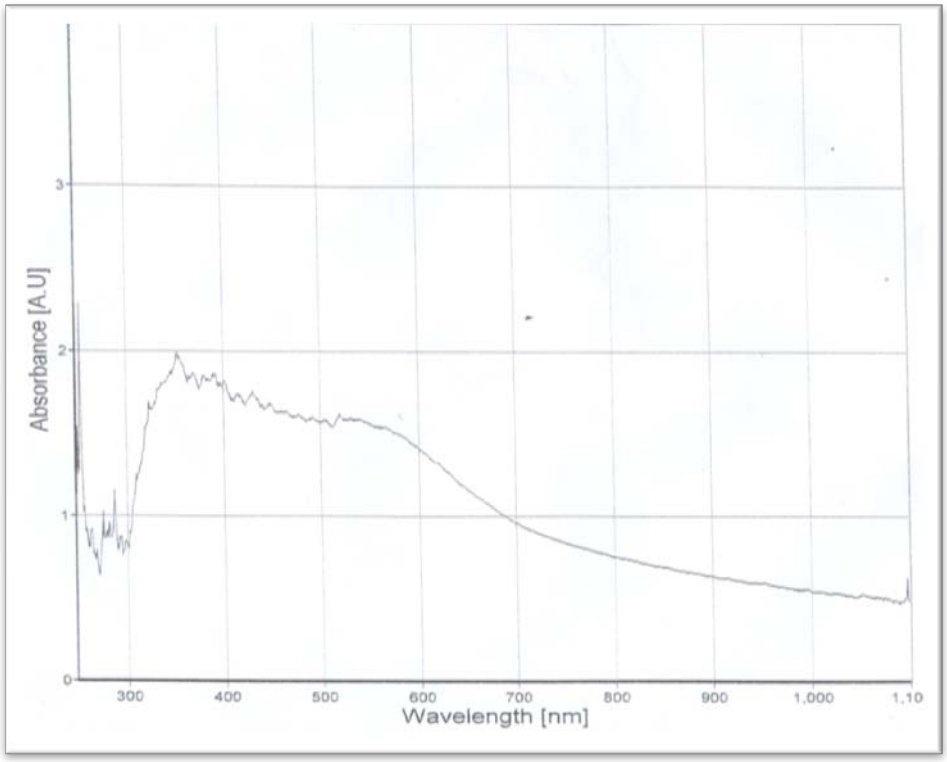

Fig. 4. Optical absorbance of prophyrin-stained TiO_2 electrode

Fig. 5 and Fig. 6 are the photocurrent-voltage characteristics of DSSCs fabricated with the *prophyrin*-dyed and un-dyed electrode respectively. The cell parameters obtained for the *prophyrin*-dyed cell were; open circuit voltage (0.26V), short circuit photocurrent (0.6mA/cm^2), fill factor (0.72) and photoelectric conversion efficiency (0.11%) while the results obtained for the plain cell were; open circuit voltage (0.24V), short circuit photocurrent (0.20mA/cm^2), fill factor (0.63) and photoelectric conversion efficiency (0.03%). The performance of the dyed cell could be compared to the results obtained by Sirimanne et al, 2008.

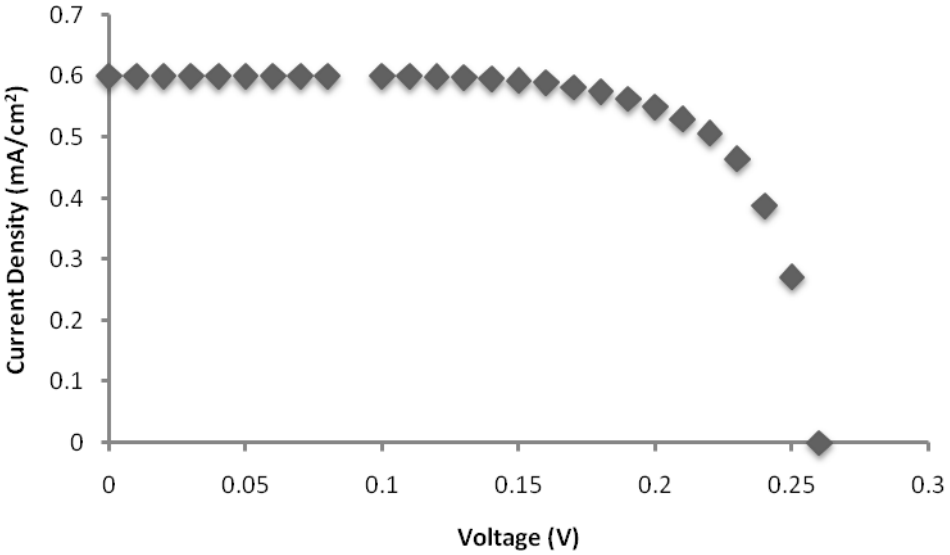

Fig. 5. The I-V curve for cell sensitized with the prophyrin dye

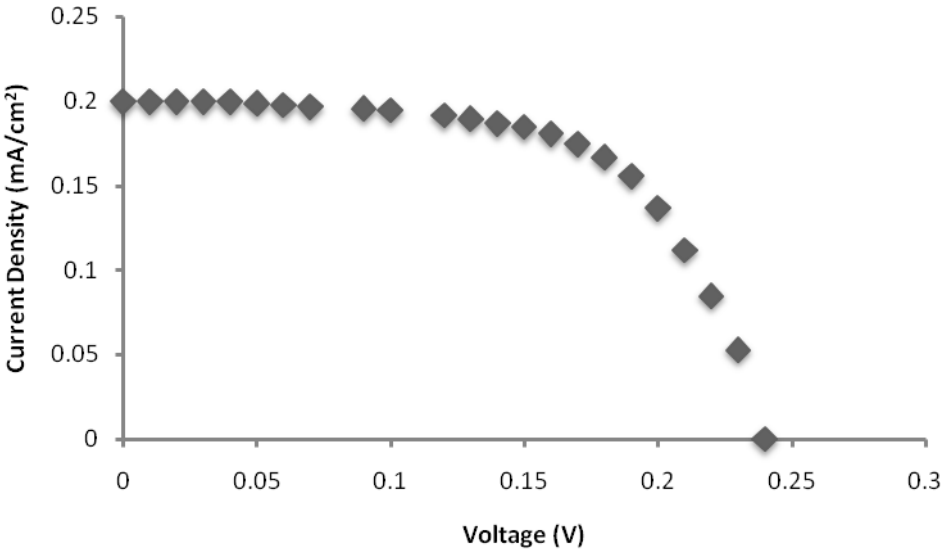

Fig. 6. The I-V curve for the plain cell

Figs. 7, 8, 9, 10 and 11 are the results of the outdoor power variation study. The *prophyrin*-dyed cell was relatively stable, and as well, performed better than the plain cell. The poor result obtained on the second day was as a result of weather condition.

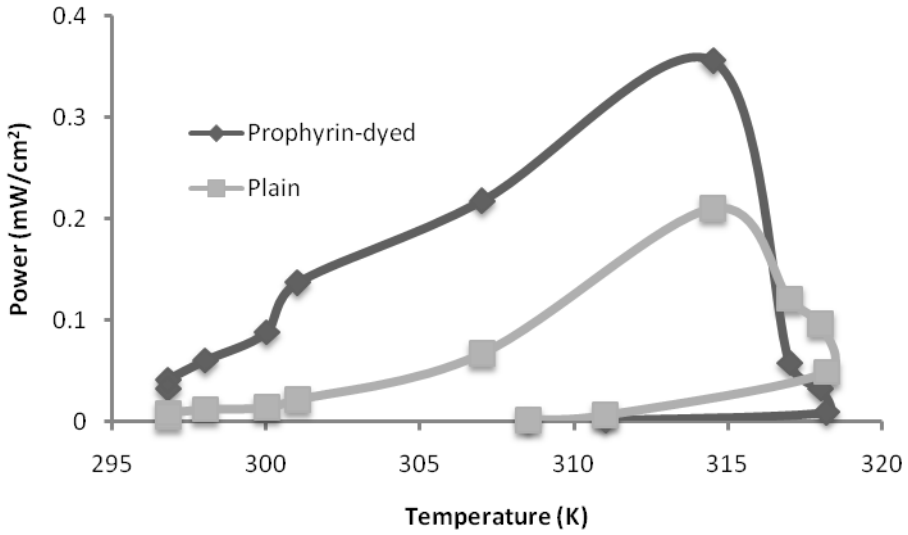

Fig. 7. Power-temperature curves for the prophyrin-dyed and plain cells (Day 1)

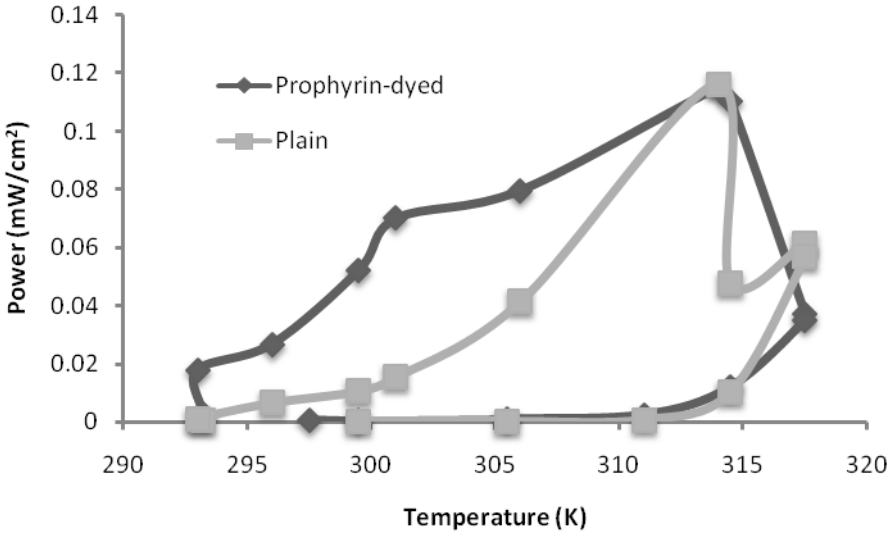

Fig. 8. Power-temperature curves for the prophyrin-dyed and plain cells (Day 2)

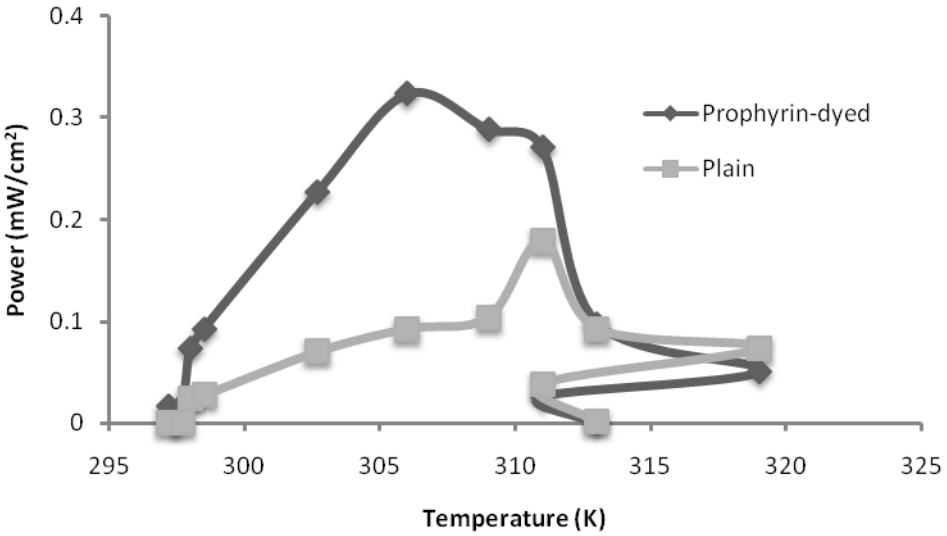

Fig. 9. Power-temperature curves for the prophyrin-dyed and plain cells (Day 3)

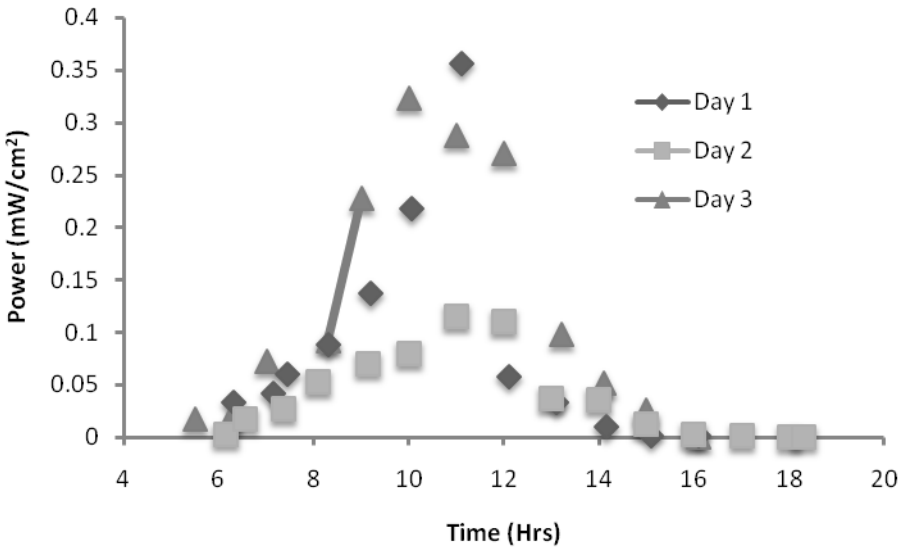

Fig. 10. Power-time curves for the prophyrin-dyed cell (Days 1, 2 and 3)

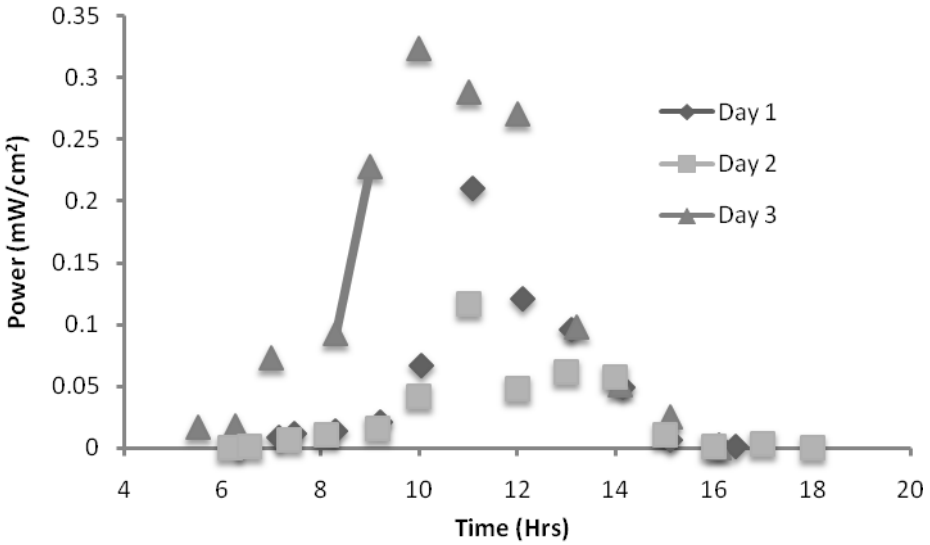

Fig. 11. Power-time curves for the plain cell (Days 1, 2 and 3)

4. Conclusion

Dye sensitized solar cells using *prophyrin*-stained and unstained electrodes have been successfully fabricated. The incident solar light to electric energy conversion efficiency was found to be 0.11% and 0.03% for the *prophyrin*-dyed and un-dyed solar cells respectively. The efficiency of the cells depend on the optical absorbance of the TiO_2 layer. The poor absorption of solar radiation by the plain cell (despite comparable high surface area) reduces the injection efficiency of carriers, and thus leads to poor photovoltaic performance. Hence, the local dye extracted from carica papaya leaves is a viable photo-sensitizer for nanocrystalline titanium dioxide electrode.

References

[1] B. O'Regan, M. Gratzel, Nature **353**, 737-740 (1991).
[2] 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).
[3] M. K. Nazeeruddin, P. Pechy, T. Renouard, S. M. Zakeeruddin, R. Humphry-Baker, P. Comte, P. Liska, L. Cevey, E. Costa, V. Shklover, L. Spiccia, G. B. Deacon, C. A. Bignozi, M. J. Gratzel, Am. Chem. Soc. 123, 1613-1624 (2001).
[4] Y. Chiba, A. Islam, Y. Watanabe, R. Komiya, N. Koide, L. Han, Jpn. J. Appl. Phys. **45**, 24-28 (2006).
[5] M. Gratzel, Acc. Chem. Res. **42**, 1788-1798 (2009).
[6] M. J. Gratzel, Photochem. Photobio. C: Photochem. Rev. **4**, 145 (2003).
[7] B. Li, L. Wang, B. Kang, P. Wang, Y. Qiu, Solar Energy Materials & Solar Cells, 549-573 (2006).
[8] R. D. McConnell, Reneweable and Sustainable Energy Reviewers, 273-295 (2002).
[9] S. M. Waita, J. M. Mwabora, B. O. Aduda, G. A. Niklasson, L. Sten-Eric, G. Claes-Goran, African Journal of Science and Technology, Science and Engineering Series **7**(2), 106 (2006).
[10] K. Tennakone, G. R. R. A. Kumara, K. G. U. Wijayantha, I. R. M. Kottegoda, V. P. S. Perera, G. M. L. P. Aponsu, Semicond. Sci. Technol. **13**(1), 134 (1998).
[11] K. Tennakone, G. R. R. A. Kumara, I. R. M. Kottegoda, V. P. S. Perera, P. S. R. S. Weerasundara, J. Photochem. Photobiol. A., Chem. **117**(2), 137 (1998).
[12] P.M. Sirimanne, and T. Soga, Sol. Energy Mater. Sol. Cells **80**, 383 (2003).
[13] P.M. Sirimanne, T. Shirata, T. Soga, T. Jimbo, J. Solid State Chem. **166**, 142 (2002).

[14] P. M. Sirimanne, V. P. S. Perera, Phys. Stat. Sol(b) **245**(9), 1828 (2008).
[15] P. Suri, M. Panwar, R. M. Wehra, Materials Science – Poland **25** (1), 137 (2007).
[16] Y. Lee and M. Kang, Materials Chemistry and Physics **122**, 284 (2010).
[17] S. Meng, J. Ren, E. Kaxiras, Nano Letters. **8**(10), 3266 (2008).