Performance of Fungal Dyes in Dye Sensitized Solar Cells as Photosensitizers

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ABSTRACT

Dye sensitized solar cell (DSSC) is a device used to convert light energy to electrical energy based on sensitization of dye molecules. Recently, numerous studies have been carried out to find natural dyes as the sensitizer. Eco friendly, low cost DSSC was fabricated using natural dyes extracted from two fungal species isolated from compost. Fungal dyes were extracted with acetone and UV-Vis absorption was characterized by UV-Vis spectrophotometry. To determine the performance and the stability of dyes, short circuit current density (J_{sc}) and open circuit voltage (V_{oc}) were recorded by dipping electrodes in dyes for 24 and 48 h. The open circuit voltage (V_{oc}) and short circuit current density (J_{sc}) of dye extracted from *Aspergillus* sp. at 24 h were 463 mV and 7.06×10^{-5} A/cm^{-2} while 491 mV and 2.41×10^{-5} A/cm^{-2} at 48 h respectively. V_{oc} and J_{sc} of the dye extracted from *Penicillium* sp. were 559 mV and 3.71×10^{-5} A/cm^{-2} at 24 h while 558 mV and 2.937×10^{-5} A/cm^{-2} at 48 h. There is a clear variation of conversion efficiency (η) in both dye solutions between dipping time periods. Therefore this study revealed that fungal dyes are suitable as photosensitizers on DSSC fabricated by gel polymer electrolyte. The dye extracted from *Penicillium* sp. is more effective and more stable than the dye extracted from *Aspergillus* sp.

KEYWORDS: Conversion efficiency, Current density, Dye sensitized solar cell, Natural dye, Voltage

INTRODUCTION

The mostly used energy resources at present are fossil fuels and nuclear energy. The excessive consumption of fossil fuels during the last few decades and uneven distribution of fossil fuels in the world have led to serious environmental issues, primarily together with many other pollutants. Nuclear power is also caused for some safety issues associated with radioactive waste disposal (Abbott *et al.*, 2010). So the development of renewable and environmental friendly energy source is essential to overcome these problems. Solar energy is a good, alternative, renewable energy source and the solar cells provide a convenient method to convert solar energy directly into electricity. However the major issue of this solar energy is the high cost of production of Si-based solar cell at present. Therefore the development of low cost, dye sensitized solar cells (DSSCs) has a great potential to offer a reliable method to convert solar energy to electricity (Bandara *et al.*, 2013).

Dye sensitized solar cell is a device based on the sensitization of wide band gap semiconductors using dye molecules. Recently, DSSCs have received an enormous attraction due to their promising solar energy conversion ability (Kim *et al.*, 2013). Dye molecules are the key component of a DSSC to have an increased efficiency through their abilities to absorb visible light photons (Jiao *et al.*, 2011). Therefore the cell performance totally depends on the type of dye used as a sensitizer (Kim *et al.*, 2013). Dye sensitized solar cell designs involve transition metal coordinated compounds (e.g. Ruthenium complexes) as sensitizers because polypyridyl of their strong, visible absorption, long excitation lifetime and efficient metal-to-ligand charge transfer. But these types of synthetic dyes are having adverse impact on environment and also very expensive (Jiao *et al.*, 2011).

The development of alternative environmental friendly photosensitizers at low cost has become a scientific challenge. Recently, some researches have focused on developing DSSCs using easily available, dyes extracted from natural sources such as flowers, vegetables, fruits *etc.* as a photosensitizer (Kim *et al.*, 2013).

At present the natural dyes are obtained mostly from plant parts for photosensitizer (Sharma *et al.*, 2012). At present, bacterial and fungal dyes are widely used in the textile industry, leather industry and food industry (Lopes *et al.*, 2013). Early studies have confirmed the non-toxicity and biodegradability of the fungal pigments (Sharma *et al.*, 2012).

This study was conducted to investigate the possibility of using fungal dyes as a sensitizer in DSSCs fabricated by gel polymer electrolyte. Pigments produced by fungal species extracted from compost samples were used as photosensitizer for DSSC in this study. Further attempt was made to increase the dipping time of the electrodes in the dye solutions in order to extend the time for absorption. Thereby, it was aimed to investigate the performance variation of DSSCs.

MATERIALS AND METHODS

Experimental Site

This study was carried out in the Soil Science laboratory of Department of Plantation Management, Faculty of Agriculture and Plantation Management and Polymer Electronics Research laboratory of Department of Electronics, Faculty of Applied Sciences, Wayamba University of Sri Lanka from December 2015 to May 2016.

Fungal Culture

Compost samples collected from Regional Agriculture Research and Development Centre at Makandura, Gonawila were used to prepare a serial dilution series according to standard procedure. It was prepared up to 10^{-16}. The last four diluted compost solutions (10^{-13}, 10^{-14}, 10^{-15}, 10^{-16}) were cultured in antibiotic added Potato Dextrose Agar (PDA) media using the spread plate technique with two replicates. Then the plates were kept in an incubator at 28 °C for 3-4 days. Following this procedure, fungi were isolated and pure cultures were made on the same media. Out of all isolated fungal species, two deep colour pigment (Red and Black) producing fungi were selected for pigment extraction.

Extraction of Dye

These red and black dye samples were tried to dissolve in ethanol, acetone, acetonitrile and acetic acid. Acetone become the most successful solvent for these two fungal species. After extraction, these two dye samples were kept in culture tubes without exposure to sunlight until they were applied to the solar cell. These black and red colour dyes were used as the sensitizers in solar cell. Then dye solutions were characterized by UV-Vis absorption using a UV spectrophotometer.

Solar cell Assembly

Glass strips (FTO) were cleaned using standard methods. Titanium oxide (TiO_2) was weighed and ground for about one minute. Then, three drops of acetic acid were added and ground for a few minutes. One drop of Triton-X and three drops of acetic acid were added and the mixture was ground until it became a pulp. Then six drops of acetic and a few drops of ethanol were added into the mixture and grinding was continued until all TiO_2 particles were ground well. Few drops of ethanol were added time to time to the mixture while grinding. After preparing the TiO_2 paste, the electrodes were made by doctor blade method on FTO glass strips and drying was done in open air. When the electrodes were completely dried, 1 × 1 cm area was formed by scratching off the excess TiO_2 paste. Finally the electrodes were sintered at 450 °C temperature for 45 min. One set of sintered electrodes were dipped in black colour and red colour for 24 h separately. The other set was dipped in black colour and red colour dye mixtures for 48 h.

Gel polymer electrolyte (GPE) was prepared using poly(methyl methacrylate), ethylene carbonate, propylene carbonate and tetrapropylammonium iodide [PMMA (200 mg), EC (300 mg), PC (300 mg) and $Pr_4N^+I^-$ (400 mg)]. The ratio of $Pr_4N^+I^-$ to I_2 was 10:1. PMMA was weighed and put into a clean bottle with some acetone. Acetone was used to dissolve PMMA. It was heated at about 60 °C while stirring on a magnetic stirrer until acetone was evaporated. Then the other materials except I_2 were added and heated at about 80 °C while stirring until a viscous homogenous solution was resulted. After that, I_2 was added and again mixture was stirred for a few minutes.

Dye sensitized solar cells were fabricated by sandwiching GPE in the configuration FTO glass-TiO_2 -dye-GPE-Pt electrode. They were characterized by measuring photo current and voltage under the irradiation of 100 $mWcm^{-2}$.

The photoelectric conversion efficiency (η) was calculated using the following equation.

$$\eta(\%) = \frac{Jopt \times Vopt}{Pin} \times 100$$

Where, $Jopt$ and $Vopt$ are the optimum short circuit current density and optimum open circuit voltage respectively and Pin is the maximum light intensity.

The fill factor (FF) was calculated using the following equation.

$$FF = \frac{Jopt.Vopt}{Jsc.Voc}$$

where, Jsc and Voc are the short circuit current density and open circuit voltage.

RESULTS AND DISCUSSION

Identification of Fungus

The isolated pigment produced fungi were cultivated on PDA. Fungi were identified by key of illustrated genera of imperfect fungi (Barnett *et al.*, 1998). The red dye producing fungi was identified as *Penicillium* sp. while black dye producing fungi was *Aspergillus* sp.

UV-Vis Absorption Spectra

Figure 1 and 2 shows the UV-Vis absorption spectra of the fresh dye solutions extracted from *Aspergillus* sp. and *Penicillium* sp. The maximum absorbance of the dye solutions should be in between 380-700 nm (which is the visible range of the electromagnetic spectrum) in order to use the dyes for DSSCs. The wavelength of the maximum absorbance in *Aspergillus* sp. and *Penicillium* sp. dye solutions were 416 and 523 nm respectively. These absorbance readings showed that, both dye solutions can absorb solar light.

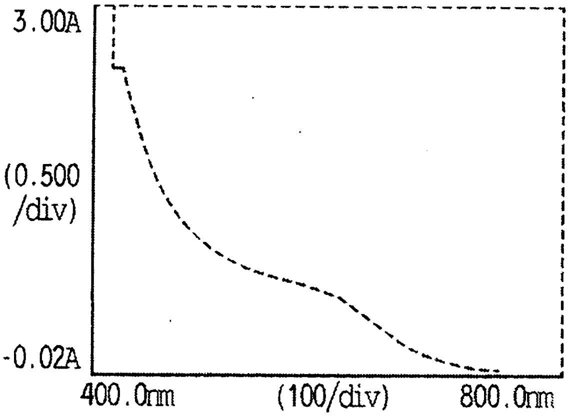

Figure 1. UV-Vis absorption spectra of *Aspergillus* sp. dye

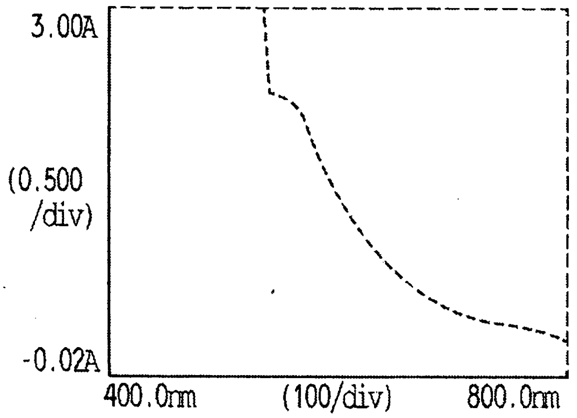

Figure 2. UV-Vis absorption spectra of *Penicillium* sp. dye

Solar Cell Characterization

The I-V measurements for the DSSCs fabricated with the two types of electrodes are shown in Figure 3 and Figure 4. The short circuit current density (J_{sc}) and V_{oc} were obtained for all types of DSSCs. When I-V characteristic curves of black and red dye solutions with electrodes dipped in dye solutions for 24 hours were compared, with the behavior of curve in *Penicillium* sp. dye solution is relatively better than the curve of the *Aspergillus* sp. dye solution. After dipping the electrodes for 48 h also the curve of DSSC with *Penicillium* sp. dye has higher performance than the curve for *Aspergillus* sp. dye.

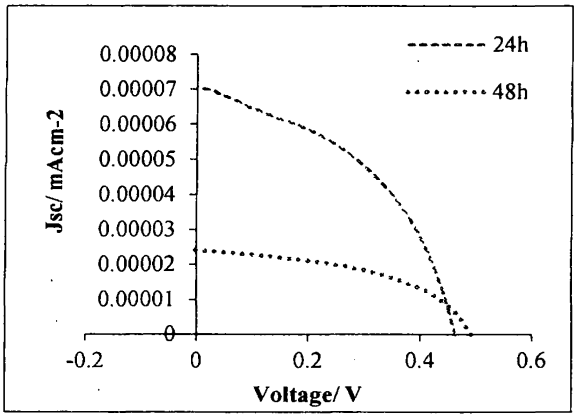

Figure 3. I-V characteristic curves of dye sensitized solar cells (DSSCs) with *Aspergillus* sp. dye dipping time 24 and 48 h

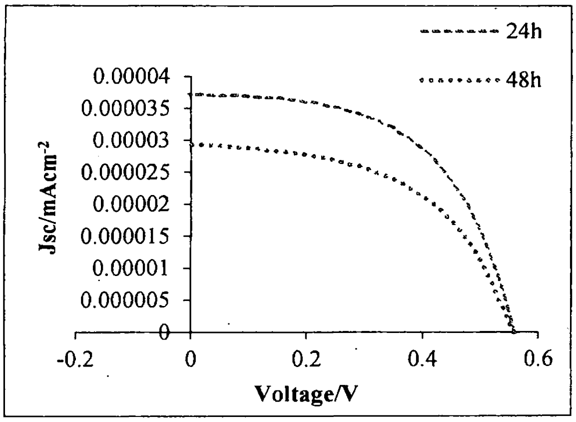

Figure 4. I-V characteristic curves of dye sensitized solar cells (DSSC) with *Penicillium* sp. dye dipping time 24 and 48 h

At 24 h, the open circuit voltage (V_{oc}) and short circuit current density (J_{sc}) in *Aspergillus* sp. dye were 463 mV and 7.06×10^{-5} A/cm^{-2} respectively. At 48 h V_{oc} and J_{sc} were 491 mV and 2.41×10^{-5} A/cm^{-2} respectively (Table 1). Although the current density has been reduced a bit, the voltage has been increased by this dye. Probably, this may be due to some unwanted reaction that takes place within the cell. With respect to η, dipping time of 24 h was seemed to be satisfactory but dipping the electrodes longer time has reduced η a lot. As other factors are reducing, a slight increment of FF is not becoming dominant. Open circuit voltage (V_{oc}) and J_{sc}, values of the two types of electrodes in red colour were observed to be more stable. Variation of η is little higher but, FF remains constant. It is clear that a considerable difference between the values of *Penicillium* sp. dye for different dipping time durations was not observed. The stability of DSSCs of *Penicillium*

Table 1. Solar cell characteristics of two dye solutions extracted from two fungal sp.

Variety of dye	After 24 h				After 48 h			
	V_{oc} (mV)	J_{sc} (A/cm^{-2})	η (%)	FF	V_{oc} (mV)	J_{sc} (A/cm^{-2})	η (%)	FF
Aspergillus sp. dye	463	$7.06* 10^{-5}$	0.0144	0.4427	491	$2.41* 10^{-5}$	0.0057	0.4801
Penicillium sp. dye	559	$3.71* 10^{-5}$	0.0114	0.5523	558	$2.937* 10^{-5}$	0.0085	0.5183

V_{oc} - Open circuit voltage, Jsc - Short circuit current density, η – Conversion efficiency, FF – Fill factor

sp. dye is seemed to be satisfactory due to less difference of values between 24 h and 48 h with.the observed values, confirming that the *Penicillium* sp. dye is more suitable than the *Aspergillus* sp. dye.

CONCLUSIONS

According to these results, it is possible to conclude that fungal dyes can be used as photosensitizers for DSSC fabricated with gel polymer electrolyte. The red dye extracted from *Penicillium* sp. is more appropriate than the black dye extracted from *Aspergillus* sp. based on overall performance of the dye solution extracted from *Penicillium* sp.

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