

Original Research Article

Photoelectric Characterization of Dye-Sensitized Solar Cells Using Natural

Dye from roselle plant (*hibiscus safdariffa*) as Photosensitizer

Abstract

Dye-sensitized solar cell (DSSC) was fabricated using natural dye extracted from roselle plant. The sensitization performance related to interaction between the dye and titanium dioxide (TiO_2) surface was evaluated under 100mWcm^{-2} light intensity. The DSSC based on the hibiscus sabdariffa organic dye gave a short-circuit current density (J_{sc}) of 0.0259mAcm^{-2} , open-circuit voltage (V_{oc}) of 0.432V and fill factor (FF) of 0.594 , yielding an overall efficiency (η) of 0.0067% .

Key Words: Dye sensitized solar cell, TiO_2 , organic dye, anthocyanin

Introduction

The most well-known and studied unconventional photovoltaic system is the dye-sensitized nanostructured solar cells. Incorporation of dye molecules in some wide bandgap semiconductor electrodes was a key factor in developing photoelectrochemical solar cells. Michael Gratzel and coworkers at the Ecole Polytechnique Federale de Lausanne (Gratzel, 2003; Nazerruddin *et al.*, 1993; O' Regan & Gratzel, 1991) succeeded for the first time to produce what is known as "Gratzel Cell" or the dye sensitized solar cell (DSSC) to imitate photosynthesis, the natural processes plants convert sunlight into energy by sensitizing a nanocrystalline TiO_2 film using novel Ru bipyridyl complex. In dye sensitized solar cell DSSC charge separation is accomplished by kinetic competition like in photosynthesis leading to photovoltaic action. The organic dye monolayer in the photoelectrochemical or dye sensitized solar cell replaces light absorbing pigments (chlorophylls), the wide bandgap nanostructured semiconductor layer replaces oxidized dihydro-nicotinamide-adenine-dinucleotide phosphate (NADPH), and carbon dioxide acts as the electron acceptor. Moreover, the electrolyte replaces the water while oxygen as the electron donor and oxidation product, respectively (Lagref. *et.al* 2008; Smestad & Gratzel, 1998). It has been shown that DSSCs are promising class of low cost and moderate efficiency solar cells based on organic materials (Gratzel, 2003; Hara & Arakawa, 2003).

DSSCs are based on the photo-injection of electrons from dye molecules into an inorganic semiconductor and holes transport by a redox mediator (Hagfeldt A., *et.al* 1995). The nanoporous structure of the inorganic semiconductor provides the large surface area necessary to achieve significant optical density of the solar cell despite the low light absorption of a dye monolayer (Parkinson B A, *et.al* 1992, Argazzi R, *et.al* 1996, Bonhote P, *et.al* 1996). However, the porous electrode also plays an important role in the enhancement of recombination processes in the DSSC, thus decreasing all cell parameters and its total conversion efficiency (Hagfeldt A., *et.al* 1996, Zaban A, *et.al* 1997, Bisquert J, *et.al* 1999). Since the electrolyte

penetrates throughout the entire porous structure, a large surface area is available for a reaction between the photoinjected electrons in the semiconductor and the oxidized ions in the redox mediator or oxidized dye at the semiconductor surface (Hagfeldt A., *et.,al* 1996, Tachibana Y , *et., al* 1996).

Major advantages of DSSCs are the large flexibility in shape, colour, transparency, and performance also under diffuse light. DSSCs could be integrated into large varieties of products, e.g. hand bags or clothing, indoor applications, and building-integrated photovoltaics such as roll-able devices for walls of buildings or windows. But many components of a DSSC remain to be optimized. We focus on the identification and usage of natural pigments as light harvesting elements in DSSCs. Natural pigments as photosensitizers in DSSCs have the potential to reach similar performances and stability as known from dyes based on metal complexes. It also has the disadvantage of lower efficiency than silicon cells and it is wet, so exposure to air degrades performance.

Photovoltaic performance

The dye used in dye-sensitized solar cells is extremely efficient at converting absorbed photons into free electrons in the titanium oxide layer. However, the current is limited to how many photons the dye can actually absorb. The photons that do get absorbed are the ones that ultimately produce the current. The rate at which the photons are absorbed depends on the overlap between the absorption spectrum of the titanium oxide layer (or other nanocrystalline oxide film used) and the solar flux spectrum. The maximum possible photocurrent is dependent on the overlap between these two spectra (Khalil Ibrahim Jasim 2011). In this paper, DSSC was prepared using natural dye extracted from rosella (*Hibiscus sabdariffa*) as sensitizers. The efficiency of the solar cell related to dye structures is discussed.

Experimental Section.

The FTO electrodes were washed with laury sulphate then later rinsed with water six times in an ultrasonication bath for 10mins then finally washed in propanol. The photoanode was prepared by first depositing a blocking layer on the FTO glass, followed by the nanocrystalline TiO₂. The blocking layer was deposited from a 2.5wt% TiO₂ precursor and was applied to the FTO glass substrate by spin coating and subsequently sintered at 500°C for 45mins. The 9µm thick nanocrystalline TiO₂ layer was deposited by screen printing. It was then sintered in air for 30mins at 500°C. The counter electrode was prepared by screen printing a platinum catalyst gel coating onto the FTO glass. It was then dried at 100°C and fired at 400°C for 30mins. The method of heating in water (*Aq.*) was used to extract the dye. Distilled water was the solvent for aqueous extraction. 5 g of the sample was measured using analytical scale and dipped in 50 ml of the solvent heated to 100°C for 30minutes after which solid residues were filtered out to obtain clear dye solutions. Roselle extract is rich in anthocyanins. It was reported that anthocyanin obtained from roselle are delphinidin and cyanidin complexes (T. Frank *et.,al* 2005, N. Terahara *et.,al* 1990). The chemical structure of cyanidin and delphinidin in the hibiscus sabdariffa dye is shown in figure 4a

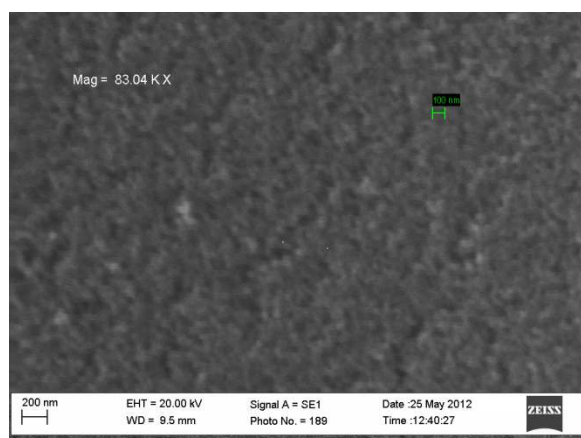
The sintered photo anode was sensitized by immersion in the sensitizer solution at room temperature overnight. Co-sensitization was achieved by immersing the photoanode in the extracts. The cells were assembled by pressing the photoanode against the platinum-coated counter electrode slightly offset to each other to enable electrical connection to the conductive side of the electrodes (fig 1). Between the electrodes, a 50µm space was retained using two

layers of a thermostat hot melt sealing foil. Sealing was done by keeping the structure in a hot-pressed at 100°C for 1min. the liquid electrolyte constituted by 50mM of tri-iodide in acetonitrile was introduced by capillary action into the cell gap through a channel previously fabricated at opposite sides of the hot melt adhesive, the channel was then sealed with an epoxy based 2 part resin.

Characterization

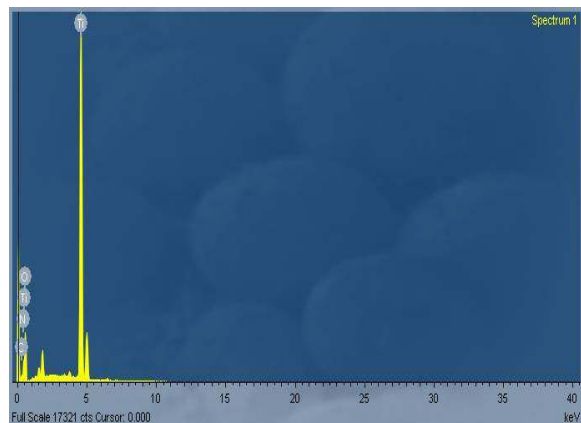
The current-voltage (I-V) data was obtained using a Keithley 2400 source meter under AM1.5 (100mW/cm²) illumination from a Newport A solar simulator. Scanning electron micrographs of the nanocrystalline TiO₂ films are taken with Carl Zeiss SEM. The absorption spectrum of the dye was recorded on Ava-spec-2048 spectrophotometer. The cell active area was 1.8cm². Thickness measurement was obtained with a Dektac 150 surface profiler. X-ray microanalysis was carried out with INCA EDX analyzer. Sheet resistance was obtained with a Signatone four point probe resistivity apparatus.

Results and Discussion



The Scanning electron microscope surface morphology of TiO₂ sample.

The SEM micrograph shows that the TiO₂ nanoparticles produced have a mean particle size of about 25nm. It also reveals that the surface is porous and has agglomeration.



EDX Image Showing the Elements Present in the TiO₂ Compound

The elements present in the TiO₂ are Titania, Chlorine, Oxygen and Nitrogen. Nitrogen is present due to the blower that was used to dry the TiO₂ semiconductor.

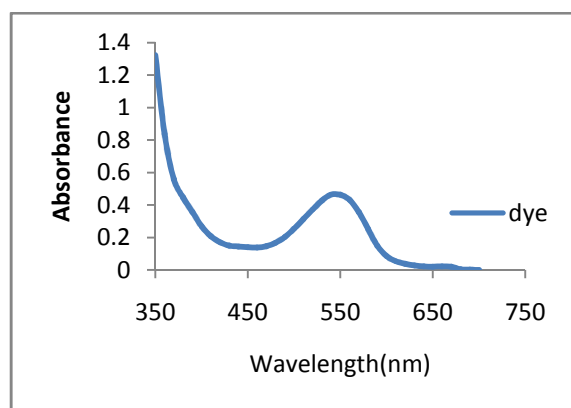


Figure 1a. UV-vis spectra of the dye

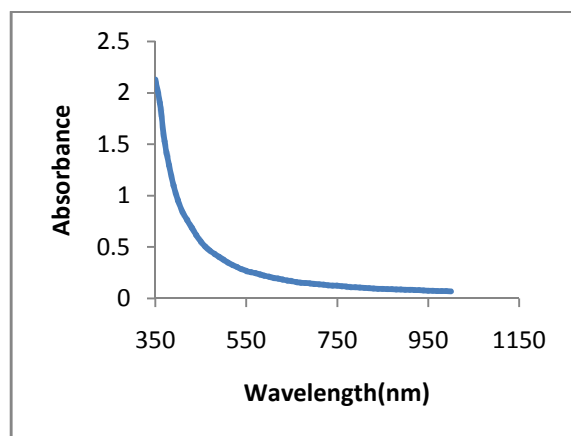


Figure 1b. UV-vis spectra of TiO₂ without dye.

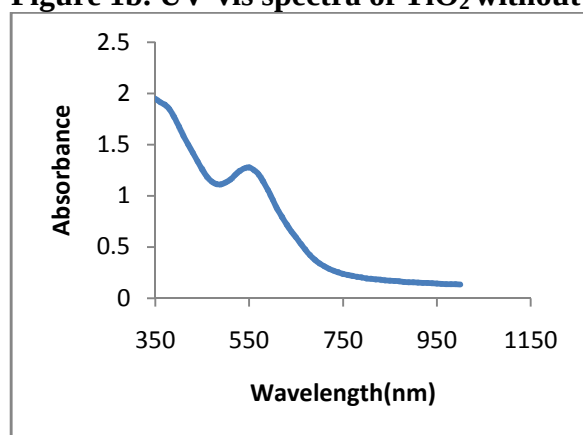
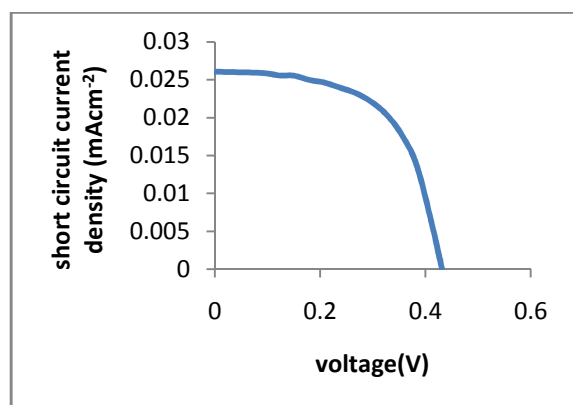


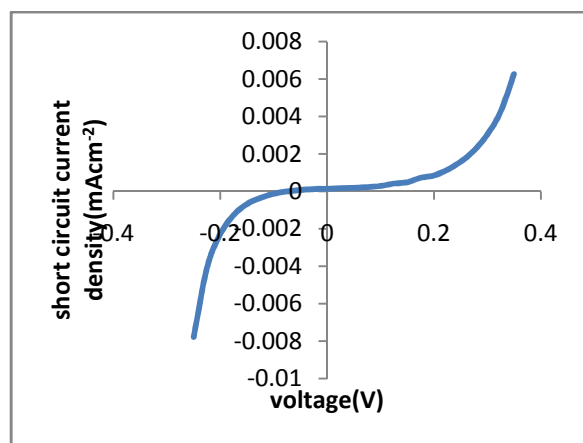
Figure 1c. UV-vis spectra of TiO₂ with dye

Figure 1 showed the absorbance of the dye and TiO₂ with and without the dye within the wavelength range of 350-1000nm. The absorption peak of the dye was observed around 550 nm (indicated in Fig 1a), and the optical absorption enhancement was observed in the dye-loaded

116 TiO₂ films. The relative changes in optical absorption of the TiO₂ film with and without dye are
 117 shown in Fig. 1b and 1c. The relatively broad and strong enhancement is observed in the range
 118 of 470–650 nm with a maximum peak around 550 nm, which coincides with the band position of
 119 decorated TiO₂ (Fig. 1c).



120
 121 **Figure 3a. Photocurrent density-voltage (*J-V*) curve under illumination.**



122
 123 **Figure 3b. Photocurrent density-voltage (*J-V*) curve without illumination**

125 This enhanced absorption and broadened spectrum absorption of figure 1c was mainly attributed
 126 to the interaction between the dye and TiO₂. These features suggest that dye molecules in the
 127 environment of TiO₂ can absorb more photons, presumably due to the spectral overlap between
 128 the dye and TiO₂.

129 Figure 3a showed the photocurrent density–voltage (*J-V*) curve of the DSSC under illumination
 130 and Figure 3b showed the *J-V* curve of the DSSC without illumination. In the dark, the cell
 131 behaves as a diode, and under illumination the *J-V* curve is shifted by the value of the current
 132 generated by the cell. Based on the *J-V* curve, the *fill factor* (FF) and solar cell efficiency (η)
 133 were determined following the equation:

$$134 \quad FF = \frac{P_{\max}}{P_{in}} = \frac{I_{\max} V_{\max}}{I_{sc} V_{oc}}, \quad \eta = \frac{FF \times J_{sc} \times V_{oc}}{P_{IRRADIANCE}} \cdot 100\%$$

135 Where $V_{\max}$ = maximum voltage (V); $I_{\max}$ = maximum current (mA/cm²); J_{sc} = short current
 136 density (mA/cm²); V_{oc} = open circuit V and P_{inc} = light intensity (W/cm²)

The open-circuit voltage (V_{oc}), short-circuit current density (J_{sc}), fill factor (FF), and overall conversion efficiency (η) are summarized in Table 1. Adenike *et.,al* 2013 once reported an obtained solar energy conversion efficiency of 0.002% using hibiscus sabdariffa extract. Better result was obtained using our proposed method. As shown in Fig. 3a and Table 1, the overall conversion efficiency was remarkably improved, which was caused by the used of distilled water as extracting solvent of the sensitizer which allows better chemical connections between the dye and the semiconductor and subsequently lead to donation of more conduction electrons into the conduction band of the semiconductor instead of ethanol as extracting solvent as used in there research.

Sample	$J_{sc}(\text{mAcm}^{-2})$	$V_{oc}(\text{V})$	FF	$\eta(\%)$
DSSC	0.0259	0.432	0.594	0.0067

Table 1. Performance characteristics of DSSC under 100mWcm^{-2} .

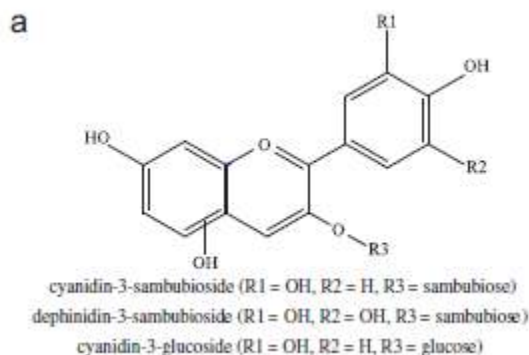


Figure 4a. Chemical structures of: cyanidin and delphinidin in rosell dye

Conclusions

Dye sensitized solar cell was prepared from anthocyanin extracts of hibiscus sabdariffa flower. The dye absorbs visible light in the range of 470nm to 650nm and its peak absorbance value was at 550nm. The dye is chemically connected to a porous layer of a wide band-gap semiconductor. The DSSCs employing the nanocrystalline TiO_2 as photoanode showed a power conversion efficiency of about 0.00670%. Poor charge transfer between the dye molecule and the TiO_2 due to low regeneration kinetics could be responsible for the low conversion efficiency of the cell Isah *et.,al* 2015.

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