Australian Journal of Basic and Applied Sciences, 9(37) Special 2015, Pages: 367-370

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Efficient Dye-Sensitized Solar Cells Using G. Atroviridis and E. Conferta Fruits

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ARTICLE INFO

Article history:
Received 10 October 2015
Accepted 30 November 2015
Available online 31 December 2015

Keywords:
solar cells; G. Atroviridis; E. Conferta; natural dyes, photovoltaic

ABSTRACT

Background: Dye-sensitized solar cells (DSSCs) were assembled by using the Eleiodoxa Conferta (*E. Conferta*) and Garcinia Atroviridis (*G. Atroviridis*) extracts as natural sensitizers of anatase-based nanostructure TiO_2 thin film coated on FTO conducting glass. Structural and optical properties of semiconductor thin film were characterized by X-ray diffractometer (XRD) and UV-VIS spectrophotometer respectively. The XRD shows single crystalline nanostructure for TiO_2 thin films. The photovoltaic properties have been investigated and the best overall solar energy conversion efficiency of 2.0% was obtained under AM 1.5 irradiation, with the *E. Conferta* extract that showed high current density (J_{sc} =2.31 mA/cm^2).

To Cite This Article: Jaafar and Madihan Yusof., Efficient Dye-Sensitized Solar Cells Using G. Atroviridis and E. Conferta Fruits. ***Aust. J. Basic & Appl. Sci.**, 9(37): 367-370, 2015*

INTRODUCTION

Dye-sensitized solar cells (DSSCs) are the third generation of photovoltaic devices for the conversion of visible light in electric energy based on the photosensitization of wide band-gap metal oxide semiconductors, (Liska and Vlachoupoulos, 1988), (Regan and Graetzel, 1991), (Graetzel, 2005). One aspect of these DSSCs photocells that is particularly attractive is the low cost of the solar energy conversion into electricity; this is possible mainly due to the use of inexpensive materials and the relative ease of the fabrication processes. In DSSCs, the dye as a sensitizer plays a key role in absorbing sunlight and transforming solar energy into electric energy. Numerous metal complexes and organic dyes have been synthesized and utilized as sensitizers. By far, the highest efficiency of DSCs sensitized by Ru-containing compounds absorbed on nanocrystalline TiO_2 reached 11–12%, (Chiba and Islam, 2006).

Recent studies have shown that metal oxides such as ZnO, Nb_2O_5, (Caramori and Cristino, 2010), SnO_2, (Fukai and Kondo, 2007) but mainly TiO_2, have been successfully used as photo-anode when a dye is absorbed in the interior of the porous layer, (Quintana and Edvinsson, 2007). The performance of DSSCs can be understood as a competition between two principal redox processes: electrons injection with rate constants of the order of picoseconds (10−15 to 10−12 s) and the regeneration of the oxidized dye with rate constants of the order of nanoseconds (10−7 to 10−9 s), (Lim and Lee, 2013). The injected electrons are transported through the TiO_2 film to a transparent electrode, while a redox-active electrolyte of I^-/I^3 − is used to reduce the dye cation charge and transport the resulting positive charge to a counter-electrode; however, before this, the photo-induced electron injection from the sensitizer dye to the TiO_2 film conduction band, initiates the charge separation, (Saji and Jo, 2011). In this sense, the sensitized dye acts as the photo driven electron pump of the device. Since the preparation of synthetic dyes normally requires multistep procedures, organic solvents and, in most cases, time consuming chromatographic purification procedures, there is interest towards the possible use of natural dyes which can be easily extracted from fruits, vegetable and flowers with minimal chemical procedures, (Sato and Murakami, 2004), (Fernando and Sendeera, 2008), (Lai and Su, 2008).

This research focus on the fabrication of dye sensitized solar cell by using extracts from the *E. conferta* and *G. Atroviridis* fruits as sensitizers. *E. Conferta* also called asam paya is a monotypic genus of flowering plant in the palm family found in Southeast Asia. This type of fruit can be found easily in rural area and never been commercialize. The mysterious of this exotic fruit also still unknown. *G. Atroviridis* (asam gelugor) an endemic species in Peninsular Malaysia, is a medium sized fruit tree that is widely used for seasoning purposes. *G. Atroviridis* exhibit strong antimicrobial, antioxidant and anti tumour promoting activities, (Mukram and Manaf, 2004). These types of fruits have been selected due

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to high acidity that can extract anthocyanin which play important role in DSSC and also never been reported by any researchers before. In this research, no waste will be produced due to all parts of the fruits will be used in this research. Therefore, our environment will not affected by any agro-based waste issue for this research.

Experiment:

Solid state dye –sensitized solar cell devices was prepared using dyes as photosensitizers, layer with nanocrystalline semiconductor oxide of TiO_2 deposited onto FTO coated glass as working electrode and carbon coated glass as counter electrodes respectively.

Preparation of TiO_2 Electrode:

The photoanode will be prepared by deposited the TiO_2 layer onto FTO conducting glass. The semiconductor paste prepare by blending 20g of TiO_2 nanopowder, 3 ml of 0.1M acetic acid and 20 ml of ethanol. The mixture will be stirred for 2 hours. Two edges of the FTO glass plate will be covered with a layer of adhesive tape. The TiO_2 will spread uniformly on the substrate by sliding a glass rod along the tape spacer. Then the coated plate will be annealed at 500°C for 30 minutes.

Preparation of Natural Dye Sensitizers:

E. Conferta and *G. Atroviridis* fruits will be grinded in mortar respectively. 30 ml of ethanol was added to the pastes and bring to boil for 30 minutes. The extract solutions will be filtered to remove solid fragments.

Graphite Coated Counter Electrode:

To prepare the counter (positive) electrodes, uncoated FTO plates were coated with carbon on the conducting side using a graphite rod or soft pencil to apply a light carbon film to the entire conductive side of the plate. Any loose graphite particles should be gently removed. This thin carbon layer serves as a catalyst for the triiodide-to-iodide regeneration reaction. For long-lasting the carbon-coated counter electrode was annealed at 450°C for a few minutes and washed with ethanol and gently blotted dry before the device is assembled.

Assembly of DSSC:

The TiO_2 coated glass will be soaked in natural dye for 24 hours for pigments stain. Then, the glass plate will be washed using ethanol and dried in air for few minutes. Next, the dye sensitized solar cells will fabricate by sandwiching the redox electrolyte between a dye adsorbed TiO_2 film electrode and coated counter electrode by firmly pressing. By illuminating the cells with a light source, the voltage across each individual can be measured.

RESULTS AND DISCUSSION

XRD Patterns of TiO_2 Thin Films:

The XRD patterns of *G. Atroviridis* and *E. Conferta* coated FTO electrode is shown in Figure 1 indicate that the films are crystalline. As is shown, *G. Atroviridis* and *E. Conferta* films exhibit high degree of crystallinity. By controlling the changes concentration of reactance, deposition time and medium of electrolyte, modification of grain size and thickness of *G. Atroviridis* and *E. Conferta* layer can be done, (Sirimanne and Zhang, 2008).

Absorption Spectra of pigment stained TiO_2:

Figure 2 shows the UV-VIS absorption spectra of pure TiO_2 coated on FTO conducting glass and the absorbed extracts on TiO_2 electrodes, TiO_2/*G. Atroviridis* and *TiO_2/E. Conferta*. The results indicate that the absorption on the TiO_2 electrodes using *E. Conferta*, the visible absorption band shifts to higher energy level, showing a broad maximum around 570 – 580 nm. Meanwhile for TiO_2 electrodes using *G. Atroviridis*, the highest peak around 575 – 590 nm. It shows that the acidic environment was important for obtaining sensitized photo-electrodes characterized by high optical densities, capable of wide absorption of visible photons in the 540 – 625 nm range. The chemical adsorption of these dyes accpeted to occur related to protonation of carboylic groups which are otherwise unable, in their anionic form to bind to the TiO_2 surface.

Photovoltaic Properties:

Figure 3 shows the variation of current-voltage curve of *G. Atroviridis* and *E. Conferta* based DSSCs. All experiments were carried out less than 1 sun illumination, (100 mW/cm^2 and air mass 1.5) with solid electrolyte. Table 1 shows the performance of natural dye as sensitizer in DSSCs was evaluated by short circuit current (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and energy conversion efficiency (η).

Based on Table 1, *E. Conferta* extracts produced promising photo electrochemical performance showing J_{sc} = 2.31mA/cm^2, V_{oc} = 0.35V, FF = 0.52 and η = 2.0%. This is due to the presence of high Anthocyanin content in the extract. With the help of Anthocyanin, the extract sticks onto the oxide surface and increases the light harvesting ability of the extract. The higher Anthocyanin contents in plant, the greater the rate of light harvesting ability and the efficiency of the cell. *G. Atroviridis* extract has least efficiency values compared to *E. Conferta* because of the low interaction between the extract and TiO_2 film. Based on Table 1, cell fabricated with raw extracts achieved highest power conversion efficiencies with maximum photocurrent, 2.31 mA/cm^2. Natural extracts produced low V_{oc} due to possible efficient electron/dye cation recombination pathways and the acidic dye adsorption environment, (Souad, 2013). The H^+ ions are potential determining ions for TiO_2 and that proton adsorption causes a positive shift of the Fermi level of the TiO_2, thus limiting the maximum photovoltage that could be delivered by the cells.

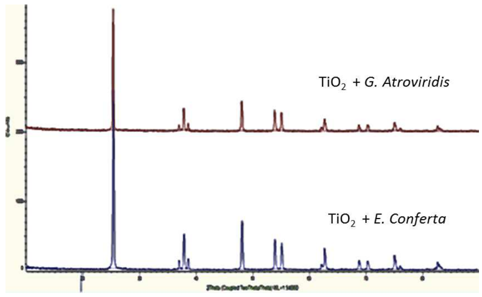

Fig. 1: XRD of TiO_2 coated FTO glass with G. Atroviridis and E. Conferta.

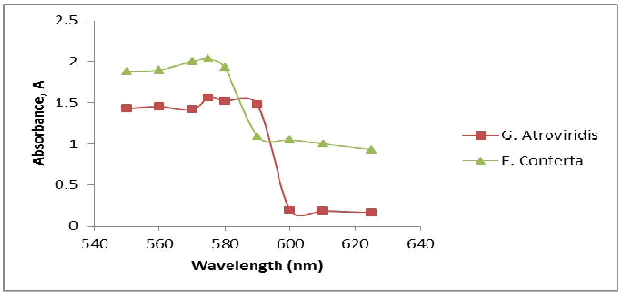

Fig. 2: Absorption spectrum of TiO_2 films adsorbed by *G. Atroviridis* and *E. Conferta.*

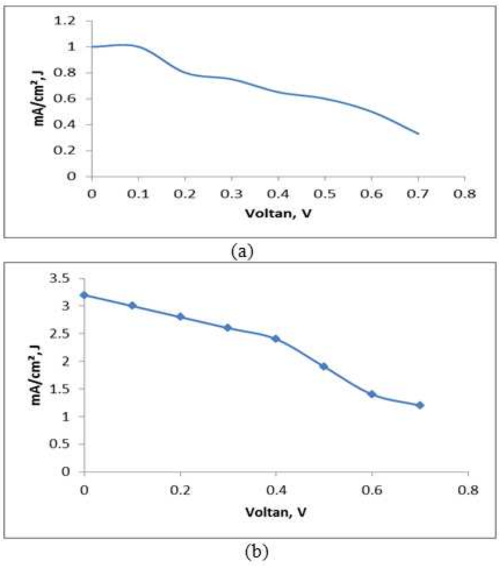

Fig. 3: Current-Voltage curve for; (a) TiO_2/ *G. Atroviridis*, (b) TiO_2/ *E. Conferta* extract sensitized solar cell.

Table 1: Photovoltaic performances of the cell.

Dye Source	Jsc (mA/cm^2)	V_{oc}/V	Fill Factor/ FF	Efficiency, η (%)
G. Atroviridis	0.53	0.35	0.32	0.30
E. Conferta	2.31	0.35	0.52	2.0

Conclusion:

In this work we have reported an investigation of two types of natural pigments extraction, *G. Atroviridis* and *E. Conferta* as natural dyes photosensitizers by describing and comparing their sensitization and Photoelectrochemical activities respectively. The raw pigments were extracted in acidic conditions from *G. Atroviridis* and *E. Conferta* achieved solar energy conversion efficiency of 2.0% which is the highest among all the sensitized cells.

Low V_{oc} and decreases in photocurrent due to dye degradation in natural dyes. Although the efficiencies obtained with these natural dyes are still below the current requirements for large scale practical application, the results are encouraging and may boost additional studies oriented to the search of new natural sensitizers and to the optimization of solar cell components compatible with such dyes.

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