Journal of Scientific Research & Reports
10(6): 1-5, 2016; Article no.JSRR.24786
ISSN: 2320-0227

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Photovoltaic Perfomance of Dye Sensitized Solar Cells Using Natural Dyes Extracted from *Bougainvillea* Flower and Mango Leaves

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Authors' contributions

This work was carried out in collaboration between all authors. Authors EJ and MYO designed the study, undertook the experimental work, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed literature searches. Authors ED, SGA and MSA managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2016/24786
Editor(s):
(1) Cheng-Fu Yang, Department of Chemical and Materials Engineering, National University of Kaohsiung, Kaohsiung, Taiwan.
(2) Luigi Rodino, Professor of Mathematical Analysis, Dipartimento di Matematica, Università di Torino, Italy.
Reviewers:
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(5) Afşin Kariper, Erciyes University, Turkey.
Complete Peer review History: http://sciencedomain.org/review-history/14358

Original Research Article

Received 1st February 2016
Accepted 16th April 2016
Published 27th April 2016

ABSTRACT

We reported an improved performance of a dye sensitized solar cells (DSSCs), sensitized with mango (*Mangifera indica*) leaves extract. Nano-crystalline titanium (TiO_2) film electrodes were sensitized with aqueous extract of *Mangifera indica* and *bougainvillea* extract. The resulting photoelectrodes were successfully incorporated in the DSSCs. The photovoltaic perfomance of the DSSCs were evaluated under 100 $mAcm^{-2}$ light intensity. The *Mangifera indica* extract sensitized solar cell gave a short circuit current density (J_{sc}) of 0.1314 $mAcm^{-2}$, an open circuit

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voltage (V_{oc}) of 0.49 V, a fill factor (*FF*) of 0.59, and an overall solar energy conversion efficiency (η) of 0.038%. Also, the *bougainvillea* flower extract sensitized cell gave a J_{sc} of 0.0134 mAcm^{-2}, V_{oc} of 0.36 V, *FF* of 0.51 yielding a conversion efficiency of 0.003%. This represents a 36% improvement in open circuit voltage over that of *bougainvillea*.

Keywords: DSSCs; natural dye extracts; sensitization; titanium dioxide (TiO_2).

1. INTRODUCTION

Photovoltaics is a promising renewable energy technology that converts sunlight to electricity, with broad potential to contribute significantly to solving the future energy problem that humanity faces [1,2]. The first generation photovoltaic solar cells based on silicon cells, although were able to achieve 24% efficiency but this requires complicated materials, processes and techniques of cells construction making it very expensive [3]. The second generation solar cells using thin layer of polycrystalline semiconductor, such as CdTe and CuIn1-xGaxSe$_2$ which is generally cheap, flexible and lightweight; however, the efficiency lower than 1st generation cells and also the toxicity of the materials is often a significant problem [4]. To date, semiconductor solar cells dominate commercial markets, with crystalline Si having an 80% share; the remaining 20% is mostly thin film solar technology, such as CdTe and CuIn1- xGaxSe$_2$ [5]. Currently, the third generation of solar cells based on nanostructured semiconductors, organic-inorganic composite material, was developed to achieve high efficiency with a more economical cost [6]. The discovery of DSSC based on TiO_2 by Oregan and Grätzel in 1991 [7] with an efficiency of 11% gives a very promising breakthrough in the field of solar cells. It is inexpensive to prepare, environmentally friendly, and the light-weight thin-film structures are compatible with automated manufacturing [8]. Despite offering relatively high conversion efficiencies for solar energy, typical dye-sensitized solar cells suffer from durability problems that result from their use of organic liquid electrolytes containing the iodide/tri-iodide redox couple, which causes serious problems such as electrode corrosion and electrolyte leakage. Consequently, it adversely affects long-term performance and durability. The efficiency and stability of DSSC system can be increase by the use of solid state organic or p-type conducting polymer hole-transport material (HTM) to construct a solid state dye-sensitized solar cells (SSDSC) [9]. Spiro-OMeTAD and bis-EDOT are 3 organic conducting polymer that provides highest performance in solid state solar cells. In comparison to the liquid electrolytes the efficiencies of SSDSC are inferior, they are around only 60% of the efficiencies obtained with the liquid electrolytes [10]. In optimizing the device performance and stability of SSDSC, various light harvesting systems are employed to enhance a photovoltaic performance and investigate their properties in SSDSC. The light respond of semiconductor could be improved by the use of sensitizing materials, including organic or organo-metallic dye, inorganic dye and quantum dot [11].

In this research work, extracts of *bougainvillea* flowers, and extract from *Mangifera indica* leaves were the natural dyes used as sensitizers in the DSSCs fabricated. The performances of the formed DSSCs show that, the *Mangifera Indica* extract has higher photosensitized performance as compared to the *bougainvillea* flower extract. This may be due to a higher intensity and broader range of the light absorption of the extract on TiO_2.

2. EXPERIMENTAL SECTION

2.1 DSSCs Assembling

The photoanode was prepared by first depositing a blocking layer on the FTO glass (solaronix), followed by the nanocrystalline TiO_2 (solaronix). The blocking layer was deposited from a 2.5 wt % TiO_2 precursor and was applied to the FTO glass substrate by spin coating and subsequently sintered at 400°C for 30 mins. The 9 μm thick nanocrystalline TiO_2 layer was deposited by screen printing. It was then sintered in air for 30 mins 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 30 mins. The leaves of *Magnifera indica* and the flower of *bougainvillea* were grinded to small particles using blender with water as extracting solvent to extract the dye solution.

The sintered photoanodes were sensitized by immersion in the sensitizer solution at room temperature overnight. Sensitization was achieved by immersing the photoanodes in the extracts. The cells were assembled by pressing the photoanode against the platinum-coated counter electrodes slightly offset to each other to enable electrical connection to the conductive side of the electrodes. Between the electrodes, a 50 μm 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 1 min. The liquid electrolyte constituted by 50 mmol of iodide/tri-iodide in acetonitrile was introduced by injection into the cell gap through a channel previously fabricated at opposite sides of the hot melt adhesive, the channel was then sealed.

2.2 Characterization and Measurement

The current-voltage (I-V) data was obtained using a keithley 2400 source meter under AM1.5 (100 mW/cm^2) illumination from a Newport A solar simulator. Scanning electron micrographs of the nanocrystalline TiO_2 films are taken with Carl Zeis SEM. The absorption spectrum of the dye was recorded on Ava-spec-2048 spectrophotometer. The cell active area was 0.5 cm^2. Thickness measurement was obtained with a Dektac 150 surface profiler. X-ray microanalysis was carriedout with INCA EDX analyzer.

3. RESULTS AND DISCUSSION

Fig. 1 shows the UV-vis absorption spectra of *bougainvillea* extract, and *mangifera indica* leaves extract. It was found that the absorption peak of *mangifera indica* leaves extract is about 380 nm while it was deduced that the *bougainvillea* extract absorbs photons best at a wave length peak of 360 nm (Fig. 1).

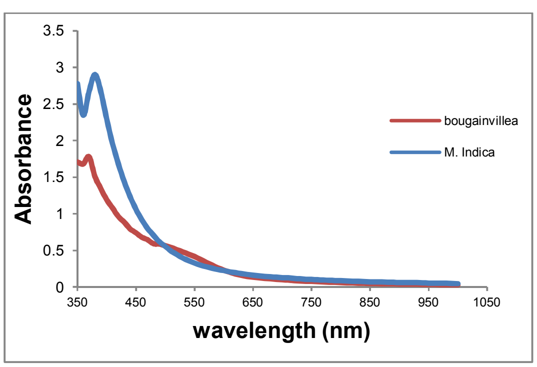

Fig. 1. Absortion spectra of *bougainvillea* flower extract and *Magnifera indica* leaves extract

Fig. 2a shows the SEM image of TiO_2 nanoparticles fabricated using screen printing method. The SEM micrograph shows that the TiO_2 nanoparticles produced have a mean particle size of about 20 nm. It also reveals that the surface is porous and has agglomeration.

Fig. 2b. Represents the EDX image of the TiO_2. The elements present in the TiO_2 are Titania, Oxygen and Nitrogen. Nitrogen is present due to the blower that was used to dry the TiO_2 semiconductor.

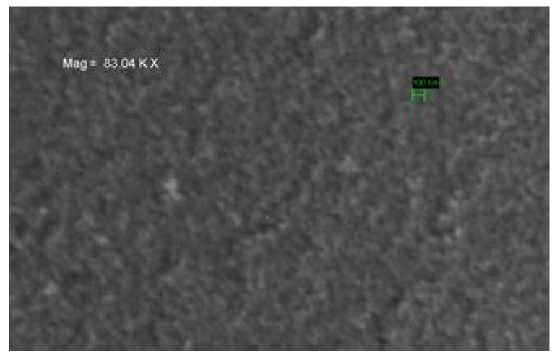

Fig. 2a. The scanning electron microscope surface morphology of TiO_2 sample

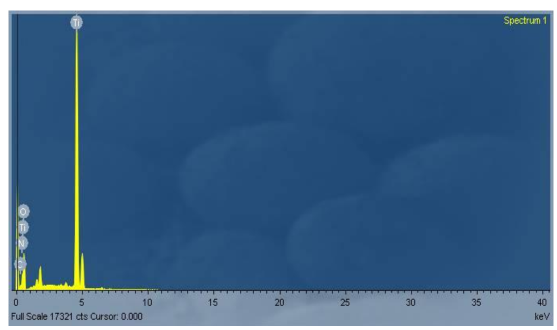

Fig. 2b. EDX image showing the elements present in the TiO_2 compound

Photovoltaic test of DSSCs using these natural dyes as sensitizers were performed by measuring the current–voltage (I–V) curves under irradiation with white light (100 mWcm^{-2}) from a solar simulator. The performance of natural dyes as sensitizers in DSSCs was evaluated by short circuit current (J_{sc}), open circuit voltage (V_{oc}), fill factor (*FF*), and energy conversion efficiency (η). The photoelectrochemical parameters of the DSSCs sensitized with natural dyes are listed in Table 1.

Table 1. Performance characteristics of DSSCs fabricated with different anodes under 100 mWcm^{-2}

Sample	J_{SC}(mAcm^{-2})	V_{OC}(V)	*FF*	η(%)
M. indica	0.1314	0.49	0.59	0.038
Bougainvillea	0.0134	0.36	0.51	0.003

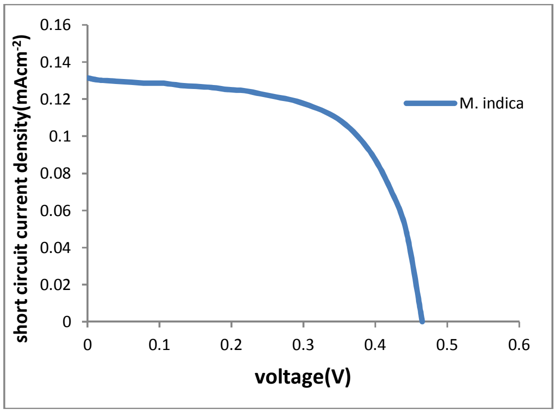

Fig. 3a. Photocurrent density-voltage (*J-V*) curve under 100 mWcm^{-2} light intensity

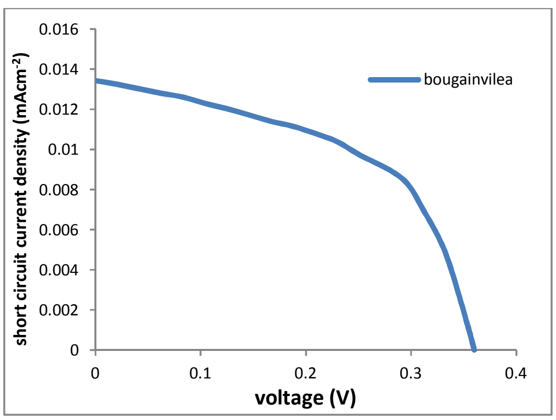

Fig. 3b. Photocurrent density-voltage (*J-V*) curve under 100 mWcm^{-2} light intensity

The typical J–V curves of the DSSCs using the sensitizers extracted from mango leaves and *bougainvillea* flowers are shown in Fig. 3a and Fig. 3b above.

Based on the curves in Fig. 3 the fill factor (FF) and solar cell efficiency (η) were determined following the equations:

$$FF = \frac{P_{MAX}}{P_{IN}} = \frac{J_{MAX} \times V_{MAX}}{J_{SC} \times V_{OC}} \quad (1)$$

$$\eta = \frac{FF \times J_{SC} \times V_{OC}}{P_{IRRADIANCE}} \times 100\% \quad (2)$$

Where,

V_{max} = maximum voltage (V);
J_{max} = maximum current density (mA/cm^2);
J_{sc} = short circuit current density (mA/cm^2);
V_{oc} = *open circuit* voltage (V) and
$P_{IRRADIANCE}$ = light intensity (mW/cm^2)

As displayed in Table 1 and Fig. 3a and 3b. a high V_{oc} (0.49 V) and *Jsc* (0.1314 mAcm^{-2}) were obtained from the DSSC sensitized by the *Mangifera Indica* leaves extract; the efficiency of the DSSC reached 0.038%. These data are significantly higher than those of the DSSCs sensitized by the second natural dye in this work. Yirga et al. [12] once reported a performance of a DSSC based on ethanol extract of *bougainvillea* spectabilis and found (V_{oc} of 0.20 V, J_{sc} of 0.088 mAcm^{-2}, *FF* of 0.374 and efficiency of 0.0066%). Their results was superior to our results (V_{oc} of 0.36 V, J_{sc} of 0.0134 mAcm^{-2}, *FF* of 0.51 and efficiency of 0.003%). The differences in the results is due to the extracting solvent used. Moreover, as shown in Table 1, the V_{oc} of the DSSC using the *mangifera indica* leaves extract as sensitizer is comparable to that of the DSSC sensitized by a *bougainvillea* flower. However, the DSSC sensitized by *mangifera indica* extract is mainly composed of chlorophyll in this work, which offers high conversion efficiency. This is because there are available bonds between the dye and TiO_2 molecules through which electrons can transport from the excited dye molecules to the TiO_2 film [13]. This result indicates that the interaction between the sensitizer and the TiO_2 film is significant in enhancing the energy conversion efficiency of DSSCs.

4. CONCLUSIONS

Sensitization of a dye solar cell with extracts of *bougainvillea* flowers and *Mangifera indica* leaves extract were demonstrated. The cell sensitized with *M. indica* leaves extract showed a lower J_{sc}, V_{oc}, *FF* and η. Using water as extracting solvent, the energy conversion efficiency (η) of the cells consisting of *bougainvillea* flower extract and *M. indica* leaves extract was 0.003%, and 0.038%, respectively. The *M. indica* extract has higher photosensitized performance as compared to the *bougainvillea* flower extract. This is due to the better charge transfer between the mango dye molecule and the TiO_2 surface which is related to a dye structure [12].

ACKNOWLEDGEMENT

The authors are grateful to the physics advanced laboratory, Sheda Science and Technology Complex (SHESTCO), Abuja, Nigeria for the use of their research facilities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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