Investigation of Effect of Electron Tunneling on the Photovoltaic Performance of Syzygium Anisatum Dye-sensitized Solar Cell

Temitope Abodunrin
Covenant University Ota Ogun State, Nigeria

Oluseyi Olanrewaju Ajayi
Covenant University Ota Ogun State, Nigeria

Patricia Popoola
Tshwane University of Technology

Electron Tunneling, Performance Analysis and Prospect of Micro-energy Generation in Ringwood (Syzygium Anisatum) Dye-sensitized Solar Cell

[1]T. J. Abodunrin, [2]O. O. Ajayi, [1]M. E. Emetere, [3]A. P. I. Popoola, [3]U. O. Uyor and [4]O. Popoola, *Member, IAENG*

Abstract— Energy continues to be the currency that drives all technology. Thus, the quest for energy remains vital to energy sustainability. In the wake of several adverse consequences of indiscriminate combustion of fossil fuel, there is an urgency to exploit our natural environment for ecologically benign alternatives. Ringwood also known as *S. anisatum* or Aniseed is a common sight in many ornamental gardens. It provides the customary thick layer of plush greenery typical of such settings. In addition, its characteristic aromatic leaves are capable of attaining a height of 45 metres. These attributes consolidated in the choice of Ringwood as a suitable candidate with a rich and viable store of solar energy. This gave the impetus to convert this *S.anisatum* store of photons of sunlight to electricity. Preliminary phytochemical screening results revealed the presence of phenols, flavonoids, tannins, glycosides, terpenoids and protein, a wide chromophore selection for charge transport. The study of *S.anisatum* absorbance-wavelength properties with UV/VIS spectroscopy shows *S.anisatum* dye extract having multiple peak absorbances with its optimum in the near ultraviolet region although, it absorbs optimally in the visible region of the electromagnetic spectrum. This is a Porphyrin dye characteristic, a desirable attribute that facilitates wider spectrum of solar energy absorption. The output photovoltaic performance of *S.anisatum* dye-sensitized solar cells revealed a short circuit current of 0.07 mA, fill factor value of 0.84 and the output efficiency was 0.027 % using KBr electrolyte. This is a comparatively good result considering previous records of dye-sensitized solar cell photovoltaic performance. The significance of these results from molecular perspective was explored with the aid of scanning electron microscopy (SEM). A need to boost the efficiency necessitated the interpretation of SEM micrographs with Gwwydion software. The presentation of possible areas for charge transport within the electron shells of *S.anisatum* dye nanocomposite, and regions where tunneling occurs provided a much needed insight for future studies. Consequently, this study is very instrumental in understanding the dual effect of charge transport/tunneling on output performance of dye-sensitized solar cell technology. The application is particularly relevant in modelling, photovoltaic simulations and energy efficiency models.

Index Terms— **bandgap, energy efficiency, energy harvesting, electron tunneling**

Manuscript received December 10, 2018; revised December 14, 2018.

T. J. Abodunrin is with the Covenant University Department of Physics P.M.B. 1023, Ota, Ogun State, Nigeria. phone:+2347030380040;e-mail:Temitope.Abodunrin@ covenantuniversity.edu.ng).

M. E. Emetere works at Department of Physics, Covenant University, P.M.B 1023, Ota, Ogun State, Nigeria. (e-mail: moses.emetere@covenantuniversity.edu.ng)

O. O. Ajayi is with Covenant University, Mechanical Engineering Department P.M.B 1023, Ota, Ogun State, Nigeria. (e-mail: oluseyi.ajati@covenantuniversity.edu.ng).

I. Introduction

Energy released by the sun in just an hour is sufficient to meet all mankind's energy needs annually [1]. A pertinent enquiry remains deploying the appropriate technological device to adequately harvest this energy crop for solving the growing needs of the teeming global population. A lot of research effort has been geared towards production and refinement of several technologies. The history of solar technology began from mimicry of biosynthetic process in plants, this led to the consequent manufacture of silicon solar panels [2]. Till date, silicon solar cells dominate the photovoltaic market. Their efficiency of 25% remains a very attractive feature despite a comparatively high cost, inability to withstand extreme temperature conditions, undeveloped methods for disposing of expired panels and a complicated manufacturing process [3]. These limitations prompted several studies aimed at obtaining cheaper substitutes for silicon solar cells yet combining salient photovoltaic efficiency output. This brought to the fore, an era of thin film production. They satisfied the basic condition, they were cheaper photovoltaics but, lacked the high efficiency characteristic of silicon solar cells. The films were cheap however, the equipment for depositing the films were quite expensive. In practice, the greater the accuracy, the higher the cost of equipment. In addition, technical know-how of operating this equipment was required for optimal performance [4]. It therefore seemed a breakthrough was in sight with the advent of dye-sensitized solar cell technology. They were distinguished by a low-cost price, uncomplicated process of manufacture, readily available raw materials, ability to withstand high temperatures and operation under conditions of diverse lighting, requires no special disposal system and ecologically benign [5]. This made dye-sensitized solar cells a prospective viable substitute for silicon solar cells but for the persistent challenge of poor efficiency and long- term stability [6]. A solution to the problem of poor efficiency came through the discovery of perovskite solar cells. Perovskite solar cells have recorded an efficiency of 18% with a promise of better output performance if the challenge of rapid deterioration in air and unfavorable redox reaction are addressed [7]. In view of this, present day energy research focus is directed at investigating suitable properties in dye-sensitized solar cells which may be incorporated in perovskite structures. This is hoped would usher in the future of photovoltaic technology. The incentive for this work lies in exploring the photovoltaic properties and performance of dye extracts of a common ornamental plant. The significance of this result is to utilize part of its energy store to perform work. Future research would benefit from examining co-sensitization of dyes incorporated on perovskite frames as a means of boosting the present output efficiency of dye-sensitized solar cells.

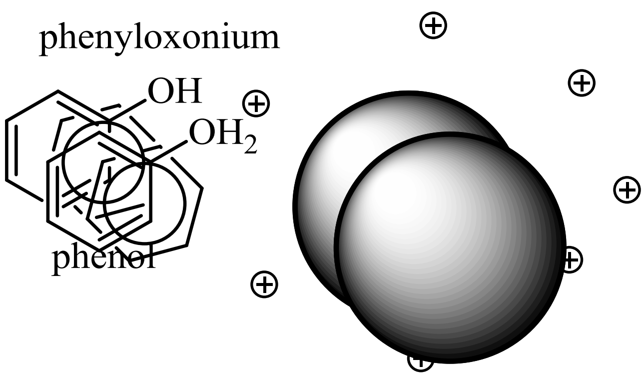

Fig. 1. Phenol chromophore's function in charge transport.

II. MATERIALS AND METHOD

A. Dye Extraction

200 grams of *S.anisatum* leaves were harvested and air dried until they assumed constant weight. The process of dye extraction followed standard procedures in methods [8]. The leaves were milled and spread out for some hours to eliminate vapor and discourage fungal growth. The dried coarse leaf flakes were then soaked using 2.5 litres of methanol in thin layer chromatography tanks to extract the dye. The pH of the solution was determined, the methanolic mixture was separated using a Stuart RE 300 rotary evaporator to obtain Ringwood dye.

B. Phytochemical Analysis

The phytochemical screening of *S.anisatum* was carried out under similar laboratory processes described by Najm et al., 2017. 1 g of *S.anisatum* was dissolved in 100 ml of distilled water and left for 24 hours. 2 ml of dye extract was added and vigorously shaken in 2 ml of distilled water (DW), presence of persistent layer of bubbles indicated the presence of saponins. 5 ml was dilute ammonia solution was added to 2 ml of dye extract, two drops of conc. H_2SO_4 was added to this mixture, a yellowish colour revealed the presence of flavonoid. 2 ml of dye extract was added to 1 ml of Molisch's agent in addition to two drops of conc. H_2SO_4 and shaken together, a purple colour indicated the presence of carbohydrate (CHO). 1 ml of dye extract was added to 2 ml of 5% ferric chloride, a greenish colour revealed the presence of alkaloid [9].

C. UV/VIS Spectroscopy

1 g of *S.anisatum* dye extract was dissolved in 100 ml of methanol, 10 ml was measured into a Cuvet. The calibration and standardization of the equipment was done and methanol was used as the reference liquid before the UV/VIS of the extract was obtained [10].

D. Scanning Electron Microscopy

S.anisatum was prepared by spreading 20 g of the extract on a plate, this specimen was mounted on the stage set-up and observed when electron signals are sent and back scattered as electrons. The signals are scanned and received by the secondary electron detector, they are sent to a monitor and the information obtained is the micrograph representation of the sample [11].

E. Photovoltaic Characterization of S.anisatum DSC

An active area of 1.68 cm^2 of indium doped tin oxide (ITO) was exposed to insolation. TiO_2 of Degussa 99.8 % assay was uniformly blended with conc. HNO_3 acid, to which a few drops of cellulose acetyl was added to facilitate the surface cohesion. This smooth paste was applied by doctor blade method onto the ITO conducting side. This was sintered using Vecstar furnace at 450^0C for 1.5 hours. The result was a TiO_2 photoanode. The counter electrode was prepared by, coating the conducting side of a second ITO slide with soot over a naked Bunsen flame in a simulated vacuum enclosure. The slides were allowed to cool at room

ISBN: 978-988-14048-5-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

temperature, then 0.1 ml of dye extract is then deposited on the TiO_2 photoanode. The two conducting slides are fastened with crocodile clips, two drops of iodine solution and liquid n-type electrolytes are inserted in-between the sandwiched slides [12]. This set-up was connected in parallel with a resistive load and multimeter according to Ohm's law and exposed to irradiation under 1.5 air mass conditions.

III. RESULTS AND DISCUSSION

A. Phytochemical Analysis

The phytochemical screening result revealed the following active chromophores: phenols, flavonoids, tannins, glycosides, alkaloids, saponins, terpenoids and protein. The pH of the solution was 5 and the most predominant phytochemical constituent is the phenolic content and its role is illustrated in Figure 1. It articulates with other functional ligands thus, extending the ancillary structure of *S.anisatum* in the DSC, this is the lengthening mode it uses to facilitate charge transport.

B. UV/VIS Spectroscopy

S.anisatum dye records peak absorbances at 350-400 nm and 680 nm respectively, this represents near ultraviolet and visible regions of the electromagnetic spectrum respectively as shown in Figure 2. Thus, the dye exhibits a porphyrin characteristic of absorption which implies that, it is absorbs optimally a large amount of solar energy. Previous studies show that the highest efficiency record was observed in porphyrin dyes.

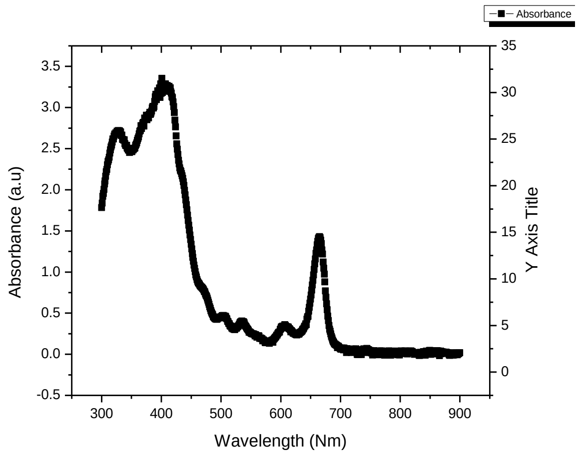

Fig. 2. UV/VIS of *S.anisatum* dye extract.

C. SEM Microscopy

The Scanning electron micrograph of *S.anisatum* reveals a multivariate non-crystalline structure as shown in Fig. 3(a). Using Gwwydion program software, it predicts the electron dynamics at the microstructural level further. The red dots signify the electron shells of *S.anisatum* dye. There are more electrons in the conduction band, the mid-region than at the peripheral sides. The external layer depicts the valence band of *S.anisatum* dye, where fewer electrons occupy. This is a departure from the norm, usually the converse occurs in most substances. The implication of this is that, the phenol's aromatic property aids the electron transitions from the valence band to the conduction band. The blue area indicates where electron tunneling occurs, these are possible recombination trap sites. The upper red dots signify the excited shells where are fewer still due to the band gap energy required to make the transition [13].

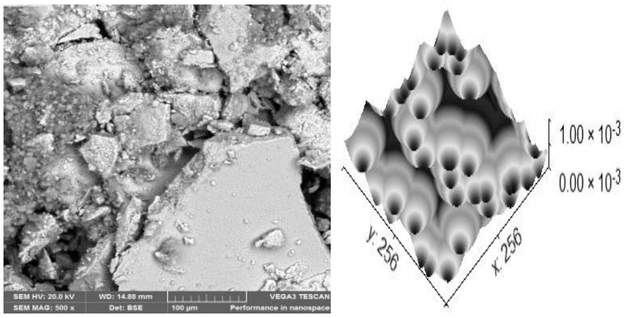

Fig. 3. SEM Micrograph of *S.anisatum* and the Gwwydion Plot.

D. Photovoltaic Characterization

The output performance of *S.anisatum* DSC was determined from the following parameters; short circuit current (I_{sc}) of 0.07 mA, open circuit voltage of 68.8 mV, fill factor (*ff*) value of 0.84 and the output efficiency (η) was 0.027 % as shown in Fig. 4. The *ff* and η were calculated from 1 and 2 respectively. Where A is active area (in metres) of ITO exposed to insolation and P_{in} represents the power intensity of the radiation (in Wm^{-2}).

$$ff = \frac{P_{max}}{I_{SC} V_{OC}} \quad (1)$$

$$\eta = \frac{I_{SC} V_{OC}}{P_{in} \times A} \quad (2)$$

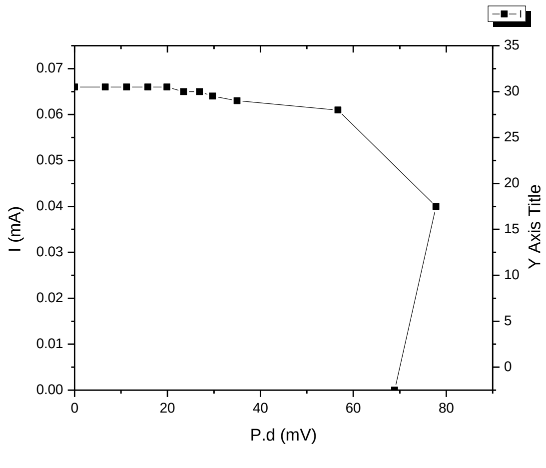

Fig. 4. I-V Curve of *S.anisatum* DSC.

E. Conclusion and Recommendation

1. *S.anisatum* DSC generated electricity from photons of sunlight under standard air mass condition of 1.5 atmosphere.
2. *S.anisatum* exhibited a rare porphyrin characteristic absorption which enabled it absorb radiant energy optimally.

ISBN: 978-988-14048-5-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

3. A fill factor of 0.84 indicates a high quality of DSC, this was further buttressed by the Gwwydion plot.
   The significance of this result is that, *S.anisatum* dye can be synthesized and grafted into optoelectric devices and fibers for application of its porphyrin effect in energy saving devices. S.anisatum dye could be co-sensitized with other dyes that have favorable kinematics to promote better redox reactions and increase the efficiency.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the technologists at department of Mechanical Engineering, University of Johannesburg, South Africa for their assistance with characterization of the samples. They also wish to convey their appreciation to the technologists in Physics laboratory of Covenant University for their assistance during the research. They are also grateful to Covenant University for the provision of the apparatus used for the completion of this work.

REFERENCES

[1] M. K. Nazeeruddin, E. Baranoff and M. Grätzel, Dye-sensitized solar cells: A brief overview. *Solar Energy*, vol. 85, pp. 1172–1178, 2011.
[2] A. Malik and E. Grohmann, Environmental Protection Strategies for Sustainable Development, Strategies for Sustainability, *Dyes-Environmental Impact and Remediation*, pp. 114-117, 2012.
[3] S. Ito, T. N. Murakami, P. Comte, P. Liska, C. Grätzel, M. K. Nazeeruddin and M. Grätzel, Fabrication of thin film dye sensitized solar cells with solar to electric power conversion efficiency over 10%, *Thin Solid Films*, vol. 516: 4613–4619, 2008.
[4] K. Kalyanasundaram and M. Grätzel, Artificial photosynthesis: biomimetic approaches to solar energy conversion and storage, *Current Topics in Biotechnology*, vol. 3, pp. 298-310, 2010.
[5] P. Melhem, P. Simon, J. Wang, P. Simon, J. Wang, C. Di- Bin, B. Ratier, Y. Leconte, N. Herlin-Boime, M. Makowska-Janusik, A. Kassiba and J. Boucle, Direct photocurrent generation from nitrogen doped TiO2 electrodes in solid-state dye-sensitized solar cells: towards optically-active metal oxides for photovoltaic applications. *Solar Materials and Solar Cells*, vol. 117, pp. 624-631, 2013.
[6] D. B. Menzies, Q. Dai, L. Bourgeois, R. A. Caruso, Y. Cheng, G. P. Simon and L. Spiccia, Modification of mesoporous TiO_2 electrodes by surface treatment with titanium(IV), indium(III) and zirconium(IV) oxide precursors: preparation, characterization and photovoltaic performance in dye-sensitized nanocrystalline solar cells. *IOP Nanotechnology*, vol. 18(12), 2007.
[7] H. Masood, J. Vahid and G. Afsahar, Dependence of energy conversion efficiency of dye sensitized solar cells on annealing temperature of TiO_2 nanoparticles, *Material Science in Semiconductor Processing*, vol. 15(4), pp. 371-379, 2012.
[8] T. Abodunrin, A. Boyo, M. Usikalu, L. Obafemi, O. Oladapo, L. Kotsedi, Z. Yenus, M. Malik, Microstructure characterization of onion (*A.Cepa*) peels and thin films for DSSCs. *Materials Research Express*, vol. 4, 2017.
[9] A. S. Najm, A. B. Mohamad and N. A. Ludin, The extraction and absorption study of natural dye from *Areca catechu* for dye sensitized solar cell application. *AIP Conference Proceedings*, vol. 1838(1), 2017.
[10] C. Longo and M. A. de Paoli, Dye-sensitized solar cells: a successful combination of materials. *Journal of the Brazilian Chemical society*, vol. 14(6), pp. 889-901, 2003.
[11] B. E. Hardin, H. J. Snaith and M. D. McGehee, The renaissance of dye-sensitized solar cells. *Nature Photonics*, vol. 6, pp. 162-169, 2012.
[12] L. U. Okoli, J. O. Ozuomba and A. J. Ekpunobi, Influence of local dye on the optical band-gap of titanium dioxide and its performance as a DSSC material. *Research Journal of Physical Sciences*, vol. 1, pp. 6-10, 2013.
[13] V. H. Nguyen, U. Gottlieb, A. Valla, D. Munoz, D. Bellet and D. Munoz-Rojas, Electron tunneling through grain boundaries in transparent conductive oxides and implications for electrical conductivity: the case of ZnO: Al thin films, *Materials Horizon*, vol. 4, 2018.

ISBN: 978-988-14048-5-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)