

Assembly of Dye-Sensitized Solar Cell using the Stem and Grain of Sorghum Bicolor as Sensitizers

Akingbade Fatai¹, Boyo Adenike^{2*}, Oluwole Surukite³ Abudusalami Ibrahim⁴

^{1,2}Department of Physics, Lagos state university, Ojo, Lagos, Nigeria

³Department of Botany, Lagos state university, Ojo, Lagos, Nigeria

⁴ Department of Chemistry, Fountain University, Oshogbo, Lagos, Nigeria

*Email Corresponding author: adenikeoboyo@gmail.com

Abstract

Red anthocyanins from sample A (stem of sorghum bicolor) and sample B (grains of sorghum bicolor) were employed as TiO₂ dye – sensitizers. Solar cells sensitized by the extracts of sample A achieved the following for outdoor measurement; I_{SC} = 0.0023mA/cm², V_{OC} = 0.0022V,

P_{max} = 3.666mV/cm², FF = 0.7212, η = 1.7554 and for sample B outdoor measurement FF = 0.7961, I_{sc} = 0.00178mA/cm², V_{oc} = 0.0014V, P_{max} = 4.96 x 10⁻⁶mW/cm² and η = 4.221 under the illumination of solar energy 4.7x10⁻³ W/cm² respectively. The indoor measurement values for the same dyes sensitized cells determined for sample A are I_{sc}=0.0182mA/cm², V_{OC} = 0.004 V;

P_{max} = 3.299 x 10⁻⁷ mW/cm², FF = 0.4512, η =0.15 and sample B achieved I_{SC} = 0.01378 mA/cm²; V_{OC} = 0.005 V, P_{max} = 3.5 x 10⁻⁷ mW/cm², FF = 0.5511 and η =0.18 respectively.

The results show that Sample B (indoor and outdoor measurement) has higher efficiency than sample A. This is due to the constituent of the extract .Sample A and B show a successful conversion of visible light into electricity by using natural dyes as band-gap semiconductor sensitizer in dye-sensitized solar cells .This can be use in large scale to reduce power and energy requirements for future industry designs.

Key Word: Sorghum Bicolor, Dye-sensitized solar cell, Solar light energy conversion, TiO₂

1. Introduction

One of the biggest challenges ahead of human kind is to replace the fossil fuel with renewable energy sources while keeping pace with the worldwide increasing thirst for energy because of the increasing population and rising demand from developing countries. This challenge has to be answered with a low-cost solution using abundantly locally available raw materials. The sun is an obvious source of clean and cheap energy, already used by nature to sustain almost all life on earth. Therefore, harnessing the power of the sun with the photovoltaic technologies appears to be the only reasonable large scale answer to the energy challenge (Hara et al 2003). Presently, the world energy consumption is 10Tetrawatts (TW) per year, and by 2050, it is projected to be about 30TW. The world will need about 20TW of non-CO₂ energy to stabilize CO₂ in the atmosphere by mid- century. The simplest scenario to stabilize CO₂ by mid-century is one in which photovoltaic (PV) and other renewable are used for electricity (10TW), hydrogen for transportation (10TW) and fossil fuel for residential and industrial heating (10TW) (Zweibel, 2005).Thus, PV will play a significant role in meeting the world future energy demand. Among varieties of renewable energy sources in progress is the solar cell. This means harvesting energy directly from the sunlight using photovoltaic. The solar cells that have recorded the highest photon to conversion efficiency are the first generation devices based on single silicon crystal (Belfar and Mostefaoui, 2011). The problem with this solar cell is their high cost production and installation. Various researchers (Konan et al, 2007, Bhatti et al, 2012) have work on second generation devices consisting of semiconductor thin film, in order to reduce the high cost of production and improve the efficiency of first generation solar cells, although the efficiency challenges has not been removed. The third generation solar cells are the dye sensitized solar cells, heterojunction cells and organic cells. These are similar to plants that used photosynthesis to absorb energy from sunlight (Zainudin et al 2011; Efurumibe et al, 2012). DSSCs use dyes or sensitizers” to convert sunlight into electricity (Gratzel et al 2003).

This study therefore intends to extract natural dye from the stem and grains of sorghum bicolor. Also to investigate the performance of solar cells fabricated using stems and the grains of sorghum bicolor as a sensitizer to convert solar energy into electricity. Sorghum bicolor is perhaps the world’s most versatile crop and grown across West Africa. This plant belongs to the family of proaceae .It is called Poroporo ,Oka-baaba in Yoruba, Kaara - Daawa in Hausa and Okri in Igbo . Sorghum plays an important role as a food security crop especially in semi arid lands of Kenya. It can survive drought conditions for some weeks by rolling up its leaves and this decreasing transpiration. The whole plant is often used as windbreaks, forage, hay, or silage. Their stems are used for building, fencing, weaving, broom making and firewood. The seeds are fed to poultry, cattle and swine (Tsuborama et al 1976). Figure 1 illustrates the physical appearance of this wonderful plant and its grain:



Fig. 1: Physical appearance of sorghum bicolor plant

2.0 Structure of Dye Sensitized Solar Cell

The main parts of single junction dye sensitized solar cell are illustrated schematically in figure 2. The cell is composed of four elements, namely, the transparent conducting and counter conducting electrodes, the nanostructured wide band gap semiconducting layer, the dye molecules (sensitizer), and the electrolyte. The transparent conducting electrode and the counter electrode are coated with thin conductive and transparent film such as fluorine-doped tin dioxide (SnO_2) (Gratzel et al 2005). The figure 3 below illustrates the red dye adsorbed onto a titanium dioxide surface (Martinson et al. 2008)

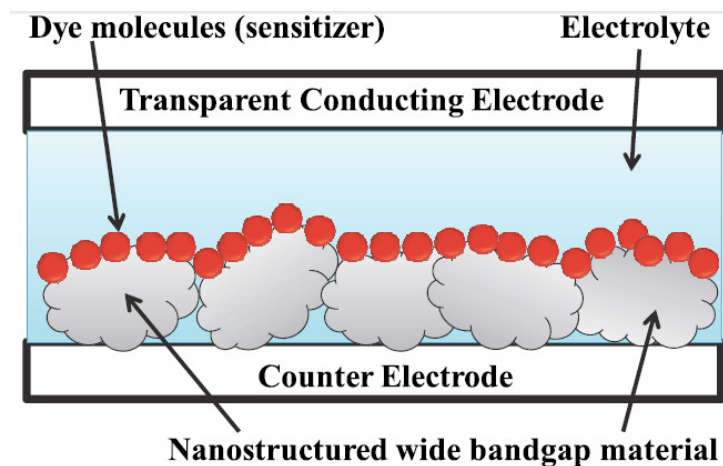


Figure 2: Schematic of the structure of the dye sensitized solar cell.

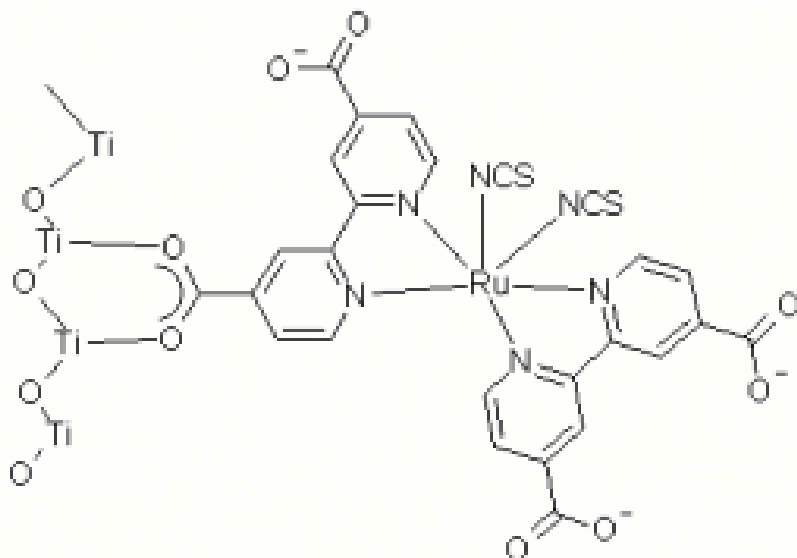


Fig. 3 : Red dye absorbed on a titanium dioxide surface

3.0 Method of Extraction

The stem and grains of sorghum bicolor were purchased from Lusada market, Igbesa in Ado- Odo/Ota Ogun State. Cold extraction method was used to extract the dye from sample A and B. This method was employed because distillation is possible at lower temperature and possibility of re-using solvent used for the extraction. 50g of the stem of sorghum bicolor labeled sample A and the grains of sorghum bicolor labeled sample B each were weighed using OHAUS Electronic weighing balance model brain weight B1500 made in USA and crushed with blender in order to increase the surface area of the samples to enhance speedy extraction. Each of the crushed samples were soaked in acidified 490cm³ of methanol (CH₃OH) i.e. 1% of 1Molar solution of HCL was added to 490 cm³ of methanol in separate covered bottles and placed inside SLAUART SSL1 ORBITAL SHAKER at 25rpm for 12hours. The mixtures were allowed to stay for another 12hours which made the soaking period to be 24hours.

The extract of each of the samples were decanted to remove the residual part of the samples.

Simple distillation was carried out at 65⁰C i.e. the boiling point of methanol in order to concentrate the dye of the samples.

This distillation process is necessary for the following reasons:

- To increase the concentration of the dyes
- To recover part of the solvent i.e. Methanol used for the extraction in its pure state which can still be re-used.

3.1.1 Measurement OF SAMPLE A AND SAMPLE B EXTRACT (DYE) OF pH

The measurement of the pH of the sample's extracts were carried out with JENWAY 3505 PH meter , PH 7.47 was obtained for the extract of sample A and PH 5.14 was obtained for the extract of sample B . These values are known as samples pH.

1.0ml from extract of sample A and B were measured and diluted with methanol to obtained PH 3.0 and 1 .0 respectively. Magnetic stirrer was used to enhance thorough mixing of the dilution.

3.1.2 Spectrophotometer Analysis

Spectrophotometer analysis of the extracts of sample A at the pH 7.47, 3.0 and 1.0 and sample B at the pH 5.14, 3.0 and 1.0 were carried out using SURGISPEC SM-23D surgifield medical spectrophotometer at the range of frequencies 350 to 1000nm which corresponds to the frequencies of visible light spectrum to obtained absorption rate of the extract . In order to have the absorption of the samples with TiO₂, 3ml of HNO₃ + 1ml of dye (either extract of sample A or B) + 1g of TiO₂ are taken. Also, Spectrophotometer measurement of 1g of TiO₂ + 3ml of HNO₃ was done. The corresponding absorbance -wavelength characteristics for all extract are shown in the figure 4 -9, absorption of the extract with TiO₂ is shown in figure 10 -12.

3.1.3 Fabrication Procedure OF Dye-Sensitized Solar Cell.

The TiO_2 solution (paste) was prepared by the incremental addition of 20ml of nitric acid solution to 20g of colloidal TiO_2 powder in a mortar and pestle while grinding for about 20minutes to enhance a uniform and lump-free paste.

A digital multimeter was used to check which side of the FTO glass purchased from HARTFORD GLASS COMPANY USA is conductive and the reading was 32.0Ω .

Adhesive –tape are applied to the face of the conductive glass plate in order to create on opening of dimension $1.5 \times 1.5\text{cm}^2$ at the centre of the glass. This tape formed about $40\mu\text{m}$ deep mold into which the TiO_2 solution can flow and at the same time masks a strip of the conductive glass so that an electrical contact can later be made. Three drops of TiO_2 paste was dropped at one edge of the opening and spread uniformly using glass rod. The film was then allowed to dry in air for 1minute. The tape was then carefully removed and the film was annealed and sintered in an oven at 100°C for 20 minutes. The TiO_2 –coated conductive glass was allowed to slowly cool to room temperature. The prepared TiO_2 - coated conductive glass which is called TiO_2 electrode was dipped into the dyes solutions for 10minutes. It was then taken out from the dye solution and washed with fresh methanol and allowed to dry for another 5minutes

3.1.4 Preparation of Counter Electrode

The counter electrode was prepared using a conductive glass of dimension $2.5 \times 7.5\text{cm}$ purchased from HARTFORD GLASS COMPANY USA.

The conductive surface of the glass was coated with carbon generated form candle flame. This serve as catalyst for the tri-oxide to iodide generation reaction .This electrode prepared is known as positive electrode (Anode). The stained dried electrode (cathode) was then placed on the table such that the film side faced up, and the catalyst- coated electrode (anode) was placed on the top so that the conductive side of the counter electrode faces the TiO_2 film. The two opposing glass plates are offset so that all of the TiO_2 is covered by the counter electrode and the strip of the glass not coated by TiO_2 was exposed. The two exposed sides of the glasses serve as cathode and anode respectively. Two binder clips were used to gently hold the plates together at the other edges. Two drops of iodide electrolyte solution of 0.5M was then placed at the edges of the plates binder clips are alternatively opened and closed while in place. The electrolyte was drawn into the place between the electrodes by capillary action and in order to wet stained TiO_2 film.

3.1.5 Measurement of Photoelectric Conversion efficiency of the DSSC

The completed solar cell was then taken outside under the illumination of sunlight to obtain the outdoor measurement for current and Voltage. A 50W, 12V halogen lamp manufactured by GE lighting, LLC Nela park assembled in USA was used obtain indoor measurement for current and Voltage using sorghum bicolor solar cell. Solar energy conversion efficiency (the photocurrent -voltage) was measured by using digital multimeters under the illumination of sunlight and 50W halogen lamp. The active area of the cell is $1.5 \times 1.5 \text{cm}^2$.The circuit diagram of the cells for the measurement of $I - V$ is shown in the figure 4.

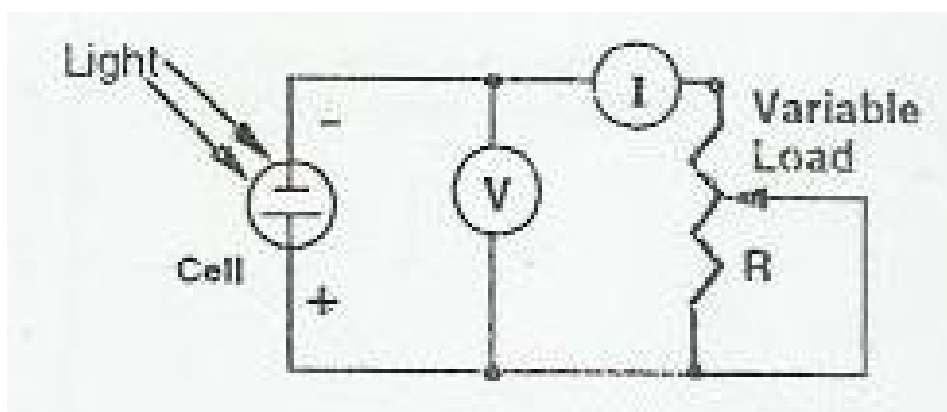


Figure 4: Circuit diagram for solar cells measurement

4.0 Results and Discussion

The figures 5-10 shows the acquired absorption spectra at the wavelength 350 – 1000nm of visible light spectrum for extract (dye) of sample A and sample B .we observed that only the extract (dye) of sample A according to figure 6 gives better absorption of 220 at wavelength 500nm which falls within the range of 400nm to 800nm parts of electromagnetic spectrum.

Extract (dye) of sample B also show absorption values of 1.488, 5.3 and 3.0 respectively at wavelength of 350nm which does not fall within the range of visible part of electromagnetic spectrum.

Absorption – wavelength characteristics of 1ml of extract (dye) of sample A and sample B mixed with three mills of HNO₃ on 1g of TiO₂ at the wavelength of 350 – 1000nm respectively are plotted in figure 11 – 13

Better absorption of visible part of electromagnetic spectrum was obtained with extract of Sample A. TiO₂ also showed a reasonable absorbance with HNO₃ at PH 1.00.It therefore showed that the extract of sample A absorbed visible part of electromagnetic spectrum than extract of sample B despite the fact that both samples are from the same source. This is due to the structure of the sample B extract resulting in a stronger steric hindrance for anthocyanin to form bond with oxide surface and prevents the anthocyanin molecules from arranging on the TiO₂ film effectively (Mor et al, 2006). Hence, this leads to a deficiency of electron transfer from the dye molecules in the conducting band of TiO₂ (Boyo et. al 2012).

Figures 14-17 is the photovoltaic performances that were obtained with a sandwich cell under illumination by simulated solar light (outdoor measurement) and 50W halogen lamp (indoor measurement). The photocurrent – voltage curves of the assembled solar cells are used to evaluate the cells performance.

Table 1 – 2 show the photo electrochemical parameters of the cells sensitized with natural extracts (dyes) of sample A and B for outdoor measurement and indoor measurement respectively. It was observed that the efficiency of cells assembled with extract of sample B is of greater value than sample A for the indoor measurement and outdoor measurement as shown in the tables 1-2. This shows that sample B has ability of harvesting solar energy than sample A

5.0 Conclusion

Successful conversion of visible light into electricity was achieved by red anthocyanins from the extracts of sample A and sample B as TiO₂ dye-sensitizers. The anthocyanins present in the extracts are capable to be chemically absorbed onto the semi-conductor surface, sensitizing it to the visible region of the spectrum even though extract of sample A has low absorption values. The energy of the dye excited state is also appropriate to promote the electron injection into the semiconducting band, consequently, converting the sunlight into electrical output. Therefore the use of natural dyes can be an alternative for a lower cost production of dye-sensitized solar cells, being environmentally friendly, renewable and clean source of energy. It is also useful to demonstrate several important scientific concepts (materials, semiconductors, molecules devices etc.) for educational purposes.

REFERENCES

- Belfar, A. and Mostefaoui (2011). Simulation of $n_1 - n_2$ microcrystalline silicon tunnel junction with AMPS – ID in a Si: H/NC – Si: tandem solar cells. *Journal of applied science*, 11: 2932 – 2939
- Bhatti, M. T., Rana, A .F. Khan and Ansarfi M. I (2012). Effect of annealing on electrical properties of indium Tin Oxide (ITO) Thin Films. *Journal of applied science*, Volume 2, 570-573
- Boyo A. O. Boyo H. O Shitta M.B.A, Abdusalam I., Fajana O.O and Awodibo M.A (2012). Fabrication of Dye - solar cells (DSSC) device using lawsonia intermis leaf, *international Journal of pure and applied physics*, Volume 8, Number 2 , 59 - 68.
- Efurfumibe, E.L., Asisgbu, A.D. and Onuu, M.U. (2012). Mathematical modeling of electron transport through the anode (TiO₂) of a standard dye sensitized solar cells. *Asian Journal of applied science* volume 5, 34 - 42.
- Gratzel, M. (2003). Dye-sensitized solar cells. *Journal of photochemical and photobiology C. Photochemistry review* 4, 145 -153
- Gratzel, M. (2005). Solar energy conversion by Dye-sensitized photovoltaic cells. In *org. Chem*, Vol. 44 pp. 6841 – 6851
- Hara, K. and Arakawa, H. (2003). Dye-sensitized solar cells, In: *Handbook of photovoltaic science and Engineering*, A. Luque ad s. Hegedus, (Ed); Chapter 15, pp. 663 – 700, John Wiley and Sous, LTd, ISBN: 0 – 471 – 49196 – 9.

Konan K. Soraka, J.K., Zouneu, J.I and Gbaha P., (2007). Structure and morphological analysis of CuInSe_2 thin films prepared by vacuum free CSVT for photovoltaics cells. *Journal of applied science* volume 7,478 - 483.

Martinson, A. B. F., hamann, T.W., Pellin, M.J, and Hupp, J.T., (2008). New architectures for dye-sensitized solar cells. *Chemistry - Eur. Journal*, Volume 14, 44578 – 4467.

Mor, G. K; Shanker, K., Paulose, M; varghedse, O.K and Grimes, C.A (2006). Use of highly ordered TiO_2 nanotube Arrays in Dye- sensitized solar cells. *Nonaletters*, volume 6, issue 2, 215 – 218.

Tsuboroma, H., Matsumura, M., Nomura, Y., Amamiya, T. (1976) *Nature* 261, 402.

Zainudin, S.N.F., Markom, H. Abdulah, R., Adami and Tasirm, S.A (2011). Supercritical anti - solvent process for enhancement of dye – sanitized solar cell efficiency: A review , *ASIAN. J. Applied sci.*, volume 41. 331 – 342.

Zweibeli K. and gree, M.A. (ed) (2005). *Progress in photovoltaics research and application* volume 8, issue I, 171 – 185.

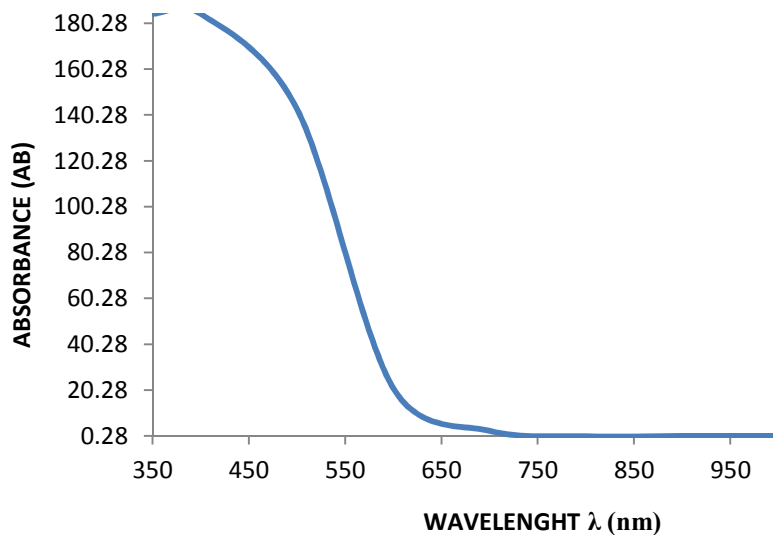


Fig.5: Light absorption spectra of Extract (dye) of sample A at PH 7.47

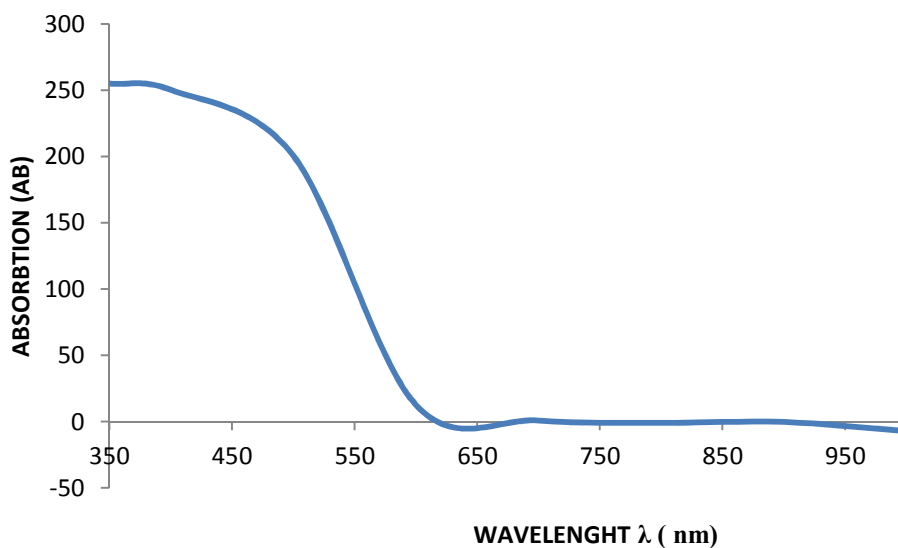


Fig. 6: Light absorption spectra of Extract (dye) of sample A at PH 3.00

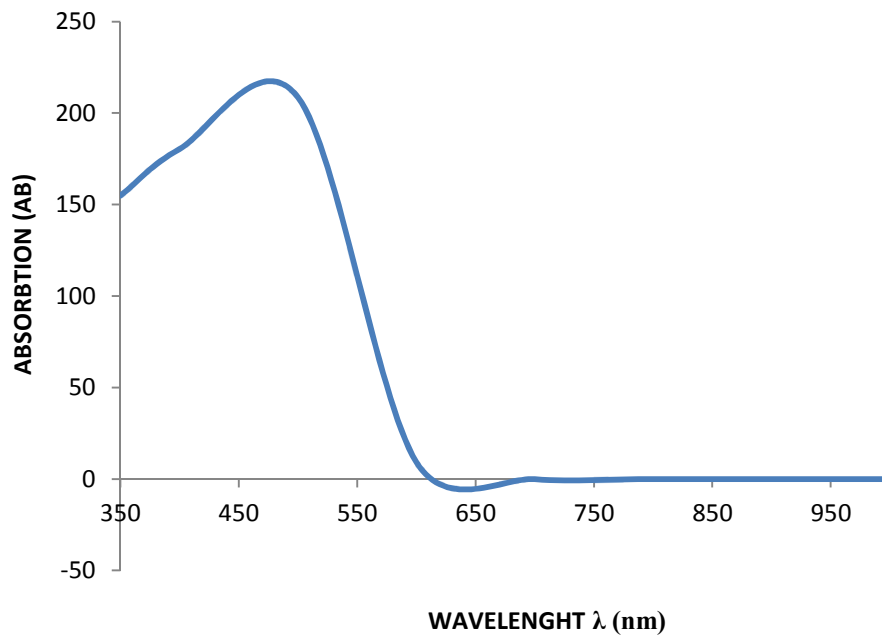


Fig. 7: Light absorption spectra of Extract (dye) of sample A at PH 1.00

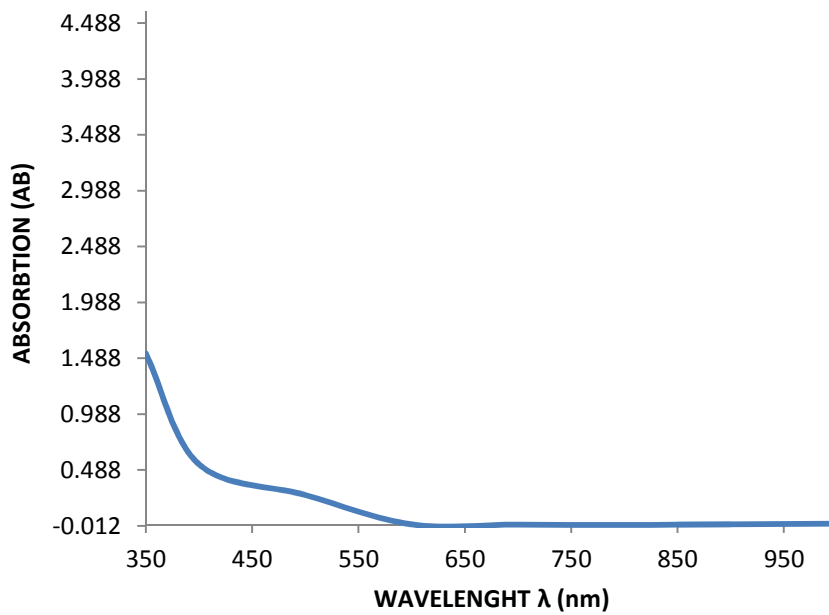


Fig8: Light absorption spectra of Extract (dye) of sample B at PH 5

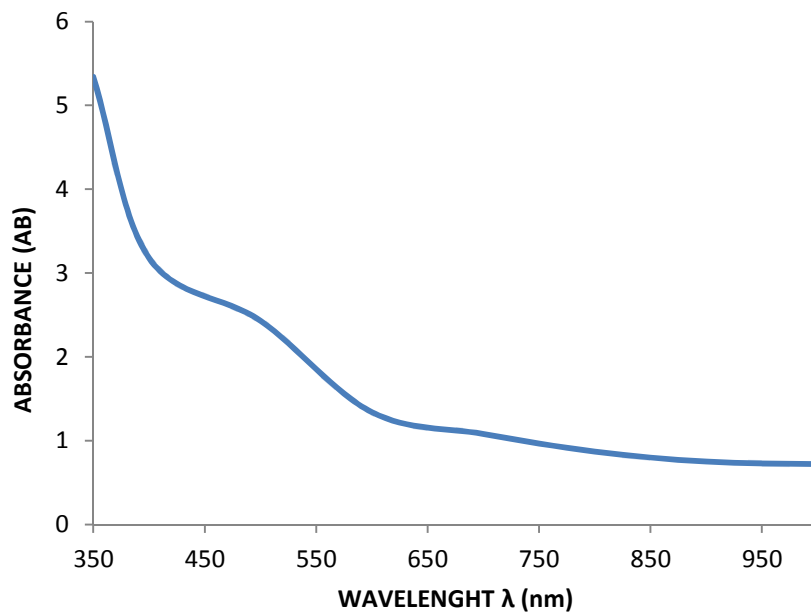


Fig. 9: Light absorption spectra of Extract (dye) of sample Bat PH 3.00

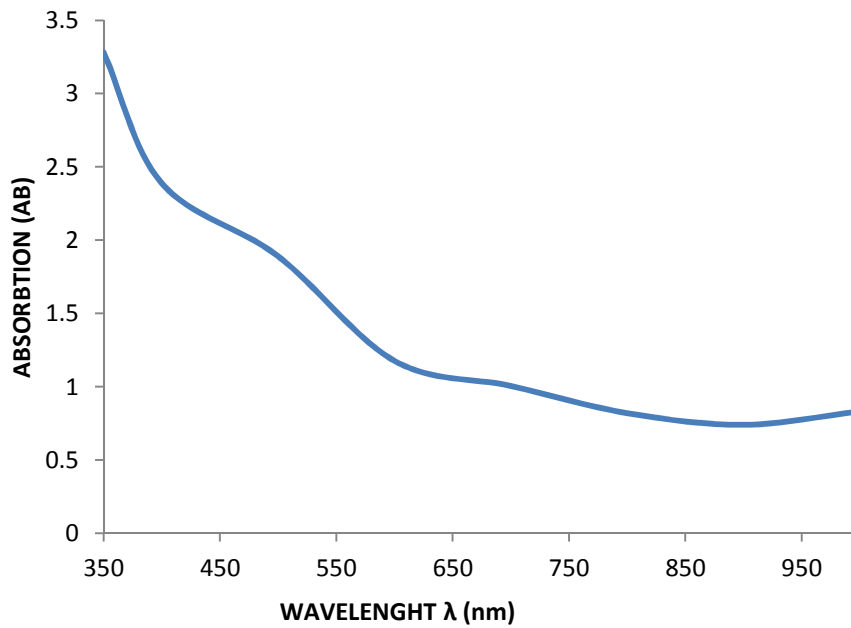


Fig. 10: Light absorption spectra of Extract (dye) of sample B at PH 1.00

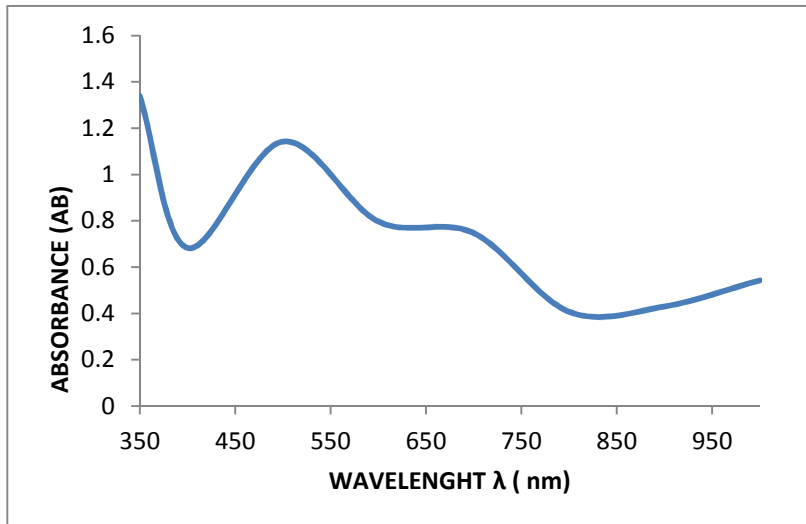


Fig. 11: Light absorption spectra of 1ml of extract (dye) of sample A + 3ml of HNO₃ on 1g of TiO₂.

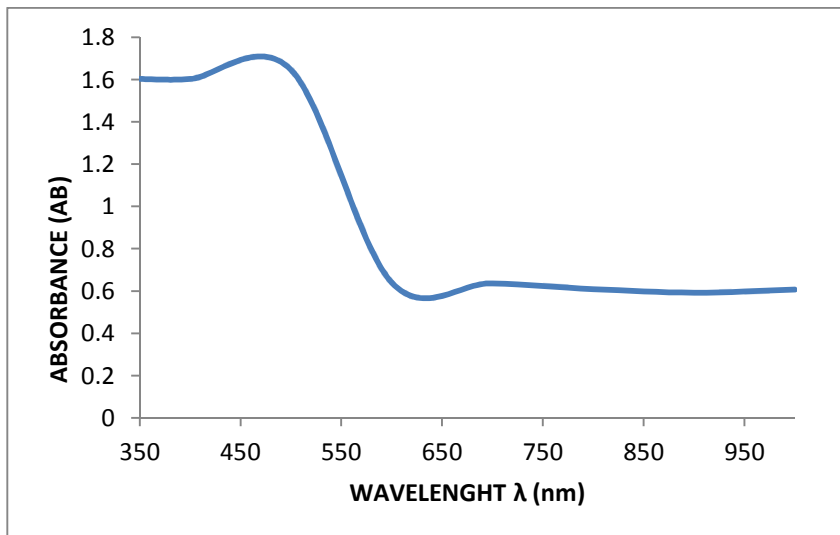


Fig. 12: Light absorption spectra of 1ml of extract (dye) of sample B + 3ml of HNO₃ on 1g of TiO₂.

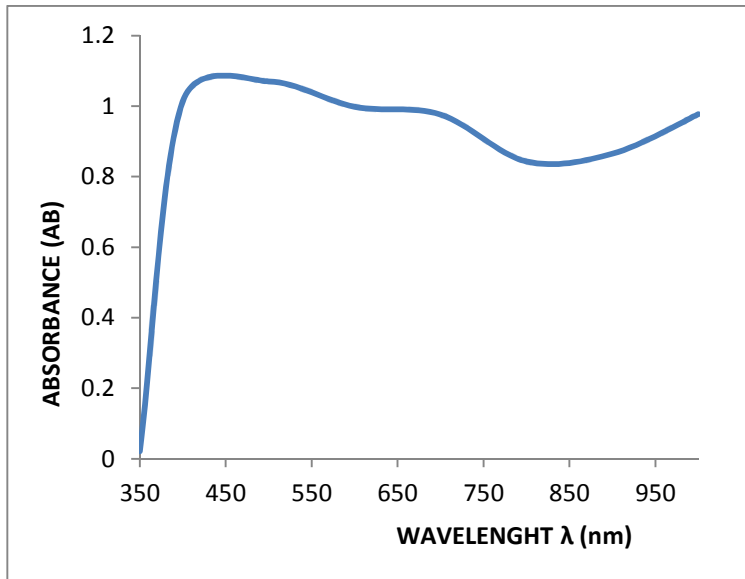


Fig.13: Light absorption spectra of 3ml of HNO₃ on 1g of TiO₂.

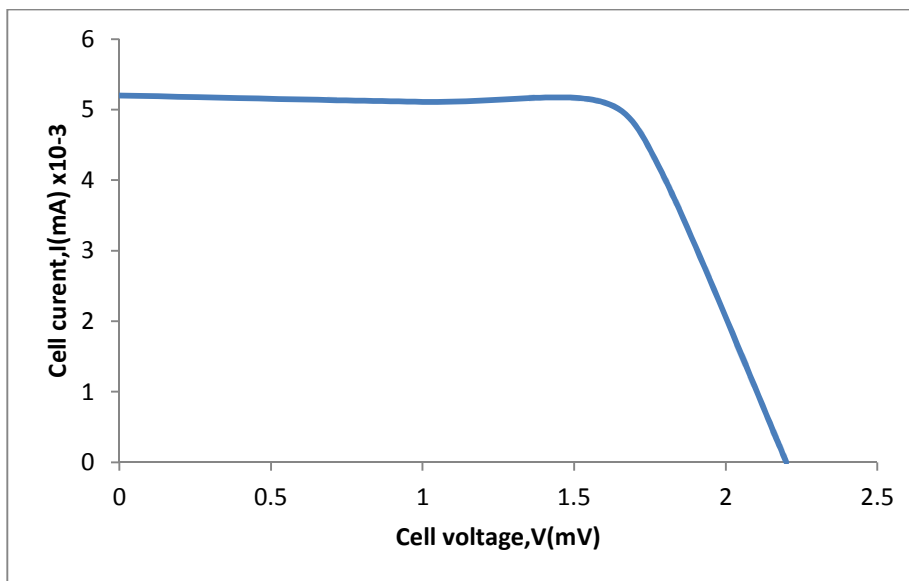


Fig. 14: I-V curve for sample A extract sensitized solar cell of 1.5 × 1.5 square centimeter (outdoor measurement).

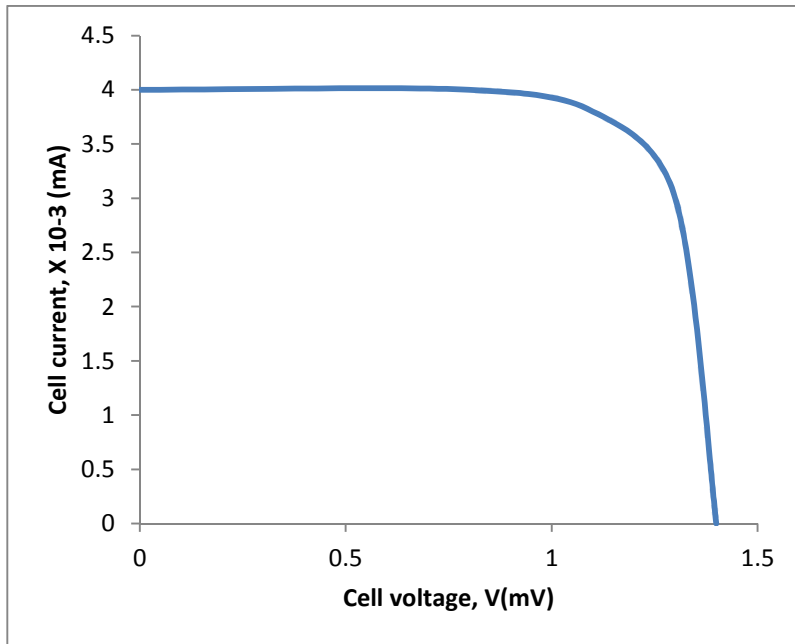


Fig. 15: I-V curve for sample B extract sensitized solar cell of 1.5×1.5 square centimeter (outdoor measurement).

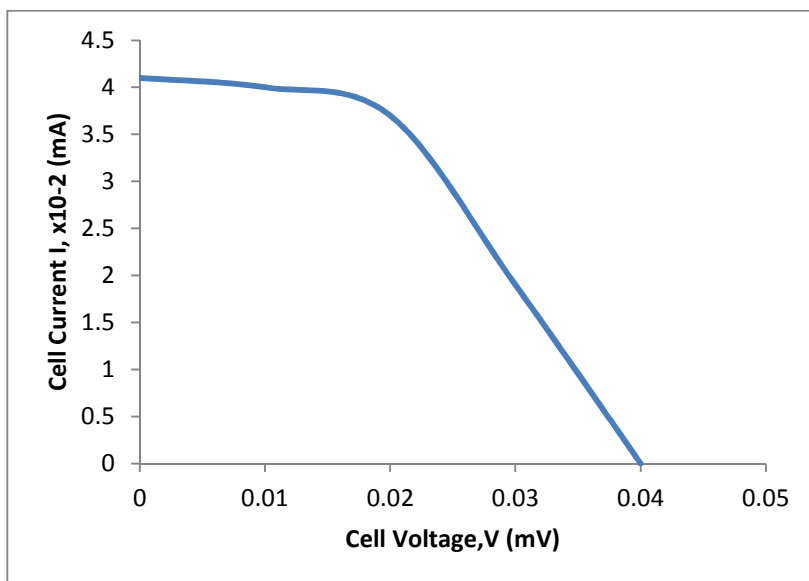


Fig. 16: I-V curve for sample A extract sensitized solar cell of 1.5×1.5 square centimeter (outdoor measurement).

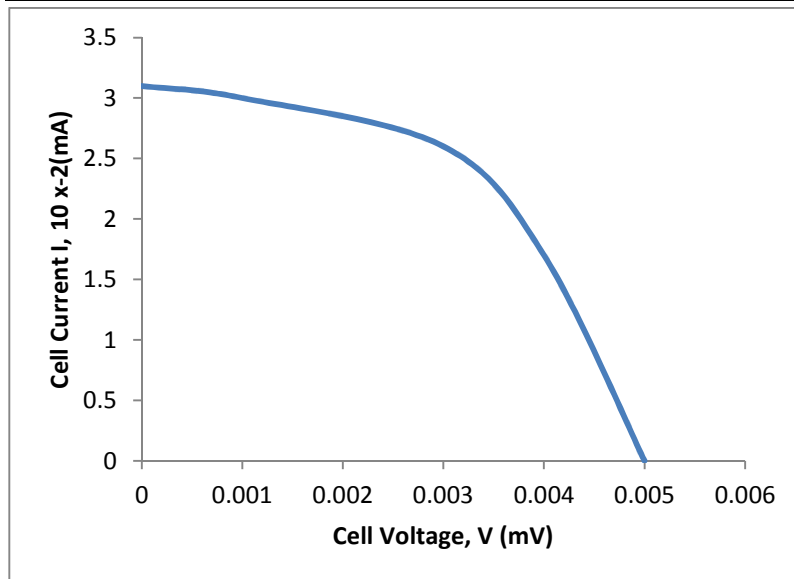


Fig.17: I-V curve for sample B extract sensitized solar cell of 1.5×1.5 square centimeter (*outdoor measurement*).

Table 1. Outdoor Measurement for cells of sample A and B

Extracting Solvent	Extract	Voc (mV)	I _{SC} (mA/cm ²)	η%	FF
Cold extraction Method	Sample A	220	0.00023	1.7554	0.7212
Cold extraction Method	Sample B	140	0.00178	1.891	0.7961

Table 2. Indoor Measurement for cells of sample A and B

Extracting Solvent	Extract	Voc (mV)	I _{SC} (mA/cm ²)	η%	FF
Cold extraction Method	Sample A	40	0.0182	1.4799	0.4512
Cold extraction Method	Sample B	50	0.01378	1.7554	0.55110

This academic article was published by The International Institute for Science, Technology and Education (IISTE). The IISTE is a pioneer in the Open Access Publishing service based in the U.S. and Europe. The aim of the institute is Accelerating Global Knowledge Sharing.

More information about the publisher can be found in the IISTE's homepage:

<http://www.iiste.org>

CALL FOR PAPERS

The IISTE is currently hosting more than 30 peer-reviewed academic journals and collaborating with academic institutions around the world. There's no deadline for submission. **Prospective authors of IISTE journals can find the submission instruction on the following page:** <http://www.iiste.org/Journals/>

The IISTE editorial team promises to review and publish all the qualified submissions in a **fast** manner. All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Printed version of the journals is also available upon request of readers and authors.

IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digital Library, NewJour, Google Scholar

