Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI:10.21474/IJAR01/1472
DOI URL: http://dx.doi.org/10.21474/IJAR01/1472

RESEARCH ARTICLE

EFFECT OF ANNEALING TEMPERATURE ON THE ELECTRICAL PROPERTIES OF TITANIUM DIOXIDE (TiO_2) - ROSELLE DYE SENSITIZED SOLAR CELL.

B. I. Adamu[1], H. Y. Hafeez[2] and I.I. Ibrahim[1].

1. Department of Physics, Federal University Dutse, Jigawa State, Nigeria.
2. SRM Research Institute, SRM University, Kattankulathur,603203, India.

Manuscript Info

Manuscript History

Received: 12 July 2016
Final Accepted: 19 August 2016
Published: September 2016

Key words:-
Dye Sensitized Solar Cell, Roselle, TiO_2, ITO Glass Slides, Annealing Temperature.

Abstract

A Titanium Dioxide-Roselle Dye sensitized solar cell with a dimension of 20 x 20 mm was fabricated using Doctor-Blade Method. Some of the samples were given annealing treatment at various temperatures of 250^0C, 300^0C, 350^0C, 400^0C and 450^0C respectively with same annealing time of 30min. The device under test (DUT) were tested using a Kiethley 2400, source meter under A.M 1.5 ($1000W/m^2$) illumination from a Newport class A solar simulator. The results shows that at the various annealing temperatures, the open circuit voltage V_{oc}= 0.091V, 0.79V, 0.78, 0.93 and 0.46V, the short circuit current density J_{sc}=42µAcm^{-2} , 16µAcm^{-2}, 109µAcm^{-2}, 505µAcm^{-2} and 8µAcm^{-2}, the fill factor FF= 0.15, 0.06, 0.03, 0.02 and 0.14 and the energy conversion efficiency, η = 6 x10^{-4}, 8 x10^{-4}, 2 x10^{-3}, 6 x10^{-3} and 5 x10^{-4} respectively. The best results of open circuit voltage V_{oc}=0.93, short circuit current density J_{sc}= 505µAcm^{-2}, fill factor FF= 0.02 and energy conversion efficiency η= 6 x10^{-3} was at temperature T= 400^0C at constant annealing time, t =30 minute compared to the other four samples annealed at temperatures 250^0C, 300^0C, 350^0C and 450^0C. These results shows that at temperature T= 400^0C the annealing treatment shows some effects on the electrical properties of the TiO_2-Roselle Dye Sensitized solar Cell produced.

Introduction:-

A solar cell is an electronic device which convert direct solar energy into electricity using the process called photovoltaic effect. The process is achieved by shining light on the solar cell which creates an electrical current or voltage in the material that generate an electric power. Solar cell is becoming ever important as an alternative sources of energy that are both cheap, efficient and environmental friendly [1]. Compared to the fossil fuels - coal, oil, and natural gas, which were formed millions of years ago from the fossilized remains of plants and animals and are the main sources of energy today [2]. Based on the depletion of fossil fuel and the environmental hazards that it causes, the use of solar energy is certainly one of the most viable ways to solve the world's energy crisis [3]. More also, owing to the rapid consumption of conventional sources of energy through high demand despite their consequences due to pollution, solar energy is considered as promising alternative to the forecasted energy and societal challenges[4]. Renewable energy sources such as solar energy are considered as a practicable alternative because "More energy from sunlight strikes Earth per each hour than all of the energy consumed by humans in an

Corresponding Author:-H. Y. Hafeez.
Address:-SRM Research Institute, SRM University, Kattankulathur,603203, India.

entire year"[5]. As international interest about energy and climate changes increases, solar cells have become one of the most widely-researched methods of obtaining energy in "greener" ways than burning fossil fuels [6].

One of the new variants on the solar cell that is currently being researched is the dye-sensitized solar cell (DSSC), which was invented by MichealGratzel in 1991[7], where conventional systems take advantage of the semiconductor to absorb light and transport charge carriers, DSSCs separate these two functions [8]. DSSC Solar cell is a semiconductor device that transform Sun light into electricity. The most wide propagate photovoltaic device is the crystalline silicon solar cell, even though, the cost of crystalline silicon solar cells has plunged significantly over the past decade, but the devices are still too priceyto compare with the typical grid electricity. A promising alternative to canonical crystalline silicon cells is the Dye Sensitized Solar Cells (DSSC).The working principle of dye sensitized solar cell is to convert solar energy into electricity which consists of two conductive glasses and sandwiched between: nanoscale titanium dioxide, dye and electrolyte. Dye is adsorbed on the titanium dioxide when it absorbs sunlight its electron will transit from ground state to the excited state then injected into the conductive layer of the titanium dioxide and the loop finally form current. The electrolyte is mainly to carry out the redox reaction[9].

A solar cell, SC, consists of a junction of p- and n-type semiconductors. At the interface the Fermi levels of both semiconductors are the same, generating depletion region, and therefore, a charge separation[10]. When photons are absorbed in the p-type region, an electron-hole pair is created [11]. Each electron is then injected in the n-type region and the hole goes across p-type region. In the case of Thin Film Solar Cells, TFSCs the constitutes of material for the SCs production is considerably less, thus it reduces costs [12]. Some other advantages consist on the possibility of working with lighter materials and flexible substrates[13][14][15].

First and second generations photovoltaic cells are mainly assembled from semiconductors including crystalline silicon, III-V compounds, cadmium telluride, and copper indium selenide/sulphide[5]. Low cost solar cells have been the topic of intensive study for the last three decades [16]. Amorphous semiconductors were published as one of the most promising materials for low cost energy production[17]. Nevertheless, dye sensitized solar cells DSSCs forthcoming as a new class of low cost energy conversion devices with simple manufacturing procedures. Belike, there exists a compromise between the cost and quality of the solar cells. The prerequisite of the substitute material is to overcome the challenges associated with Pt-based electrodes and should provide high electrical conductivity and superior catalytic activity simultaneously. The Pt-free materials for DSSCs such as the inorganic materials have fashioned good performances for DSSCs. Among the inorganic materials, nickel sulfide (NiS) has been considered as a favorable alternative to substitute Pt for DSSCs due to its high conductivity, easy fabrication, and excellent catalytic activity. Many other research have been reported based on NiS CE [18]. In this work, we fabricated TiO_2-Roselle DSSCs assembled with less-cost carbon soot as our counter electrode material , though it shows a very low photoelectric conversion properties compare to that of Pt carbon electrode based DSSC.

Most solar cell characteristics can be obtained from simple J-V measurements. Fig.1 The short circuit current density (J_{sc}) is the current through the solar cell when the voltage across the solar cell is zero. The open circuit voltage (Voc) is the voltage across the solar cell when the current through the solar cell is zero and it is the maximum voltage available from the solar cell. The maximum power point (P_{max}) is the condition under which the solar cell generates its maximum power; the current density and voltage in this condition are defined as J_{max} and V_{max} (respectively). The fill factor (FF)and the energy conversion efficiency (η) is evaluated according equation (1) and (2) respectively. Those parameters are used to characterize the performance of the solar cell[19].

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} \qquad (1)$$

$$\eta = \frac{V_{oc} \times J_{sc} \times FF}{E} \qquad (2)$$

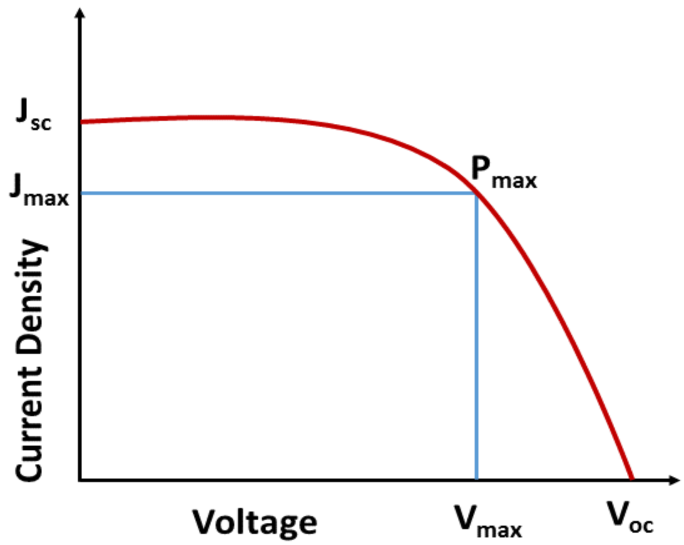

Fig.1:- Typical I-V forward bias characteristics of a solar cell.

The current density-voltage (J-V) measurement is common measurement technique used to investigate the characteristics of thin film through the current density-voltage (J-V) curve of thin films. From this curve the electrical properties of the thin films can be studied.

Annealing process is a heating process which enhanced the electron transportation in semiconductor materials [20]. Owing to the photosensitivity advantage of the Roselle flowers it was used as a dye to prepare the Roselle-dyed TiO_2 photo-electrode and afterward subject to annealing treatment to observe its effect in the process. This paper, investigate the effect of annealing treatment process on the Titanium Dioxide - Roselle Dye Sensitized Solar Cells application and the advantages of hybridization at different annealing temperatures to the performances of DSSC. The fabrication of the cell is in accordance with the procedure reported by doctor- blading.

Experimental details:-

Materials:-

Titanium Dioxide TiO_2 (79.89Mw, 99%) of Qualikems (T009111) For Laboratory Use obtained From CMAN NLT, Kabuga Kano Nigeria, Indium tin oxide coated (ITO) glass slide 25mm x 25mm with surface resistivity 10Ω/sq obtained from TECHINSTRO INDIA, VECSTAR Furnace from chesterfield U.K. (LF2 MOD, 2000W, 240V and 1200 max. temp), Newport Oriel Instruments Model 65194A-100 Solar Simulator, Adventurer OHAUS AR2740 digital weighing machine, 2 Digital DT9205A Multi-meters, voltmeter (EDM-14, 0-2V), ammeter (EDM-14, -20-100µA), micrometer screw gauge,Carbon soot, Gum acacia,White vinegar, Morning fresh, Roselle, silver paste (EN06B8) from ENSON Japan. All these materials are analytical grade and used as received without any further purification.

Fabrication of DSSCs:-

In this work, an equal amount of well blended powdered activated carbon soot was mixed with Anionic surfactant liquid (morning fresh) was used as counter electrode material. The deposition of our counter electrode on indium doped tin oxide (ITO) glass substrate was enabled through the doctor- blading method. The conducting side of a 2.5cm x 2.5cm ITO was identified and covered on each of the parallel edges with asellotape to control the thickness of the TiO_2 film. Before deposition, the glass substrates were cleaned with isopropanol, then Ethanol. The carbon paste which was prepared through Doctor-blading method was applied at one edge of the conducting glass and distributed with a squeegee sliding over the tape-covered edges. The electrodes were kept on the safer side for about 24hours before removing the adhesive tapes. The edges were cleaned with ethanol. Nanocrystalline titanium (iv) oxide was used as photo-electrode. The same blade method was adopted in depositing the TiO_2 layer and the film was allowed to dry naturally for five minutes before removing the adhesive tapes. The edges were also cleaned with ethanol. The electrodes was sintered for 30 minutes at a temperature of 400^0C using the Vecstar LF2 MOD furnace. The contained liquid of the paste burns away, leaving the Titania nanoparticles sintered together. This process ensures electrical contact between particles and good adhesion to the TCO glass substrate[21]. The furnace was allowed to cool down before removing the annealed electrode. This is because a sudden change in temperature can cause the glass to break[22]. The resulting nanoporous layer made from the sintered particles was stored in a sealed environment to avoid moisture absorption from ambient air. The TiO_2 photo-electrodes were immersed into a solution of the local dye for 15 minutes. The binder clips was cleaned with ethanol before it was rightly placed on the dyed working electrode. The conductive side of the transparent electrodes was gently placed on top of conducting carbonized side of the counter electrodes[23]. We introduced 0.5ml drops of the electrolyte (Iodide/trioxide) through one of the gap left between the two glass plates by capillary action[24]. Electrical contacts were made by applying the silver paste (ENSON, EN06B8) along the conducting side of electrode.

Photovoltaic Performance of DSSC:-

The performance of the DSSCs was determined using a calibrated AM 1.5 solar simulator Controller (Newport, Oriel instruments, Model: 69922) with a light intensity of 100 $mWcm^{-2}$ and a computer controlled digital source meter (Keithley, Model: 2400). The J–V measurements were carried out separately in order to study the effect of annealing temperature. The photoelectrochemical parameters, i.e., the fill factor (FF) and light to-electricity conversion efficiency (η), were evaluated using equation (1) and (2)

Results and Discussion:-

Results:-

Table I:- Summarized Results of Titanium Dioxide-Roselle Dye Sensitized Solar Cells Output Parameters annealed at various Temperatures.

Samples Temp.(^{o}c)	V_{oc} (v)	J_{sc}(μAcm^{-2})	P_{max} (μW/cm^2)	FF	η (%)
250	0.091	42	0.556	0.15	0.0006
300	0.79	16	0.745	0.06	0.0008
350	0.78	109	2.338	0.03	0.002
400	0.93	505	6.029	0.02	0.006
450	0.46	08	0.524	0.14	0.0005

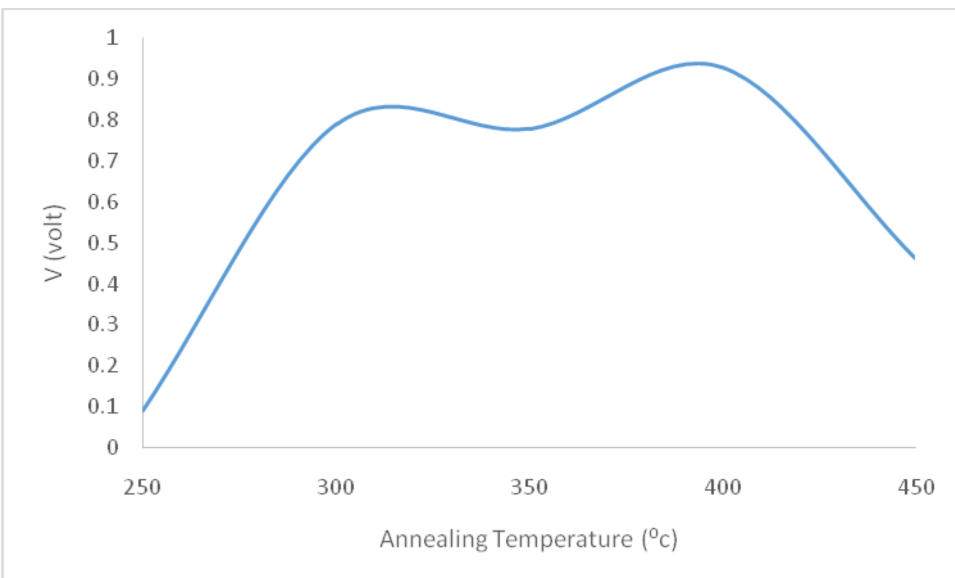

Figure 2:- Variation of Output Voltage vs Annealing Temperature.

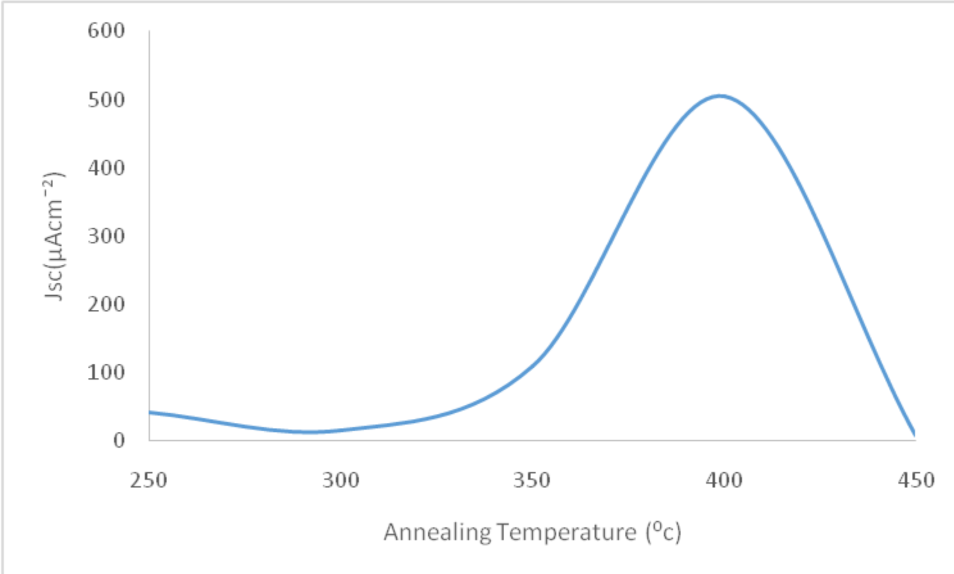

Figure 3:- Variation of Output Current Density vs Annealing Temp.

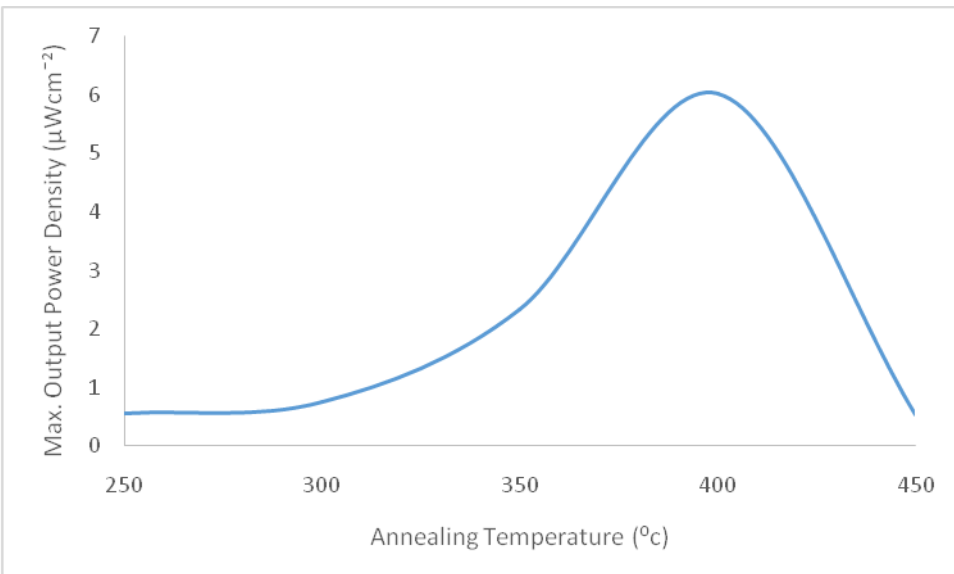

Figure 4:- Variation of Output Power Density vs Annealing Temperature.

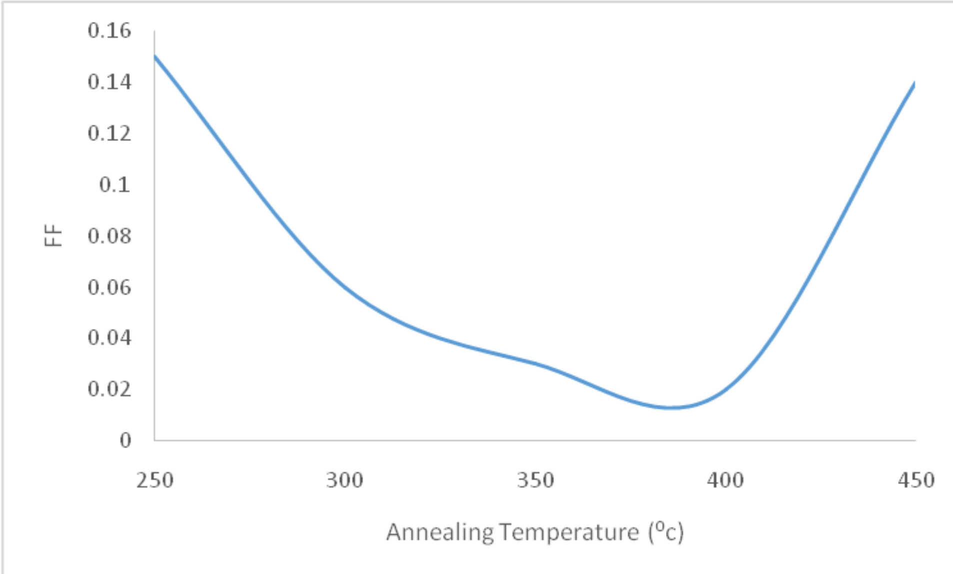

Figure 5:- Variation of Fill Factor vs Annealing Temperature.

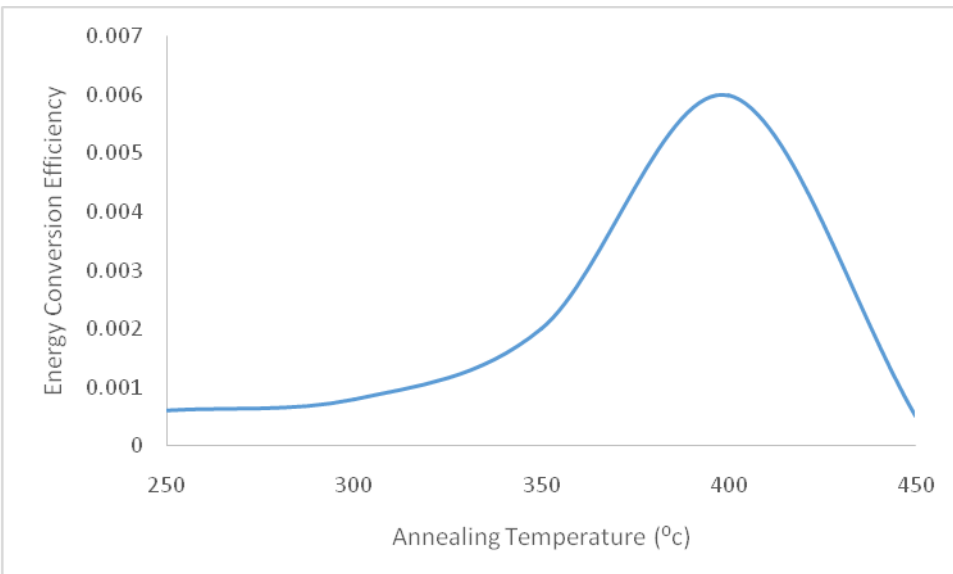

Figure 6:- Variation of Energy Conversion Efficiency vs Annealing Temperature.

Discussion

The J–V measurements were studied and it was observed that, the higher energy conversion efficiency and maximum power content generated increased with increased in annealing temperature from 250°C - 400°C, and fall at 450°C as shown in Table I. The measurement from each sample sometimes gives a very wide deviation value, due to the surface of the TiO_2 which is not homogeneous and at any temperature higher than 400°C the TiO_2 slowly turns from white brown to dark brown and at 500^0c above it turns black, owing to the presence of Gum acacia in the TiO_2 paste (cannot withstand at higher temperature). The TiO_2-Roselle Dye Sensitized solar Cell electrical properties such as J_{sc} and V_{oc} are very important parameters, Figure 2 through 6 shows the variation of J_{sc} ,$V_{oc,}$ P_{max}, Fill factor and energy conversion efficiency plotted against the annealing Temperature.

After the annealing process the parameters that characterize solar cell were measured as tabulated in table 1. It is clear from the values that annealing treatment play an important role toward the performance of the solar cell. It can be observed from the graphs in Fig 2, 3, 4 & 6 that each processes has similar trend. Its shows increase in the process as in the graph until it reaches its maximum value at 400°C. It is seen that the annealing temperature will affect the electrical properties of TiO_2-Roselle Dye Sensitized solar Cell.

Since the fill factor (FF) is inversely proportional to the product between short circuit current density and open circuit voltage[11] this parameters remain almost constant throughout this research work as reflected in Fig 5.

However, In this research work the optimum energy conversion efficiency after annealing at 400°C generated its maximum value of, 0.006% (Table I), which is reasonably good when compared with some recent advanced laboratory works.

Conclusion:-

Based on the J-V characterized properties of the TiO_2-Roselle dye sensitized solar cell and the corresponding effects on its performance, an increase in surface area overlap between two conductive was associated with a positive increase in performance of the fabricated TiO_2-Roselle dye sensitized solar cell also an increase in the annealing temperature is associated with increase in the performance of the device. Hence, the electrical properties increases as annealing temperature increase. The annealing temperatures higher than 400°C caused the electrical properties decrease. These occurred because of TiO_2 thin layer completely distorted, since it undergoes thermal degradation on the samples. This condition can cause poor adhesion of TiO_2 deposition, which resulting low dye absorption and reducing electrical-network between the particles.

References:-

1. B. I. Adamu, G. Babaji, M. H. Ali, C. E. Ndikilar, A. B. & Suleiman, and S. S. Abdullahi, "The Effect of Degradation of Electrolyte on TiO 2 - Roselle Dye Sensitized Solar Cell," *Int. J. Pure Appl. Sci.*, vol. 6, no. 1, pp. 36–45, 2016.
2. P. Teesetsopon, S. Kumar, and J. Dutta, "Photoelectrode optimization of Zinc Oxide nanoparticle based dye-sensitized solar cell by thermal treatment," *Int. J. Electrochem. Sci.*, vol. 7, no. 6, pp. 4988–4999, 2012.
3. S. Pei, A. Pandikumar, H. Ngee, and N. Ming, "Essential role of N and Au on TiO 2 as photoanode for efficient dye-sensitized solar cells," *Sol. Energy*, vol. 125, pp. 135–145, 2016.
4. N. A. Ludin, A. M. A. Mahmoud, A. Bakar, A. Amir, H. Kadhum, K. Sopian, N. Shazlinah, and A. Karim, "Review on the development of natural dye photosensitizer for dye-sensitized solar cells," *Renew. Sustain. Energy Rev.*, vol. 31, pp. 386–396, 2014.
5. K. E. Jasim, "Dye sensitised solar cells-working principles, challenges and opportunities," *Tech*, pp. 171–204, 2011.
6. A. U. Rehman, A. U. Asar, N. Ullah, R. Ullah, and M. a, "Comparative Study of Dye-Sensitized Solar Cell Based on Carbon Black and Graphite as Cathode Materials .," *Int. J. Eng. Technol.*, vol. 12, no. 05, pp. 105–107, 2012.
7. B. O'Regan and M. Grätzel, "A Low-Cost, High-Efficiency Solar Cell Based On Dye-Sensitized Colloidal TiO2 Films," *Nature*, vol. 353, pp. 739–740, 1991.
8. M. Grätzel, "Conversion of sunlight to electric power by nanocrystalline dye-sensitized solar cells ☆," *J. Photochem. Photobiol. A Chem.*, vol. 164, pp. 3–14, 2004.
9. B. I. Adamu, "Fabrication and Characterization of Titanium Dioxide - Roselle (Zobo) Dye Sensitized Solar Cell," *(Masters, Diss. Bayero Univ. Kano)*, p. 80, 2015.
10. Q. Tang, J. Duan, Y. Duan, B. He, and L. Yu, "Recent advances in alloy counter electrodes for dye-sensitized solar cells. A critical review," *Electrochim. Acta*, vol. 178, pp. 886–899, 2015.
11. R. Faccio, L. Fernández-Werner, H. Pardo, and A. W. Mombré, "Current trends in materials for dye sensitized solar cells.," *Recent Pat. Nanotechnol.*, vol. 5, no. 1, pp. 46–61, 2011.
12. M. H. Jusof Khadidi and E. A. Hamid, "Fabrication and Characterization of Titanium Dioxide-Based Sensitized Solar Cell Using Vinegar," *2nd Int. Conf. Environ. Energy Biotechnol.*, vol. 51, no. 26, pp. 139–142, 2013.
13. B. I. Adamu, G.Babaji, A. S. Gidado, I. M. Musa, & S. S. A., and H. Y. Hafeez, "Influence of Thickness on Titanium Dioxide - Roselle (Zobo) Dye Sensitized Solar Cell Experimental Detail," *Int. J. Pure Appl. Sci.*, vol. 6, no. 2, pp. 71–78, 2016.
14. O. J. O., E. A. J., and E. P. .I., "The Viability of a Natura Dye Extracted From Pawpaw Leaves as Photosensitizer For Dye-sensitized Solar Cells," *Int. Sci. Res. J.*, vol. 3, pp. 3–5, 2011.

15. B. I. Adamu, G. Babaji, H. Y. Hafeez, A. Muhammad, I. G. Shitu, I. M. Musa, and A. S. Gidado, “Fabrication and Characterization of TiO 2 -Roselle Dye Sensitized Solar Cell Cathode Using Gum Arabic,” *J. Niger. Assoc. Math. Phys.*, vol. 34, pp. 405–410, 2016.
16. A. Elsanousi, N. Elamin, S. Elhouri, and A. Abdallah, “Highly Ordered TiO 2 Nanotubes and Their Application to Dye Sensitized Solar Cells,” *J. Appl. Ind. Sci.*, vol. 1, no. 1, pp. 39–42, 2013.
17. Y. Li, S. H. Ku, S. M. Chen, M. A. Ali, and F. M. a AlHemaid, “Photoelectrochemistry for red cabbage extract as natural dye to develop a dye-sensitized solar cells,” *Int. J. Electrochem. Sci.*, vol. 8, no. 1, pp. 1237–1245, 2013.
18. D. Punnoose, H. Kim, C. H. S. S. Pavan, S. S. Rao, C. V. V. M. Gopi, and S. Chung, “Journal of Photochemistry and Photobiology A : Chemistry Highly catalytic nickel sul fi de counter electrode for dye-sensitized solar cells,” *"Journal Photochem. Photobiol. A Chem.*, vol. 306, pp. 41–46, 2015.
19. Agilent, “IV and CV Characterizations of Solar / Photovoltaic Cells Using the B1500A,” *Appl. Note B1500A-14*, no. Cv, 2014.
20. M. K. Ahmad, C. F. Soon, N. Nafarizal, A. B. Suriani, A. Mohamed, M. H. Mamat, M. F. Malek, M. Shimomura, and K. Murakami, “Optik Effect of heat treatment to the rutile based dye sensitized solar cell,” *Opt. - Int. J. Light Electron Opt.*, vol. 127, no. 8, pp. 4076–4079, 2016.
21. I. Daut, M. Fitra, M. Irwanto, N. Gomesh, and Y. M. Irwan, “TiO_2 Dye Sensitized Solar Cells Cathode Using Recycle Battery,” *J. Phys. Conf. Ser.*, vol. 423, p. 012055, 2013.
22. M. Fitra, I. Daut, M. Irwanto, N. Gomesh, and Y. M. Irwan, “Effect of TiO2 Thickness Dye Solar Cell on Charge Generation,” *Energy Procedia*, vol. 36, pp. 278–286, 2013.
23. J. O. Ozuomba, L. U. Okoli, and A. J. Ekpunobi, “The performance and stability of anthocyanin local dye as a photosensitizer for DSSCs,” *Adv. Appl. Sci. Res.*, vol. 4, no. 2, pp. 60–69, 2013.
24. T. O. Ahmed, P. O. Akusu, N. Alu, and M. B. Abdullahi, “Dye-Sensitized Solar Cell (DSC) Based on Titania Nanoparticles and Hibiscus sabdariffa,” *Br. J. Appl. Sci. Technol.*, vol. 3, no. 4, pp. 840–846, 2013.