Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 149 (2020) 128-139 EISSN 2392-2192

Fabrication of Dye Sensitized Solar Cell Based on Natural Photosensitizers

M. Nirmala*, S. Sahana, B. Iswarya, K. Maruvarasi, A. Adline Jenita and **B. Kavitha**

Sri GVG Visalakshi College for Women, Udumalpet, Tamil Nadu, 642126, India

*E-mail address: saicharan.kumar16@gmail.com

ABSTRACT

Dye Sensitized solar cells were fabricated using with natural extracts and TiO_2 is used as a semiconducting layer. The layer of nanocrytalline titanium dioxide was deposited on conductive side of the transparent Fluorine doped Tin Oxide (FTO) glass plate and the other side of the plate is coated with graphite. Voltage and Current values are measured for natural dyes coated FTO plate and I-V characteristic curves of all fabricated cells were drawn and analyzed. The highest power conversion efficiencies of Blueberry (0.79872%) and Beetroot (0.745813 %.) dyes were achieved among 10 dyes. The functional groups of Beetroot and Turmeric natural dyes were confirmed under FTIR spectroscopy. The ease and cost efficiency of the overall fabrication process, extensive availability of these fruits/juices render them novel and low-cost candidates for Solar cell applications.

Keywords**:** Natural Dyes, nanocrystalline materials, nanocrytalline titanium dioxide, Solar cell, FTIR spectroscopy, Efficiency, Functional

1. INTRODUCTION

The dye sensitized solar cell (DSSC) provides a technically and economically credible alternative concept to present day p–n junction photovoltaic devices. The dye molecules are quite small so in order to capture amount of the incoming light the layer of dye molecules needs

(Received 04 September 2020; Accepted 26 September 2020; Date of Publication 27 September 2020)

to be made fairly thick, much thicker than the molecules themselves. It shows excellent absorption in the visible region (400 nm to 700 nm), Adsorb strongly on the surface of the semiconductor, has a high extinction coefficient and be stable in its oxidized form allowing it to be reduced by an electrolyte.

Interest in the dye-sensitized solar cells increased with this development. Previous studies [1-5] show that an ideal solar cell material should have the foll0owing features such as band range within of 1 to 1.7 eV, Direct band to be speed, Easily producible, does not contain toxic substances, Good photovoltaic conversion efficiency, High absorption coefficient and Stability. Dye Sensitized Solar Cells It is a low-cost solar cell belonging to the group of thin film solar cells. It is based on a semiconductor formed between a photo-sensitized cathode (TiO_2) and an electrolyte, a photo electrochemical system. The photoelectrons are provided from a separate photosensitive dye which contains acid functional group for anchoring on TiO_2 and Charge separation occurs at the surfaces between the dye, semiconductor and electrolyte [6-10].

A DSSC is generally composed of a photoactive (PV) semiconductor, working electrode of titanium dioxide, and a counter electrode. The dye used in DSSC acts as a photosensitizer allowing solar energy to be converted to electrical energy. The type of dye used in a solar cell is one of the most crucial components influencing solar cell performance as the sensitizer is what determines the photo response of the DSSC. The dye is contained in the photo anodes that are responsible for better absorbance and stronger electron excitation properties, conclusively granting more efficient solar cell [11-15].

When incident photons on a DSSC are being absorbed by the photo-anodes, electrons are excited from the ground state to the excited state and subsequently transferred to the conduction band of the TiO_2. This process oxidizes the photo-anodes causing the electrons to travel through the electrolyte to the cathode of the cell and returns back to the anode via the circuit. This reoccurring process of moving charges generates electricity.

Several studies have been reported [16-18] in the past about the optical properties of dyes such as Anthocyanin and Chlorophyll. Anthocyanin's are brightly colored pigments found in plants and may have different colors depending on the pH. Synthetic chlorophyll and anthocyanin have been developed for the production of solar cells. Synthesis of these dyes could be controlled to obtain concentrated and minute dye particles vital for obtaining higher photoelectric conversion efficiency of solar cells. The cost of production of these dyes is however very high. Therefore someone needs to prove and discover a potential natural source of a dye with the best photoelectric conversion efficiency to improve DSSC productivity. Since natural dyes are cheaper to obtain, it would be more economical to mass produce DSSC that could be used in appliances as portable chargers or integrated into building facades. The objective of this work was to analyze and determine the most efficient natural dye and to find a consistent and reliable method for producing the cells.

2. EXPERIMENTAL

2. 1. Materials and Methods

Materials used for fabrication of DSSC

Materials used for coating the FTO plate: TiO_2 powder, ethanol, iodine electrolyte, graphite carbon pencil and distilled water were used to coat the FTO (Fluorine tin oxide coated glasses).

Extraction of dyes: For the dye, beetroot, carrot, turmeric powder, chilly powder, blueberries, tamarind, coffee powder, mint juice, orange and tomato were used. The photograph for prepared dyes and coated plates are is shown in the figure 1.

Testing of Conductive side: The substrates must be coated in the opposite of the conductive side. In order to check the conductive side UV light was used and multimeter was used to check the conductive side by placing it at the sound area.

2. 2. Methods used for the preparation of DSSC

Experimental steps were done in three parts, which are the preparation of the cathode electrode (TiO_2 electrode), preparation of the anode electrode (carbon counter electrode & Preparation of Iodine electrolyte) and the preparation of the dye solution.

Preparation of TiO_2 electrode

The TiO_2 films were made by spreading TiO_2 pastes on the fluorine tin oxide conducting glass (FTO) by using the glass rod. TiO_2 paste was prepared by mixing the TiO_2 powder with ethanol. Extensive stirring were proceeded to ensure complete dispersion of TiO_2 powder and to facilitate the spreading of the colloid on FTO glass. Droplets of each paste were placed onto the FTO glass. Cello tapes were placed on the edges of FTO glass to spread the pastes for about 10 seconds. Then, the TiO_2 was sintered at the burner for 10 minutes. The resulted electrode was then cooled down to room temperature. Thickness of the TiO_2 film was controlled by multiple coating processes in which the coated substrates were subjected repeatedly.

Preparation of Counter electrode

To prepare the counter electrode, the FTO glass was wiped with ethanol. Then, the FTO glass surface was colored by using pencil using graphite. After that, the surface was checked to ensure that there was no space that the carbon did not cover. In the preparation of liquid electrolyte, 0.127 gm of Iodine and 0.83 gm of Potassium Iodide were added into the beaker containing 10 ml of Ethylene Glycol. The mixture was mixed until there was no grain of Iodine and Potassium Iodide by using glass rod.

2. 3. Preparation of dyes

For the preparation of blueberry dye, 10 blueberries were taken and washed with distilled water. Washed blueberries grinded well and we mixed it with ethanol. Ethanol mixed blueberry mixture was taken in a tube and placed it in a centrifuge. Solid particles settled at the bottom and liquid on the top of the tube is used as a blueberry dye. No water was added into the solution. Cathode electrode was then immersed in the dye solution for more than six hours. After that, the surface of the TiO_2 photo electrode was cleaned by using the ethanol to ensure that there were no blueberry dye remained at the edge of the FTO surface.

2. 4. Assembling of DSSC

Step 1: The cathode electrode and the anode electrode were put together, overlapping each other, and a space at the end of each electrode was made.

Step 2: Three drops of iodide solution were added at the end of the electrode and the solutions were spread over the entire electrode. Then, the remaining iodide solution was wiped off using cotton swab soaked with acetone (Figure 1).

Figure 1. Photograph of Coffee & Turmeric powder dyes and dye soaked plates

Step 3: Next, electrodes were fastening using the binder clip after that, it was tested with the multi meter and corresponding readings were taken for voltage, capacitance and current. The experiment was conducted under sunlight. The same procedure was done for the other dyes. The photograph for fabrication of DSSC is shown in the Figure 2.

3. RESULTS AND DISCUSSION

3. 1. Performance of DSSC's using Natural Dyes

The current, voltage and capacitance values are measured for Coffee, Turmeric, Chili powder, Orange, Carrot, Tamarind, Mint, Tomato and Beetroot dyes coated DSSC's. Figure 3 shows the volathe and capacitance measurement for carrot dye coated DSSC. The measured value of current, voltage and capacitance for ten natural dyes are tabulated in the Table 1 and the measured values show that the voltage readings are less than the capacitance values as predicted for all the natural dyes. The graph is drawn between the Voltage (V) and Current (micro amp) values measured for the ten dyes and shown in the Figure 4.

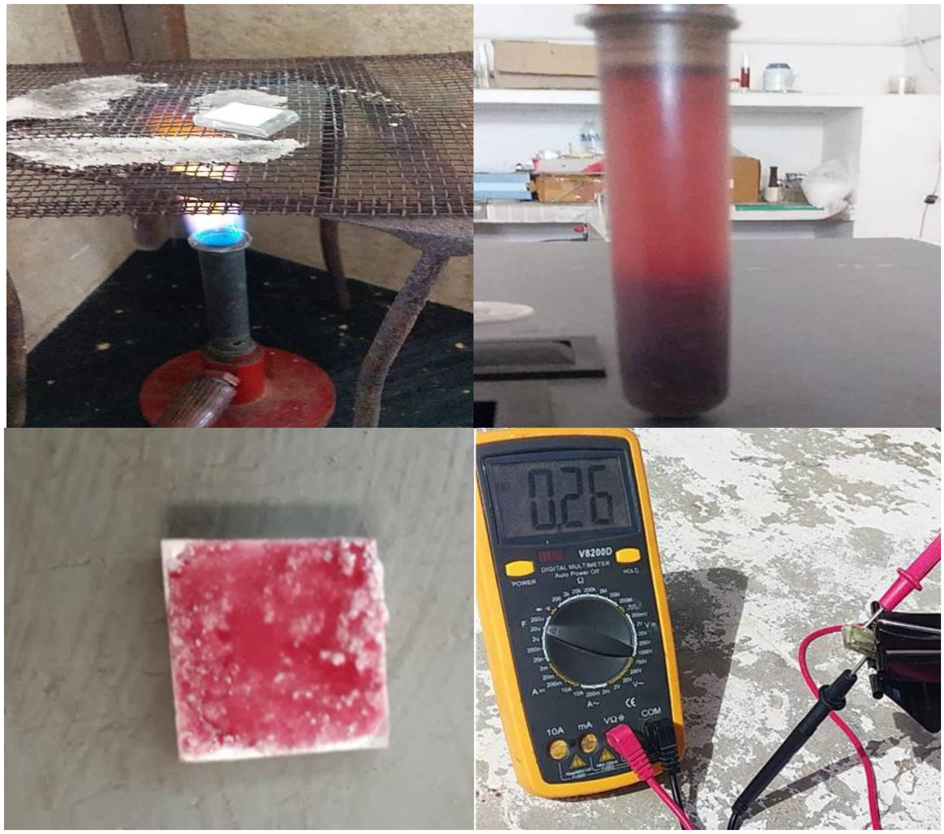

Figure 2. Photograph of Dye Sensitized Solar Cell Fabrication

Figure 3. Voltage and Capacitance readings of carrot dye

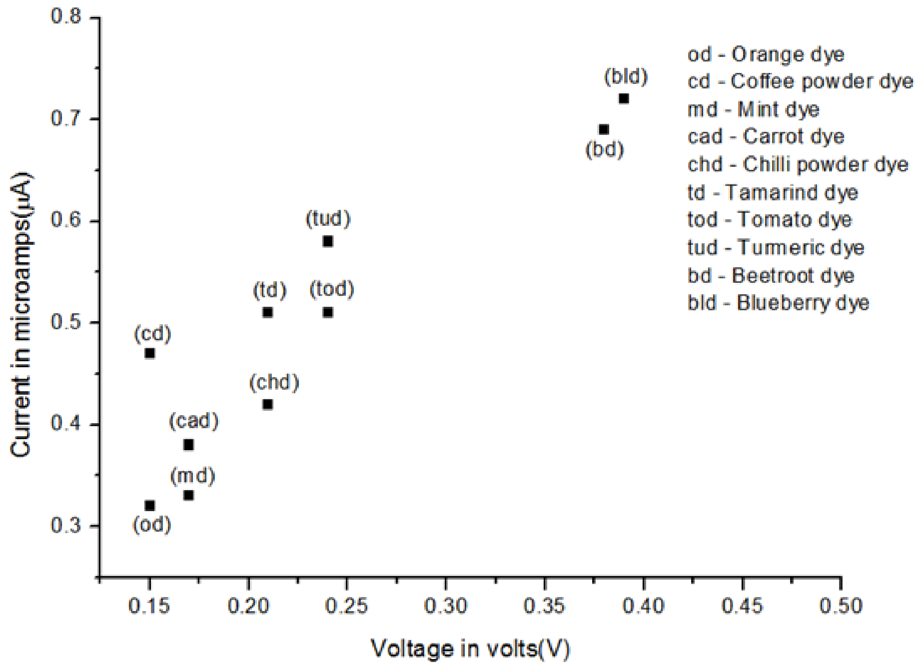

Figure 4. I-V Characteristic curve of DSSC based on natural dyes

Table 1. Specification of prepared DSSC's with different natural dyes

Dyes	Voltage readings in (Volts)	Current readings in (amps)	Capacitance readings in (Farad)	P_o (Maximum output voltage)	Pi (Maximum output voltage)	Efficiency (%)
Orange	0.15	0.32	0.21	0.000256	0.1875	0.13653
Mint	0.17	0.33	0.38	0.0002992	0.1875	0.159573
Carrot	0.17	0.38	0.26	0.00034453	0.1875	0.1837493
Blueberry	0.39	0.72	1.42	0.0014976	0.1875	0.79872
Coffee	0.15	0.47	0.27	0.000376	0.1875	0.20053
Chilly	0.21	0.49	0.71	0.0004704	0.1875	0.25088
Tamarind	0.21	0.51	0.52	0.0005712	0.1875	0.30464
Tomato	0.24	0.51	0.28	0.0006528	0.1875	0.34816
Turmeric	0.24	0.58	0.62	0.0007424	0.1875	0.395946
Beetroot	0.38	0.69	1.45	0.0013984	0.1875	0.745813

3. 2. Thickness of the FTO plate:

The thickness of TiO_2 coated FTO plate is calculated from the formula

$$t = \frac{m}{Ad}$$

where: t- Thickness, m- mass of the film (After coating-before coating), A-Area of the FTO plate, d- Density (TiO_2 powder), t- After coating-Before coating the film/Area*Density
t = 1.755-1.5/0.0001875*4.23
t = 0.00003215 mm

The photocurrent generated by the solar cell is directly proportional to the amount of the dye absorbed on TiO_2 film. This explains that more dye molecules are attracted to the increased surface of TiO_2. Then it can generate more electrons and improve the electron transport. The open circuit is almost the same and current density slightly varies according to the different dyes.

3. 3. Solar conversion efficiency measurement:

The solar conversion efficiency (η) of DSSC's can be estimated using the efficiency formula:

$$\eta = \frac{P_0}{Pi} \times 100\%$$

where: Maximum possible input Pi=1000 000 mW/m^2* cell active area (m^2), Maximum possible output P_o = V*I/A, V = Voltage reading in volts (V), I = Current reading in amps (I), Area of the FTO plate = l×b = 1.25×1.50 = 1.875 cm.

The efficiency calculation of Blueberry dye coated DSSC is given below

1) Coffee dye efficiency:

$\eta = P_o /Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$
$= 0.1875\ w/m^2$
$P_o = 0.15 \times 0.47 \times 10^{\wedge -6}/0.0001875$
$= 0.000376\ w/m^2$
$= 0.000376/0.1875 \times 100\%$
$\eta = 0.20053\%$

2) Blueberry dye efficiency:

$\eta = P_o /Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$
$= 0.1875\ w/m^2$
$P_o = 0.39 \times 0.72 \times 10^{\wedge -6}/0.0001875$
$= 0.0014976\ w/m^2$
$= 0.0014976/0.1875 \times 100\%$
$\eta = 0.79872\%$

3) Orange dye efficiency:

$\eta = P_o /Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$
$= 0.1875\ w/m^2$

$P_o = 0.15 \times 0.32 \times 10^{-6}/0.0001875$
$= 0.000256\ w/m^2$
$= 0.000256/0.1875 \times 100\%$
$\eta = 0.13653\%$

4) Tomato dye efficiency:

$\eta = P_o\ /Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$
$= 0.1875\ w/m^2$
$P_o = 0.24 \times 0.51 \times 10^{-6}/0.0001875$
$= 0.0006528\ w/m^2$
$= 0.0006528/0.1875 \times 100\%$
$\eta = 0.34816\%$

5) Chilly dye efficiency:

$\eta = P_o\ /Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$
$= 0.1875\ w/m^2$
$P_o = 0.21 \times 0.42 \times 10^{-6}/0.0001875$
$= 0.0004704\ w/m^2$
$= 0.0004704/0.1875 \times 100\%$
$\eta = 0.25088\%$

6) Mint dye efficiency:

$\eta = P_o/Pi \times 100\%$
$Pi = 1000\ 000 \times 10\text{-}3 \times 0.0001875$
$= 0.1875\ w/m^2$
$P_o = 0.17 \times 0.33 \times 10^{-6}/0.0001875$
$= 0.0002992\ w/m^2$
$= 0.0002992/0.1875 \times 100\%$
$\eta = 0.159573\%$

7) Beetroot dye efficiency:

$\eta = P_o/Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$
$= 0.1875\ w/m^2$
$Po = 0.38 \times 0.69 \times 10^{-6}/0.0001875$
$= 0.0013984\ w/m^2$
$= 0.0013984/0.1875 \times 100\%$
$\eta = 0.745813\%$

8) Carrot dye efficiency:

$\eta = P_o/Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$

$= 0.1875\ w/m^2$
$P_o = 0.17 \times 0.38 \times 10^{-6}/0.0001875$
$= 0.00034453\ w/m^2$
$= 0.00034453/0.18 \times 100\%$
$\eta = 0.1837493$

9) Tamarind dye efficiency:

$\eta = P_o/Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$
$= 0.1875\ w/m^2$
$P_o = 0.21 \times 0.51 \times 10^{-6}/0.0001875$
$= 0.0005712\ w/m^2$
$= 0.0005712/0.1875 \times 100\%$
$\eta = 0.30464\%$

10) Turmeric dye efficiency:

$\eta = P_o/Pi \times 100\%$
$Pi = 1000\ 000 \times 10^{-3} \times 0.0001875$
$= 0.1875\ w/m^2$
$P_o = 0.240.58 \times 10^{-6}/0.0001875$
$= 0.0007424\ w/m^2 = 0.0007424/0.1875 \times 100\%$
$\eta = 0.395946\%$

Table 1 show the specification of prepared DSSC's with different natural dyes. DSSC solar cells have been assembled and Voltage, current (P_o, P_i) were tested. The DSSC's fabricated with TiO_2 using Orange, Mint, Carrot, Blueberry, Coffee, Chilly, Tamarind, Tomato, Turmeric, Beetroot extracted dye shows the efficiency value of 0.13653, 0.159573, 0.1837493, 0.79872, 0.20053, 0.25088, 0.30464, 0.34816, 0.395946, 0.745813% respectively.

Fabricated DSSC using orange dye shows less efficiency value (0.13653%) and DSSC using Blueberry shows higher efficiency value (0.79872%) because it contains a higher concentration of Betacyanin. It has been observed that the dark coloured Betacyanin leads to higher efficiency. DSSC with Beetroot, Turmeric (due to the concentration of Curcumin) Tomato & Tamarind dyes shows notable efficiency values. The lower current densities in this dye as compared to other dyes could be attributed to the additional impurities resulting from imprecise extraction processes [19].

3. 4. FTIR spectroscopy

The Beetroot & Turmeric dyes are extracted and characterized by FTIR spectroscopy and shown in Figure 5. The broad band obtained at 3398.92 cm^{-1} was allocated to the stretching vibration of Phenol compound of range (3200-3550 nm). The peak obtained at 2969.84 cm^{-1} represents the stretching vibration of Alkanes of range (2850-3000 nm). The observed peak at 1638.23 cm^{-1} denotes the stretching vibration of Alkenes of range (1630-1680 nm). The presence of Alkane, Alkene and Phenol compounds in the beetroot dye proved their interaction between TiO_2 and dye will contribute to the photoelectric efficiency of the device. For the Turmeric dye the observed broad band at 3397 cm^{-1} was allocated to the stretching vibration of

(N-H) bond (3300-3500). The peak obtained at 1740.44 cm^{-1} represents the stretching vibration of (C=C) bond (1500-1900) [20].

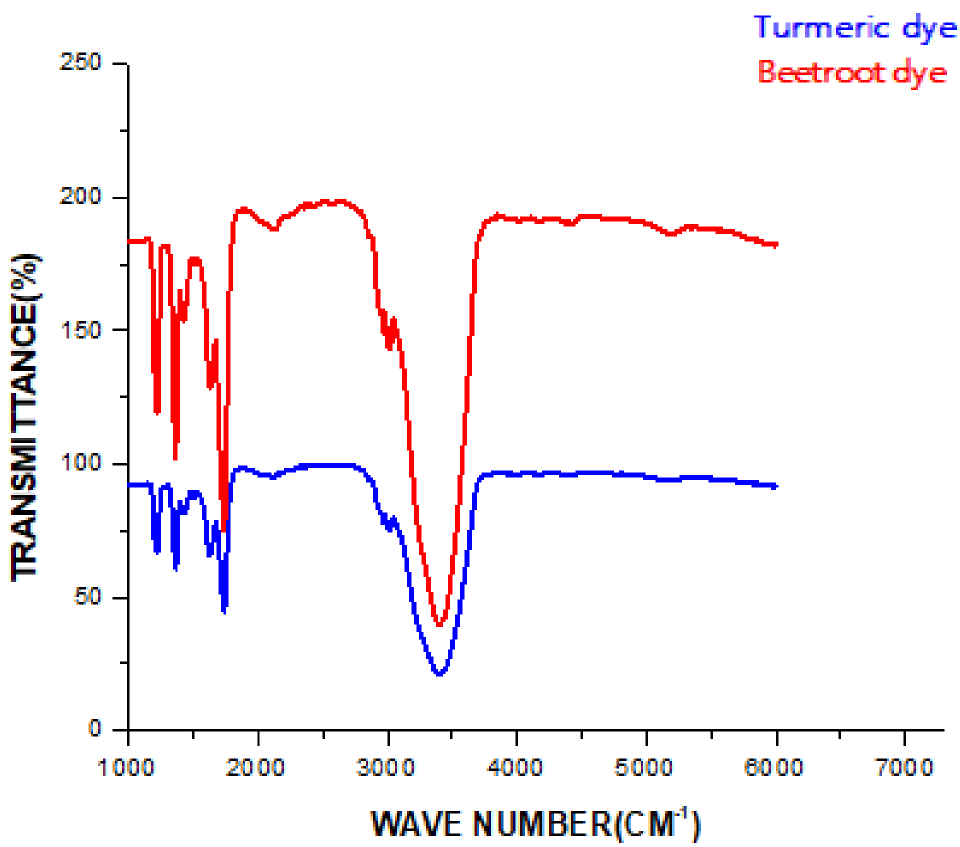

Figure 5. FTIR Spectra of Beetroot and Turmeric Dyes

4. CONCLUSIONS

In the present work, the utilization of naturally occurring dyes extracted from various commonly found fruits/vegetables (Orange, Mint, Carrot, Blueberry, Coffee, Chilly, Tamarind, Tomato, Turmeric and Beetroot) for the fabrication of DSSC's using the economical and efficient procedure. Dye extracted from Blueberry resulted in the DSSC's with the highest efficiencies. This is because darker color corresponds to increased light absorption leading to enhanced photocurrent densities.

The lower current densities in this dye as compared to other dyes could be attributed to the additional impurities resulting from imprecise extraction processes. The isolation and purification of the various isomers will address this issue and could potentially improve the power conversion efficiency. The simplicity and cost effectiveness of the overall fabrication process, widespread availability of these fruits/vegetables render them novel and inexpensive candidates for Solar cell application.

Acknowledgement

The authors are grateful to the Secretary, Director, Principal and Head of the Department of Physics, Sri G.V.G Visalakshi College for Women, Udumalpet for their excellent encouragement and support. This work was supported by DBT Star College Scheme and Department of Science and Technology (DST)

References

[1] B. O'Regan, M. Gratzel, A low-cost, high efficiency solar cell based on dye sensitized colloidal TiO_2films. *Nature* 353 (1991) 737-740

[2] I. Jinchu, C.O. Sreekala, K.S. Sreelatha, Dye sensitized solar cell using natural dyes as chromophores – Review. *Mater. Sci. Forum.* 771 (2014) 39-51

[3] S. Chang, Q. Li, X. Xiao, K.Y. Wong, T. Chen, Enhancement of low energy sunlight harvesting in dye-sensitized solar cells using plasmonic goldnanorods. *Energy Environ. Sci.* 5 (2012) 9444-9448

[4] S.P. Lim, A. Pandikumar, N.M. Huang, H.N. Lim, Enhanced photovoltaic performance of silver Titania plasmonic photo anode in dye sensitized solar cells. *RSC Adv.* 4 (2014) 38111-38118

[5] Z. Tian, L. Wang, L. Jia, Q. Li, Q. Song, S. Su, H. Yang, A novel biomass coated Ag-TiO2composite as a photoanode for enhanced photocurrent in dye sensitized solar cells. *RSC Adv.* 3 (2013) 6369-6376

[6] B. O'Regan, M. Gratzel, A low-cost, high efficiency solar cell based on dye sensitized colloidal TiO2 films. *Nature* 353 (1991) 737-740

[7] I. Jinchu, C.O. Sreekala, K.S. Sreelatha, Dye sensitized solar cell using natural dyes as chromophores – review. *Mater. Sci. Forum* 771 (2014) 39-51

[8] S. Chang, Q. Li, X. Xiao, K.Y. Wong, T. Chen, Enhancement of low energy sunlight harvesting in dye-sensitized solar cells using plasmonic gold nanorods. *Energy Environ. Sci.* 5 (2012) 9444-9448

[9] S.P. Lim, A. Pandikumar, N.M. Huang, H.N. Lim, Enhanced photovoltaic performance of silver titania plasmonic photoanode in dye sensitized solar cells. *RSC Adv.* 4 (2014) 38111-38118.

[10] Z. Tian, L. Wang, L. Jia, Q. Li, Q. Song, S. Su, H. Yang, A novel biomass coated Ag-TiO2 composite as a photoanode for enhanced photocurrent in dye sensitized solar cells. *RSC Adv.* 3 (2013) 6369-6376

[11] K. E. Jasim, Dye sensitized solar cells-working principles, challenges and oppurtunities, *Solar Cells - Dye-Sensitized Devices*, November 9, 2011.

[12] M. Gratzel, Dye sensitized solar cells. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews.* 4(2) (2003) 145-153.

[13] L. Saadoun, J.A Ayllón, J Jiménez-Becerril, J Peral, X Domènech, R Rodríguez-Clemente. Synthesis and photocatalytic activity of mesoporous anatase prepared from

tetrabutylammonium-titania composites. *Material Research Bulletin* 35(2) (2000) 193-202.

[14] M. Sokolsky, J. Cirak, Dye-sensitized solar cells: materials and processes. *Acta Electrotechnica et Informatica*, 10 (2010) 78-81.

[15] Q. F. Zhang, G. Z. Cao, Nanostructured photoelectrodes for dye-sensitized solar cells. *Nano Today*. 6(1) (2011) 91-109.

[16] Monishka Rita Narayan, Review: Dye sensitized solar cells based on natural photosensitizers. *Renewable and Sustainable Energy Reviews.* 16(1) (2012) 208-215

[17] Subbaiah Manoharan, A. Sharafali, Sambandam Anandan, Ramaswamy Murugan, Vinoth Shanmugam, Green grasses as light harvesters in dye sensitized solar cells. *Spectrochimica Acta* 135 (2014) 947-952

[18] Ahmed Torchani, M. Aziz Ben Youssef, Rached Gharbi Saif Saadaoui, Fabrication, modeling and electrical characterization of natural Dye Sensitized Solar Cell under different thermal stress conditions. *International Journal for Light and Electron Optics.* 127 (2016) 10058-10067.

[19] Marko Berginc, Franc Smole, Marko Topic Miha Filipic, Analysis of electron recombination in dye-sensitized solar cell. *Current Applied Physics* 12(1) (2012) 238-246.

[20] Panagiotis A. Angaridis, Georgios Charalambidis, Ganesh D. Sharma, Athanassios G. Coutsolelos Vasilis Nikolaou, Click-chemistry approach for the synthesis of porphyrin dyads as sensitizers for dye-sensitized solar cells. *Dalton Transactions* 4 (2015) 1734-1747

[21] Hee-Je Kim, Yeo-Tae Bin, S.N. Karthick, K.V. Hemalatha, C. Justin Raj, S. Venkatesan, Songyi Park, G. Vijayakumar, Curcumin Dye Extracted from Curcuma longa L. Used as Sensitizers for Efficient Dye-Sensitized Solar Cells. *Int. J. Electrochem. Sci* 8 (2013) 6734-6743

[22] S. Hao, J. Wu, Y. Huang, J. Lin, Natural Dyes as Photosensitizers for Dye- Sensitized Solar Cell. *Sol. Energy.* 80 (2006) 209-214.

[23] C. Giuseppe, D. M. Gaetano, Red Sicilian orange ad purple eggplant fruits as natural Sensitizers for dye-sensitized solar cells. *Sol Energy Mater Sol Cells* 92 (2008) 1341-1346.

[24] Nipun Sawhney, Soumitra Satapathi, Soumitra Satapathi, Utilization of Naturally Occurring Dyes as Sensitizers in Dye Sensitized Solar Cells. *IEEE Journal of Photovoltaics* 7(2) (2017) 539-544

[25] P. Priyadharsini, S. Theodore David, Joel. Natural Dyes and Their FTIR Spectroscopy Studies. *International Journal on Applied Bioengineering* 8(2) (2014) 15-18.