Dye-Sensitized Solar Cells using Natural Pigments

Tapas Chakrabarti[1], Abir Jana[2], Komal Kumari[3], Subir Kumar Sarkar[4]
[1]Department of Electronics & Communication Engineering
Heritage Institute of Technology, Kolkata, West Bengal, India
[2,3,4]ETCE Department, Jadavpur University, Kolkata, India

Abstract- Dye-sensitized solar cell has arisen as low cost, simple fabrication and eco-friendly device. Three Dysensitized solar cells have been fabricated and a comparative study is done on three different natural dye sensitizer and previously published authors' similar works. First sample of dye is extracted from blue Clitoria ternatea, second sample from red Hibiscus and seven varieties flower with seven different colours i.e. Red rose, Yellow rose, Orange Marigold, blue Clitoria ternatea, Indigo Iris, Violet Rose and for green colour Spinach (chlorophyll) were mixed together to form third dye (can be named as vibgyor dye). All electrical parameters related to dye-sensitized solar cells are measured and analyzed from the I-V characteristic curves by MATLAB. Natural dye sensitizer extracted from Clitoria ternatea showed the Voc, Jsc, and efficiency of 0.72V, 3.910 mA/cm2 and 2.09% respectively whereas vibgyor dye and red dye (hibiscus) showed Voc, Jsc, and efficiency of 0.78V ,1.89 mA/cm2, 0.9% , 0.370V, 0.99 mA/cm2 and 0.18% respectively..
Keywords – Clitoria Ternatea, Hibiscus, Vibgyor, IV characteristics, MATLAB.

I. INTRODUCTION

The increase in energy demand and rising concern for the environment, brought solar cell into the limelight, as it is one of the best source of sustainable, cleaner and Renewable energy.[1]. There has been huge progress in the fabrication of solar cell from last few decades [2-4]. The crystalline silicon solar cell is recently commercialized, but the cost of production is quite high, hence to make solar cell feasible for general public, production cost should be reasonable. The dye-sensitized solar cell can prove itself as a suitable alternative to silicon solar cells. It offers a major consideration as a substitute source of unpolluted and green energy owing to its numerous benefits, such low fabrication cost, great mechanical strength (robust), lightweight flexible cell and low price to power conversion efficiency ratio.

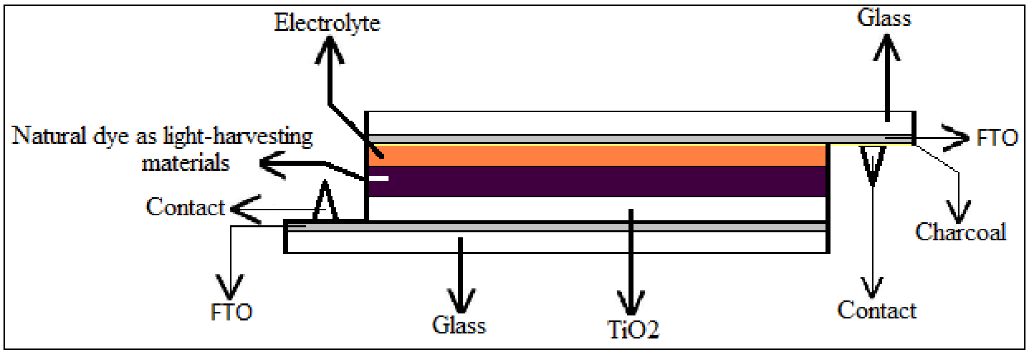
The dye-sensitized solar cell is certainly a disruptive technology and has grabbed a lot of attention in recent years. Dye-sensitized solar cells are the first photovoltaic system that employs a 3- dimensional junction to convert sunlight to electricity and it is the only solar cell that mimics the charge separation process in photosynthesis. Nature has been inspiration to develop dye-sensitized solar cell as it uses the principle of stacking in the green leaves, cell stacks thylakoids membranes so that the light will go to many molar layers of chlorophyll before it gets extinguished and the same trick is used in this solar cell, instead of pilling the thylakoids we are using Nano size titanium particles that stacked up for light harvesting. The dye-sensitized solar cell uses a molecule that is excited by sunlight and generates electric power, but the molecule is not involved in charge conduction, so the charge transport and photo induced charge separation are separated and that's not the case of in all another solar cell which are based on P-N junction semiconductor.

Among all the basic element used in dye-sensitized solar cell, dye plays an important role in absorbing sunlight and converting it into electricity [5]. The Ruthenium (Ru) complexes that are used in most of the industries are complex in synthesis, [6], hence natural dye finds its way in DSSC. The excellent dye must have broad absorption spectrum and ability to inject electron in semiconductor materials. Natural pigment extracted from flower, anthocyanin, and chlorophyll possess the above excellent qualities [7]. Anthocyanin absorbs light within 450-600 nm range [7] whereas chlorophyll absorbs light in 430-662 nm range [7]. In anthocyanin and carbonyl, the hydroxyl group is present as anchorage agent due to which pigment get attached to TiO_2 nanostructures [8] M.S.Roy et al. reported a comparatively high efficiency of 2.09% and Voc of 0.89 using Rose Bengal dye as sensitizer [9]. Sancun Hao reported 0.55 V of Voc from the dye extracted from black rice [10] where as several another study like Monzir did the study on eleven dye extracted from a tree, the dye extracted from zizyphus leaves showed the best result of Voc 0.68 and Jsc of 1.5 mA. Rachel Fran Mansa reported power conversion efficiency of 0.11% from hibiscus dye [11]. Hence it can be noticed that Anthocyanin from different flower gives a different type of performance. Thus in this paper, we will see the power conversion efficiency of dye sensitizer extracted from different flowers. Three different samples of dye are prepared to check the power conversion efficiency blue, red, and vigour dye. For vibgour dye six different flowers and for green dye spinach is employed.

http://dx.doi.org/10.21172/ijiet.122.11

II. WORKING PRINCIPLE

When dye sensitizes solar is exposed to sunlight Light passes through the transparent electrode and excites the electron residing in HOMO of dye molecules to LUMO. From there it goes to the conduction band of the TiO2 layer which acts as a metal oxide semiconductor (MOS). The electrons flow through the external circuit to the graphite cathode then flow into the iodide electrolyte. The electrolyte then transports the electrons back to HOMO of the dye molecule. In the DSSC, the dye is oxidized (loses an electron). The oxidized dye receives an electron from an iodide ion, which reduces the dye back to its original form.



Basic structure of DSSC

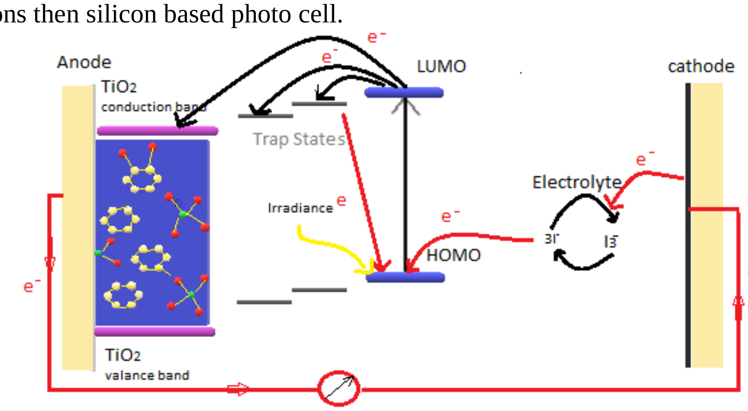
In this process the iodide ions undergo oxidation.

$$3I^- \rightarrow I_3^- + 2e^-$$

The electron that returns to the DSSC from the external circuit reduces the ion back to .

$$I_3^- + 2e^- \rightarrow 3I^-$$

In this equation we can see the reduction of tri-iodide ions to form iodide ions, the iodide ions can then be oxidized to form tri-iodide ions and electrons. The transparent anode allows sunlight to reach the dye-sensitized TiO2 nanoparticles. The use of TiO2 nanoparticles coated with light absorbing dye increases the effective surface area and allows more light over a wider range of visible spectrum to be absorbed. This allows the DSSC to absorb more light under cloudy conditions then silicon based photo cell.



Working principle of dye sensitized solar cell

III. EXPERIMENTAL DETAILS

3.1 Dye Preparation

Three different samples of dye sensitizer are prepared for comparative investigation.

DYE FROM BLUE CLITORIA TERNETIA: Few numbers of blue Clitoria ternetia flower are thoroughly washed with ethanol. Blue petals of the flower are carefully separated from base green part of the flower and then grinded in mortar and filtered. The resultant was concentrated to one fourth on a rotatory evaporator at 50°C for few seconds. 7 to 8 drops of Methanol is mixed in the flower juice and then it was stored in the airtight dark container.

DYE FROM HIBISCUS: 15 red hibiscus flower were thoroughly washed with ethanol. Red hibiscus petals were separated leaving behind a sticky portion of flower and then it was crushed in a mortar and filtered using filter paper.

The resultant was concentrated to one fourth on a rotatory evaporator at 50°C for few seconds. 7 to 8 drops of Methanol is mixed in the flower juice and then it was stored in the airtight dark container.
VIBGYOR DYE: For the preparation of vibgyor dye, six different variety of flowers were chosen, they were a Red rose, yellow rose, Orange Marigold, Blue Clitoria ternetia, Violet rose, indigo Iris and for green colour spinach were explored, they were separately washed with ethanol for 15 minutes. Coloured petals of flower were separated carefully, and were individually (flowers of one kind) grinded in mortar. After grinding the paste were filtered and heated at 80°C for few seconds to concentrate it to one fourth, resultant mixture was stored separately. Finally 0.5ml of dye from each sample were mixed together to form vibgyor dye.

3.2 Preparation Of Tio2 Suspension
6 g of titanium dioxide powder was measured and placed in a mortar. Next, 9 ml of nitric acid was poured into the mortar before crushing the mixture with a crusher until the mixture was consistent. Then, the suspension was kept in a dark container and allowed to equilibrate for 10 min. In order to break the masses into separate particles, the powder was ground in a ceramic mortar with a 1 mL of water and 0.1 ml of acetic acid to prevent aggregation of the particles. After the dust had been disseminated by the high shear forces in the viscous paste, it was diluted by slow addition of water (4 mL) under constant grinding. Finally, a detergent was added to smoothen the spreading of the colloid on the substrate.

3.3 Device Fabrication
ITO glasses were cleaned with deionized water followed by cleaning with Acetone and then it was placed in the ultrasonic bath for almost 15 minutes and dried under nitrogen flow. Its resistance was checked with help of multimeter to find the conductive side and it is of glass conductive side of ITO glass was tested by measuring the resistance of 21 Ω. Generally, it varies from 10 Ω to 30 Ω. To get the active area on the conductive side of ITO glasses, the transparent tape was used to cover all four edges of the glass, roughly up to 1mm. TiO2 paste is spread in between the tap, using doctor-blade process (>10 µm). A rose petal was washed with acetone and placed on the surface of TiO2, With help of round glass the petal place on the surface of the TiO2 layer and with help of glass pipe roller it was rolled on to make TiO2 surface same as petal surface. Rose patterned surface helps in harvesting the good amount of sunlight. After removing the tape, the sample was sintered at 110°C for 25 min. The sample was then immersed in three different dyes(hibiscus(red) dye, clitoria ternetia (blue) dye and vibgyor(mixed) dye), and left for 2 hours, its color changed from white to the color of respective natural dye sensitizer, and then heated for 10 min at 70 °C. The sample was then washed with deionized water and gently dried with tissue paper. Another electrode was prepared by coating conductive side of cleaned ITO glass with graphite as a counter electrode; it was heated for 15 minutes. Now the cell device was assembled by placing the graphite-coated slide facing down on top of the TiO2coated side.

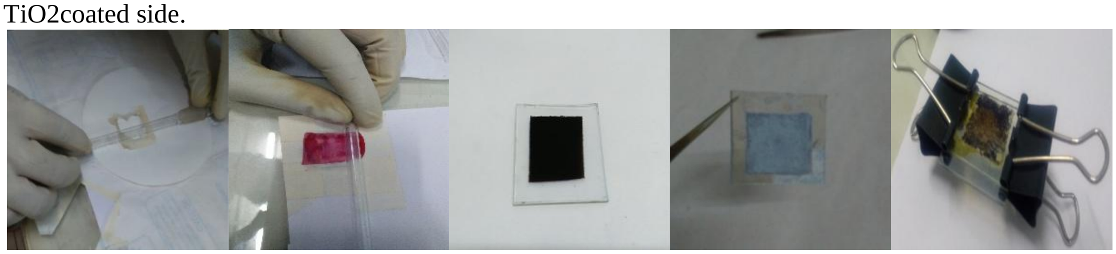


Fig. 3.a Fig.3.b Fig.3.c Fig.3.d Fig.3.e

Fig.3. (a) → Deposited thick TiO2 layer (b) →design of rose pattern on TiO2 surface. 3(c) → TiO2 and Natural dye on FTO coated glass→3(d) →Counter electrode 3(e) →Fabricated complete DSSC after giving electrolyte

IV. RESULT AND DISSCUSION

Table 1 shows all the interesting parameters like Short circuit current density (Jsc), open circuit voltage (Voc),) fill factor (FF), efficiency (η), and from the table we can observe the highest open circuit voltage is obtained from blue dye (Clitoria ternatea) i.e. 0.72V and lowest from red dye (hibiscus) i.e. 0.47V, whereas current varied from 5.5 mA/cm2 to 1.79 mA/cm2. Vibgyor dye showed average performance Voc of 0.68V and Jsc of 2.89 mA/cm2. DSSCs fabricated from various dye sensitizers. It can also be observed from the table that efficiencies obtained in this experiment (Clitoria Ternetia and Vibgyor) are considerably higher than the other DSSc. This is due to good charge transfer between the dye and TiO2. Power conversion efficiency of DSSc depends on light absorbtion capacity of dye, the structure of dye. The dye with more functional group availability of functional group (it act as syringe to insert electron in conduction band of TiO2) could generate mare Jsc, and the dye whose distance between anchoring H to LUMO is small, that dye shows more Jsc (shorter the distance between the excited state electron density, the more efficient electron could be injected into TiO2). TiO2 is a wide band gap semiconductor that only absorbs UV light and reflects all visible light, its function is to provide a lower energy level than LUMO of the dye such that the electron from LUMO of dye could be injected to the conduction band of TiO2. In this study the TiO2 layer is made mesoporous and surface structure is patterned like surface of rose petal, this helped in increasing surface area of TiO2, consequently number of dye adsorbed to the surface of TiO2 (Still increased number of dye molecule can be adsorbed on surface of TiO2 if the surface of TiO2 is made hollow nanowire). Beside absorbtion capacity and structure of dye, Trap state is another factor that affects the Power conversion efficiency of DSSc. Trap state is nearest energy level to LUMO, it is unavoidable inorganic materials so one needs to know how many trap states are there.

CBTiO 2 <Etrap state < LUMOdye

It may occur due to the structural defect of dye, chemical impurities that alter dye's electronic properties or adsorbed water in dye. This trap state is undesirable as an electron that is supposed to be injected from LUMO of dye to the conduction band of TiO2 gets trapped in this state and consequently, Jsc decreases. Figure 2 shows the working principle of DSSc with trap states. Fig3, 4, 5 shows the open circuit voltage to short-circuit current density of three different dye i.e. Blue, vibgyor and red dye.

The efficiency and Fill Factor is given by:

$$\eta = \frac{Voc * Isc}{E * Ac} * FF * 100\%$$

$Pmax = Maximun\ power\ output, E = Incident\ radiation\ flux, A = Area\ of\ collector$

$$FF = \frac{Pmax}{Isc * Voc}$$

Short circuit current and open circuit voltage measurement are done under arc lamp using illumination of 1 Sun. Highest fill factor and Efficiency is recorded for blue (Clitoriaternatea) dye. This is the comparatively high-efficiency record till date for blue dye.

Natural dye	Voc (V)	Jsc (mA/cm2)	FF (%)	Efficiency (%)	Reference
Clitoria Ternetia(blue coloured dye)	0.721	3.910	74.21	2.09	This paper
Hibiscus(red coloured dye)	0.370	0.990	50.34	0.18	This paper
Vibgyor(mixed)	0.780	1.890	61.06	0.9	This paper
Lemon leafs	0.225	0.017	54.1	0.040	[12]
Lyceum	0.580	0.420	42	0.100	[13]
Olive grain	0.5500	0.580	38	0.120	[14]
Iycium shawii	0.62	1.20	43	0.32	[14]
Zizyphus leaves	0.68	1.50	40	0.40	[14]
Yellow rose	0.609	0.74	57.1	0.26	[15]
Flowery knotweed	0.554	0.60	62.7	0.21	[15]
Chinese rose	0.483	0.90	61.9	0.27	[15]
Marigold	0.542	0.51	83.1	0.23	[15]

Table.1 Parameter comparison table of three DSSc fabricated in this paper with other DSSc fabricated using different dye sensitizer containing anthocyanin and chlorophyll

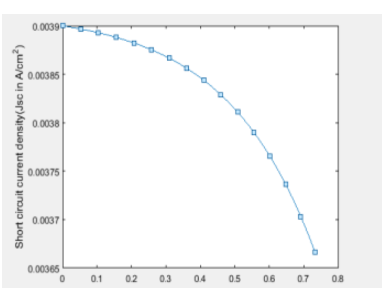


Fig.4(a)

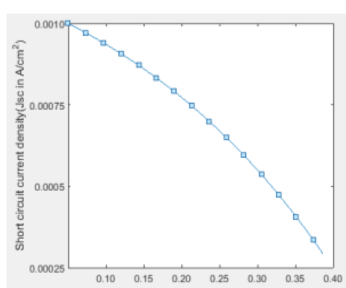


Fig.4(b)

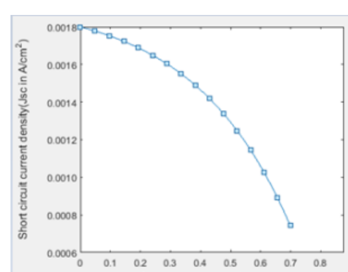


Fig.4(c)

Fig. 4(a) JV characteristics of dye extracted from Clitoriaternatea(blue dye), Fig.4(b) JV characteristics of dye extracted from vibgyor dye & Fig. 4(c) JV characteristics of dye extracted from hibiscus (red dye)

http://dx.doi.org/10.21172/ijiet.122.11

V. CONCLUSION

In this paper we have compared and analyzed three different natural dye sensitized solar cells, first sample using extraction from Clitoria (blue), second from Hibiscus and the third from a combination of seven different dyes of the VIBGYOR. The maximum efficiency was obtained for the first sample (2.622%), followed by the third sample (1.2%) and finally the second sample (0.4235%), respectively. In the DSSC all the available wavelengths of colors apart from the dye color are absorbed. This is the reason why the third sample (VIBGYOR) yields lower efficiency than the first sample (blue dye). With regards to our observations, the most suitable dye to achieve good efficiency is from Clitoriaternatea (blue dye). As the global trend is shifting towards tapping unconventional energy sources and eco-friendly materials, dye-sensitized solar cells are attracting the interest of researchers and industries alike. Commercialization of the DSSC can result in low-cost, easily-to-fabricate, environment-friendly alternatives to existing solar cell technology.

VI. REFERENCE:

[1] Chopra, K. L., Paulson, P. D. & Dutta, V. (2004). Thin-film solar cells: An overview, progress in photovoltaics. Res. Appl., 12, 69–92.

[2] Singh, G. K. Solar power generation by PV (photovoltaic) technology: A review. Energy 53, Science 350, 944–948 (2015).

[3] Chen, W. et al. Efficient and stable large-area perovskite solar cells with inorganic charge extraction layers Fabricated on Plastic Substrates. ACS Nano 9, 3760–3771 (2015).

[4] Yoo, K. et al. Completely Transparent Conducting Oxide-Free and Flexible Dye-Sensitized Solar Cells 1–13 (2013).

[5] Rachel Fran Mansa,* Gobinat Govindasamy, Yan Yan Farm, Hafeza Abu Bakar, Jedol Dayou and Coswald Stephen Sipaut Hibiscus Flower Extract as a Natural Dye Sensitiser for a Dye-sensitised Solar Cell.

[6] H. M. Upadhyaya, S. Senthilarasu, M.-H. Hsu, and D. K. Kumar, ―Recent progress and the status of dye-sensitised solar cell (DSSC) technology with state-of-the-art conversion efficiencies,‖ Sol. Energy Mater. Sol. Cells, vol. 119, pp. 291–295, Dec. 2013.

[7] R. Hemmatzadeh and A. Jamali, ―Enhancing the optical absorption of anthocyanins for dye-sensitized solar cells Enhancing the optical absorption of anthocyanins for dye-sensitized solar cells,‖ J. Renew. Sustain. Energy, vol. 13120, no. 2015, 2015.

[8] I. C. Maurya, Neetu, A. K. Gupta, P. Srivastava, and L. Bahadur, ―Natural Dye Extracted From Saraca asoca Flowers as Sensitizer for TiO 2 -Based Dye-Sensitized Solar Cell,‖ J. Sol. Energy Eng., vol.138, no. 5, p. 51006, Jul. 2016.

[9] M.S. Roy, P. Balraju, M. Kumar, G.D. Sharma, Dye-sensitized solar cell based on Rose Bengal dye and nanocrystalline TiO2, Sol. Energ. Mat. Sol. C 92 (2008) 909–913.

[10] Sancun Hao, Jihuai Wu *, Yunfang Huang, Jianming Lin, Natural dyes as photosensitizers for dye-sensitized solar cell. Solar Energy 80 (2006) 209–214

[11] Rachel Fran Mansa, Gobinat Govindasamy, Yan Yan Farm, Hafeza Abu Bakar, Jedol Dayou and Coswald Stephen Sipaut, Hibiscus Flower Extract as a Natural Dye Sensitiser for a Dye-sensitised Solar Cell. Journal of Physical Science, Vol. 25(2), 85–96, 2014

[12] Mounir Alhamed, Ahmad S. Issa, A. Wael Doubal, Studying of natural dyes properties as photo-sensitizer for DSSC, J. Electron Devices 16 (2012) 1370e1383.

[13] A.G. Tamirat, W.N. Su, A.A. Dubale, C.J. Pan, H.M. Chen, D.W. Ayele, J.F. Lee,B.J. Hwang, Efficient photoelectrochemical water splitting using threeDimensional urchin-like hematite nanostructure modified with reduced grapheme oxide, J. Power Sources 287 (2015) 119e128

[14] Monzir S. Abdel-Latif,Mahmoud B. Abuiriban, Taher M. El-Agez, and Sofyan A. Taya, Dye-Sensitized Solar Cells Using Dyes Extracted From Flowers, Leaves, Parks, and Roots of Three Trees. Vol.5, No.1, 2015.

[15] Huizhi Zhou, Liqiong Wu, Yurong Gao, Tingli Ma Dye-sensitized solar cells using 20 natural dyes as sensitizers, Journal of Photochemistry and Photobiology A: Chemistry 219 (2011) 188–194.