Dye-Sensitized Solar Cell Synthesis Using Green Extract: Natural Approach

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Abstract: ***A sensitizer is a key component of an efficient solar design during the dye sensitization process. In the natural resources such as chlorophyll, a simple molecule of green dye can play an important role in the synthesis of solar cells. This report presented various natural dyes, which are very efficient for preparation of environment friendly solar cells. In green leaf, chlorophyll is present in wast majority and responsible for the harvesting large amount of visible light. Several modules such as leaves, fruits, flower petals, barks and stems used together for the preparation of sensitizers. Among the four natural dyes, a max efficiency of 0.13% have been found for radish leaves during the synthesis of dye sensitized solar cells.***

Keywords: Dye Sensitized Solar Cell, Pigment, Natural Dye, Eco-friendly Approach

1. Introduction

Dye-sensitized solar cells (DSSCs) are devices for the conversion of visible light into electricity current and photosensitization of wide band-gap metal oxide semiconductors can be the mostly used process. Usually, the photo-anode is prepared by adsorbing a dye over a porous TiO_2 layer. By this approach, the dye extends the spectral sensitivity of the photo-electrode, enabling the collection of lower energy photons. Due to its crucial role in such systems, considerable efforts directed towards the development and improvement of new families of organic dyes. Since the preparation of synthetic dyes normally requires multistep procedures, organic solvents and, in most cases, time consuming chromatographic purification procedures, there is interest towards the possible use of natural dyes which can be easily extracted from fruits, vegetable and flowers with minimal chemical procedures. Dyes are capable of delivering DSSCs with high conversion efficiency as compared to natural DSSCs [1-4]. On the other hand, natural dyes have several advantages over rare metal complexes such as ruthenium-based complexes, because ease of extraction with minimal chemical procedures, large absorption coefficients, low cost, non-toxicity, environmentally friendly, easily biodegradable and wide availability[5-8]. Moreover, synthetic organic dyes have been fraught with problems, such as complicated synthetic routes and low yields [9]. Thus, several dyes extracted from natural pigments including anthocyanins, carotenoids and chlorophylls used as sensitizers in DSSC. Chlorophyll is the well-known and dominant natural pigment in terms of absorbing specific wavelengths of the visible light, converting sunlight to chemical energy. The common types of chlorophyll are “chlorophyll a” present in all photosynthetic plants and “chlorophyll b” found widely in higher plants and algae. It possesses a common basic structure that is a porphyrin structure consisting of four pyrrole rings. The presence of magnesium ion in the center is the unique feature of the chlorophyll structure and it plays an important role in the absorption of light energy. Chlorophyll in its raw form is not an efficient sensitizer for DSSC applications because lack of binding sites to TiO_2. The solar cell divided according to their material composition such as single crystal silicon, poly crystalline silicon and dye based solar cell. Silicon base solar cells generally used because of their high conversion efficiency, stability and repeatability. However, the cost of silicon base solar cell is higher than dye sensitized solar cell (DSSC).[1] DSSC is firstly developed by O’Regan and Gratzel al. in 1991[10], is adopted due to its environment-friendly nature, low production cost, controllable optical properties, simple fabrication steps and high conversion efficiency. Dye as sensitizer plays important role in transforming the solar energy to electrical depending upon their absorption [11-14]. It was found that the green pigment of most of plants is rich of chlorophyll. Chlorophyll a and b are the two most common types.[5,15,16] The molecular structure consists chlorine ring with Mg center, along with different side chains and hydrocarbon trail. It has seen that the chlorophyll absorption is in region red and blue color and derives its color by reflecting green. The absorption level of a photon depends on on number numberof leaf used or chlorophyll concentration [14-16]. Dyes like ruthenium give high conversion efficiency up to 10% but these are highly expensive and non-eco-friendly. Alternate of toxic dye is a natural dye, whose conversion efficiency is good and is non-toxic, biodegradable, cheaper and easy to extract.[5,13,14,17] As like simple cell, DSSC made up of working electrode (anode), dye as a sensitizer, electrolyte redox couple, and cathode as shown in Fig. 1.

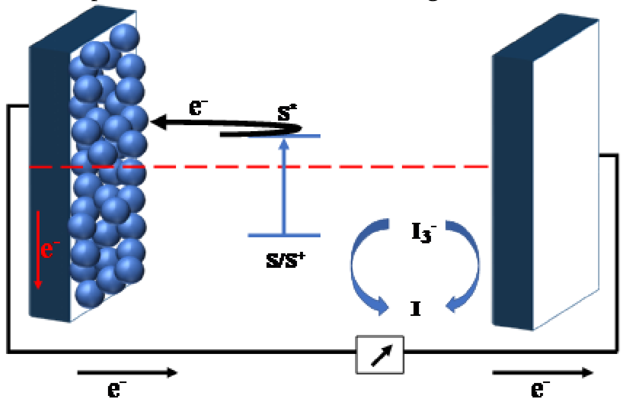

Figure 1: Principle operation of Dye sensitized solar cell

For DSSC, nano-crystalline TiO_2 is a commonly used semiconductor because of its wide band-gap and high electron negativity as working electrode coated on transparent ITO coated glass. In the mechanism of DSSCs, photons absorbed by a sensitizer and electron moves toward conduction band of TiO_2 photo electrode from photo excited state of dye molecule as given in equation 1 and 2.

Electrolytes work as a mediator and help to regenerate dye in its ground state as shown in equation 4.[2][17]

$S + photon --- S^*$	Absorption	(1)
$S^* + TiO2 - electron\ (TiO2) + S^+$	Injection process	(2)
$e^-\ (TiO2) + C.E --- TiO2 + e^-_{C.E} +$ (electrical energy)	Energy generation	(3)
$S^+ + 3/2\ I^- --- S + 1/2\ I_3^-$	Regeneration of dye	(4)
$1/2 I_3^- + e^-_{C.E} --- 3/2\ I^- + C.E$	Regeneration reaction	(5)

The counter electrode (cathode) material should be highly conductive as platinum, low resistance to charge transfer and high current transfer rate. We have used carbon is used because of low cost, high thermal resistance, high corrosion resistance. [3]

2. Experimental

Materials

Transparent glass substrate with one side conductive ITO (Indium Tin Oxide) coated of size 2*2 cm^2 area with surface resistivity 15-25 Ω/sq. as body of DSSC. Nano powder TiO_2 of size of 7 nm (Purchased from Merck) used as photoactive material with lower band gap of 3.2 eV. Nano-porous coating of TiO_2 will increase probability of light absorption in dye.[16]

Dye extraction process

In a typical procedure, leaves of coriander, peppermint, Spinach and radish obtained from nearby field. Obtained leaves washed thoroughly several time with ultrapure distilled water, dried at 60 °C for 1.30 h in a vacuum furnace and after that kept into a hot air oven for 30 min. A fine paste of all dyes separately made by dissolving of 5g of each into ethanol (25 mL) and place in a dark environment for 24 h. After that filtered with filter paper and again dried at 80 °C for an hour. Finally, the obtained components kept in cooled dark environment (5-10 °C) and used for further processes.[4,5]

Fabrication of DSSC

The fabrication of DSSC was done using ITO coated glass (resistivity of 24 Ω cm) was covered with nano TiO_2 (~7 nm) by the help of doctor blade technique. The Coated glass heated at 450 °C for 30 min then cooled to 25 °C temperature and merged in natural dye solution for 1-2min.[6,9] Second electrode coated with graphite by pencil stick form single thin layer of graphite over ITO coated glass. Potassium iodide based electrolyte added between two prepared ITO coated glasses. Fig.2 portrays the fabricated DSSC with or without light sources.

(a) (b)

Figure 2: Fabricated DSSC (a) without light source (b) with lamp as light source

Measurement and characterization

UV-Visible spectrophotometer (Lambda 25, Perkin Elmer) used for absorption spectra of extracted dye. Perkin Elmer FTIR analysis done in the range of 400-4000 cm-1 using KBr. Photoluminescence spectrophotometer (LS 45, Perkin Elmer) used for emission spectra[4].

3. Results and Discussion

Optical studies of extracted natural dyes

The UV-Vis. Absorption spectra of extracted natural dyes shown in Fig.3. The absorption of dyes is in region of chlorophyll a type. The absorption bands of four dyes are mentioned in Table 1.

Table 1

Dye name	1st absorption peak (nm)	2nd absorption peak (nm)
Coriander	664.19	417
Peppermint	664.48	415.97,432.66
Radish leaves	664.84	415.24
Spinach	664.48	433.87

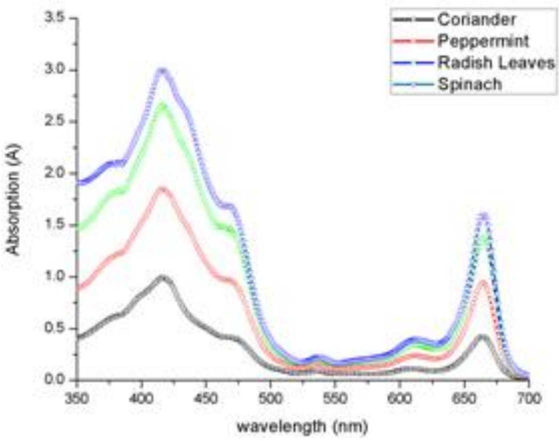

Figure 3: Absorption spectra of raw green extract

FTIR spectral study

FTIR spectroscopy used for the identification of components present in the dye extract shown in Fig 4. It was found that the broad band at 3600-3200 cm^{-1} revealed the presence of hydroxyl groups. The band of sample becomes narrow from 3600-3200 cm^{-1} to 3500 – 3300 cm^{-1} after dyeing by natural dyes, suggesting the presence of hydrogen bonds. The existence of one or more hydrogen bond donor and one acceptor would expect to lead to more hydrogen bonds, which could make the hydrogen bond behavior more complicated.

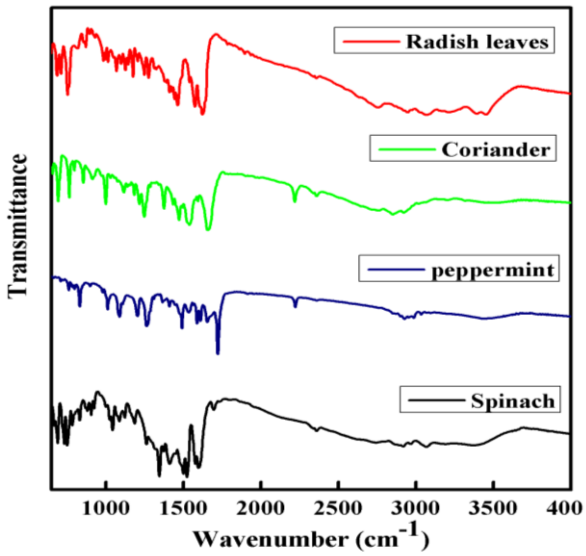

Figure 4: FTIR graph of dye samples

Photoluminescence spectral study

The green dyes coriander, radish, spinach, and peppermint are having max absorption at 200nm, 400nm wavelength. If the excitation values given to 200 nm and 400 nm then the emission of dye is nearly at 340nm and 650nm respectively. The emission spectra of green extract are nearly at 340nm as shown in Fig. 5.

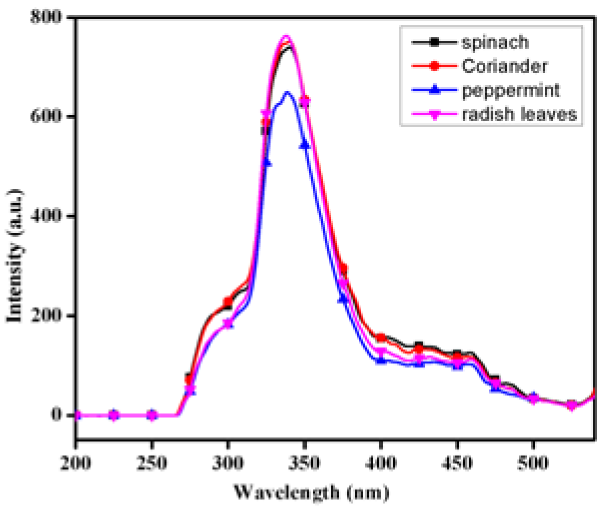

Figure 5: Green Dye Emission Spectra

Efficiency Measurements: DSSC conversion efficiency of light energy to electrical energy can be given by

$$\eta = \frac{P_{MAX}}{P_{IN}} \quad (6)$$

Where P_{MAX} is the maximum output and P_{IN} is the input power (incident light on DSSC) measured in mWcm^{-2}. [14][9] Efficiency of different fabricated Dye sensitized solar cell is shown in Table 2.

Table 2: Efficiency of different fabricated dye sensitized solar cell

Dye sample	Current(uA)	Voltage(mV)	Efficiency (η %)
Coriander	273	426	0.073
Peppermint	274	439	0.08
Radish leaves	349	570	0.13
Spinach	320	547	0.11

4. Conclusion

In this work, natural dyes extracted from locally available plants leaf used as sensitizers for DSSC. These natural dyes used as a light harvesting material extracted using Ethanol. The comparisons of extracted Pigment and its effect on the absorption spectra were investigated. The dye solutions extracted from parts of the plant material contains chlorophyll. The as-prepared DSSC were assembled using coated ITO glass as a counter electrode, natural dye anchored TiO_2 film as a photo-anode. When chlorophyll pigments used as a light harvesting, did not offer high conversion efficiencies, due to lack of available interaction between the dye and TiO_2 molecules resulting low loading on the surface TiO_2 films. Generally, natural dyes as sensitizers/light harvesting materials for DSSCs are promising because of their environmental friendliness, low-cost of production and simple manufacturing technique.

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References

[1] Renato Hunter, Monica Rubilar, Boris Pavez, Eduardo Morales, Simont Torres Julio Leyrer, Development of dye-sensitized solar cells based on naturally extracted dye from the maqui berry (Aristotelia chilensis) *ELSIVIER Optical* Materials, 60 (2016) 411-417.

[2] H.M. Wub, T.L. Chenc, K.D. Huangd, C.S. Jwoe, Y.J. Loa H. Changa, Dye-sensitized solar cell using natural dyes extracted from spinach and ipomoea, *journal of alloys and compounds*, 495 (2010) 606-610.

[3] Taher M. EL-AGEZ, Kamal S. ELREFI, Monzir S. ABDEL-LATIF Sofyan A. TAYA, Dye-sensitized solar cells based on dyes extracted from dried plant leaves, *Turkish Journal of Physics*, (2015) 24-30.

[4] Abu Bakar Mohamad, Norasikin A. Ludin, Abd. Amir H. Kadhum, Kamaruzzaman Sopian Mahmoud A.M.Al-Alwani, Dye-sensitised solar cells: Development, structure, operation principles, electronkinetics, characterisation, synthesis materials and natural photosensitisers, *Elsevier Renewable and Sustainable Energy Reviews*, 65 (2016) 183-213.

[5] Johnson Irudayaraj Joseph Sagaya Kennedy Arockiasamy, Natural Dye Sensitized CuO Nanorods for Luminescence Applications, *Ceramics International*, 42 (2016) 6198-6205.

[6] Sholeh Hadi Pramono, Dody Fanditya, M. Julius Eka Maulana, Effect of Chlorophyll Concentration Variations from Extract of Papaya Leaves on Dye-Sensitized Solar Cell, *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, 9 (2015) 49-52.

[7] M.H.Buraidah, S.N.F.Yusuf, M.A.Careem, S.R.Majid, and A.K.Arof M.M.Noor, Performance of Dye-Sensitized Solar Cells with (PVDF-HFP)-KI-EC-PC Electrolyte and Different Dye Materials, *International Journal of Photoenergy*, (2011) 5.

[8] Antonio Attanzio, Eva Busatto, Thibaud Etienne, StefanoCarli, Antonio Monari, Xavier Assfeld, Marc Beley, Stefano Caramori, and Philippe C. Grosa Walid Sharmoukh, 2,5-Dithienylpyrrole (DTP) as donor component in DTP-π-A organic sensitizers: photophysical and photovoltaic properties, *RSC Advances*, (2015) 4041-4050.
[9] A. M. Al-Alwani Mahmoud, Abu Bakar Mohamad, Abd. Amir H. Kadhum, Kamaruzzaman Sopian, Nor Shazlinah Abdul Karim Norasikin A. Ludin, Review on the development of natural dye photosensitizer for dye-sensitized solar cells, *Renewable and Sustainable Energy Reviews*, (2014) 386-396.
[10] C.O. Sreekala and K.S.Sreelatha Jinchu. I, Dye Sensitized Solar Cell using Natural Dyes as Chromophores - Review, *material science forum*, 771 (2014 39-51.
[11] Monishka Rita narayan, Review: Dye sensitized solar cells based on natural photosensitizers, *Renewable and Sustainable Energy Reviews*, (2012) 208-215.
[12] Subbaiah Manoharan, Sharafali. A, Sambandam Anandan and Ramaswamy Murugan Vinoth Shanmugam, Green grasses as light harvesters in dye sensitized solar cells, *spectrochimica acta*, (2014) 947-952.
[13] 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.
[14] Marko Berginc, Franc Smole, Marko Topic Miha Filipic, Analysis of electron recombination in dye-sensitized solar cell, *Current Applied Physics*, (2012) 238-246.
[15] Panagiotis A. Angaridis, Georgios Charalambidis, Ganesh D. Sharma and Athanassios G. Coutsolelos Vasilis Nikolaou, Click-chemistry approach for the synthesis of porphyrin dyads as sensitizers for dye-sensitized solar cells, *Dalton Transactions*, (2015) 1734-1747.
[16] Mohamed M.S.Abdel-Mottaleb,HodaS.Hafez and Mona Saif M.S.A.Abdel-Mottaleb, J-Aggregates of Amphiphilic Cyanine Dyes for Dye-Sensitized Solar Cells: A Combination between Computational Chemistry and Experimental Device Physics, *International Journal of Photoenergy*, (2014) 6
[17] Umar Ahmadu, Adamu Idris, Mohammed Isah Kimpa, Uno Essang Uno, Muhammed Muhammed Ndamitso, Noble Alu Kasim Uthman Isah, Betalain pigments as natural photosensitizers for dye-sensitized solar cells: the effect of dye pH on the photoelectric parameters, *Materials for Renewable and Sustainable Energy*, 4 (2015) 39.