RESEARCH PAPER | Engineering | Volume : 4 | Issue : 6 | June 2014 | ISSN - 2249-555X

Dye Sensitized Solar Cells for The Transformation of Solar Radiation into Electricity

KEYWORDS: Solar Cell, Clean Energy, Natural dyes, Photosensitizers

N.T. Mary Rosana
Research Scholar, Department of Chemical Engineering, Sathyabama University, Chennai-119, India

Joshua Amarnath . D
Professor , Department of Chemical Engineering, Sathyabama University, Chennai-119, India

ABSTRACT *The requirement for energy is ever increasing in recent days due to the rapid urbanization and industrialization, and the need for the innovation of clean energy and eco-friendly technologies is of prime importance in the present scenario. Solar energy is abundant in nature and is a promising alternative due to its remarkable benefits on comparison with the other available renewable energy technologies. Dye Sensitized solar cell commonly referred to as DSSC, is a third generation solar cell and it is basically used for the conversion of abundantly available solar energy into electrical energy. In this paper, a crisp review has been made on DSSC and its working principle with special emphasis on the various natural dyes and their reported conversion efficiencies.*

Introduction
Solar radiation is the abundant source of energy on earth. The conventional silicon based solar cells are not widely preferred due to their high production cost and efficient manufacturing techniques. Dye sensitized solar cells (DSSC's) have gained considerable attention due to their eco friendly nature, attractive appearance, economical fabrication procedures and ease of manufacture. It is a growing and an intense research field with a potential in the framework of non-conventional energy technologies. DSSC's are the modern devices used for the conversion of solar energy into electrical energy based on the sensitization of the wide band gap semiconductor. It was first developed by Grätzel and his coworkers in 1991 at Swiss federal institute of technology, Lausanne, Switzerland.

Objective of the paper
Aims to understand the concepts related to DSSC's and to analyze the various methodologies adopted by researchers involved in DSSC field to explore the solar cell applications with special emphasis on the natural photosensitizers.

Components of a DSSC
The DSSC consists of the following components

1. Semiconductor film Electrode
2. Electrolyte
3. Counter electrode
4. Photosensitizer

Semiconductor film Electrode
The semiconductor serves as a carrier onto which the dye molecule with suitable anchoring groups are absorbed. The wide band gap semiconducting materials such as Titanium dioxide (TiO_2), zinc oxide (ZnO), and tin dioxide (SnO_2) have been reported by researchers for their large band gap and high electron mobility. Titanium dioxide is well preferred due to its wide availability, non-toxic nature, biocompatibility, and good chemical stability under visible irradiation. Doctor blade technique, screen printing, electrophoretic deposition etc. are the most widely used techniques for forming the titanium dioxide thin films.

Electrolyte
The Electrolyte is an essential component in a DSSC which mediates the electrons between the photo electrode and the counter electrode. The electrolyte used influences the essential parameters such as short circuit current density (J_{SC}) and the open circuit voltage (V_{OC}). The commonly used electrolyte is iodide/ tri iodide (I^- /I^{3-}). In addition, room temperature ionic liquids (RTIL's) have been reported as alternatives. Solid state electrolytes possess high mechanical stability and simple fabrication. Quasi solid electrolytes were developed which involves a combination of both the solid and liquid electrolyte with the aim of eliminating the drawbacks associated with solid state electrolytes. Various additives are also added to the electrolyte to improve the open circuit voltage and to increase the stability.

Counter Electrode
The Counter electrode should possess good electro catalytic activity and it serves the purpose of transferring the electrons from the external circuit to the redox electrolyte. Carbon (C) has been reported as the material for the preparation of counter electrode. Platinum (Pt) is the desired material for DSSC applications and various research groups have fabricated the cells with platinum counter electrodes to achieve the best conversion efficiencies.

Photosensitizer
The dye molecule is used as a photosensitizer in the performance of a DSSC. It serves as the absorber of sun's radiation and plays a vital role in increasing the efficiency of the cell. A typical photosensitizer must possess the following requirements.

1. Strong absorption in the visible region
2. It must carry appropriate attachment chemical groups to bind strongly with the semiconductor surface
3. Capable of injecting the electrons upon excitation
4. It should be more stable in order to withstand many turnover cycles
5. It should be cost effective in nature

Working principle of a DSSC
DSSC is a regenerative solar cell. The absorption of light from the light source by the dye molecule which acts a photosensitizer initiates the process of generating electric power. After the light absorption and excitation, an electron from the excited state of the dye molecule is injected into the conduction band of the Titanium dioxide semiconductor layer. The electrons that are injected travel through the semiconductor layer into an outer electrical circuit to generate electric current. The dye that has lost the electron is in turn regenerated and returned back to the normal state by the electron donation from the electrolyte used in the cell. The iodide is regenerated by the reduction of the tri iodide at the counter elec-

Volume : 4 | Issue : 6 | June 2014 | ISSN - 2249-555X

trode. The voltage that is produced in the DSSC is attributed to the difference between the Fermi level of the electron in the solid and the redox potential of the electrolyte.

Dye as a photosensitizer

The structure of the dye plays an essential role in DSSC's. Some of the dyes reported in DSSC's are

- **Synthetic Dyes**

Inorganic metal based dyes

The Ruthenium dyes are well recognized as photosensitizers in DSSC's due to their photoelectrochemical characteristics, high stability and for their intense absorption in the visible and near infrared region and is attributed to the metal to ligand charge transfer (MLCT) transition. The cis - bis(4,4'–dicarboxy -2,2' bipyridine) (dithiocyanato) Ruthenium (II) ($RuL_2(NCS)_2$ complex) referred to as N_3 dye is capable of absorbing a wide range of visible light in the range of 400-800 nm. The (4,4'4''-tricarboxy-2,2':6',2''-terpyridine) (trithiocyanato) Ruthenium (II) (Black Dye) (Ru L' $(NCS)_3$ Complex) is reported for its absorbance in the near IR region up to 900 nm. Along with these dyes, the Tetra butyl ammonium salt of N_3 dye known as N719 was also reported. Various research groups focus on the molecular engineering of metal sensitizers with the aim of improving the efficiency. Recently, a high efficiency of 13% is reported with Porphyrin based dye by Prof. Grätzel with Cobalt (II/III) electrolyte under AM 1.5G solar simulation.

The main drawbacks associated with the Ruthenium based dye is its expensive nature, rare availability, require skilled synthesis and poses major environmental threat.

Metal free Squaraine dyes

The conversion efficiency of organic dyes has increased significantly and it is comparable with the Ruthenium dyes. Squaraine dyes are investigated for their intense absorption in the visible and near infrared region. Most of the squaraine dyes are synthesized by the condensation of squaric acid with suitable aromatic compounds. synthetic routes have been developed to synthesize both symmetrical and unsymmetrical squaraine based dyes with the aim of increasing the overall conversion efficiency of the DSSC. Das and coworkers have reported various squaraine based dyes with different synthetic strategies. Recently an Indoline based squaraine dye is reported by Prof. Grätzel with a conversion efficiency of 6.74% with I^-/I^{3-} electrolyte under AM 1.5 solar illumination.

- **Natural Dyes**

Natural dyes prove to be a viable alternative to the synthetically obtained dyes due to their low cost, easy availability, simple extraction procedures and non-toxic nature. Usage of natural dyes does not pose any threat to the environment. Natural dyes have been extracted from flowers, fruits, stems, vegetables using cost effective procedures and successfully used as molecular sensitizers in the fabrication of DSSC's. The plant material possessing natural pigments such as anthocyanin, chlorophyll, carotenoid and Betalain have been studied by different research laboratories to find its role as a photosensitizer in harnessing the enormously available sun's radiation. Few of the conversion efficiencies reported by researchers have been listed in the table. Some of the pigments of prime interest are

Anthocyanins

These are the flavonoid compounds possessing complex structures and are also abundantly available in nature. The anthocyanin is basically responsible for absorbing light in the visible region and is therefore responsible for colours from red to blue range . The hydroxyl groups found in the anthocyanins can bind themselves to the TiO_2 nano structured film due to the phenomenon of chemical adsorption. Different kinds of anthocyanins have been isolated from plants and are the derivatives of flavylium ion.

Betalains

These are the water soluble pigments which show bright colours in flowers found in plants of the order caryophyllales. They consist of betacyanins and betaxanthins. Betalains are reported for their antioxidant activity. Their light absorption behavior is in the visible region and they possess (-COOH) functional groups in order to attach themselves to the TiO_2 layer.

Table - Reported efficiencies of some naturally extracted dyes

Natural dye source	Pigment	η(%)	Ref
Sicilian prickly pear	betaxanthin	2.06	[8]
Red frangipani flowers	anthocyanins	0.301	[9]
Ivygourd	β carotene	0.08	[9]
Wormwood	chlorophyll	0.9	[10]
Purple cabbage	anthocyanin	1.47	[10]
Rosella	Cyanidin, Delphinidin	0.7	[11]
Blue pea	Ternatin	0.05	[11]

Conclusion

Dye sensitized solar cells prove to harvest the abundantly available solar radiations. Natural dyes can be used effectively as photosensitizers due to their low cost, non-toxic nature, cost effective extraction procedure and wide availability. Though the efficiencies reported with the extracted natural dyes are considerably less on comparison with the synthetically produced ruthenium dyes and other organic dyes, the values are academically interesting and hence the search for novel natural photosensitizers can be carried out so as to explore its applications in harnessing solar energy and to achieve a considerable efficiency. Thus incorporating naturally extracted dyes in DSSC's paves a way for sustainable development and a greener environment.

REFERENCE

[1]Jiawei Gong , Jing Liang, K. Sumathy (2012), Review on Dye- Sensitized Solar cells(DSSCs): Fundamental Concepts and novel materials, Renewable and sustainable energy reviews, 16, 5848-5860. | [2]Monishka Rita Narayan, (2012), Review: Dye sensitized solar cells based on natural photosensitizers, Renewable and sustainable energy reviews, 16, 208-215. | [3]Brian O Regan, Michael Grätzel(1991), A low cost high efficiency solar cell based on dye sensitized colloidal TiO2 films, Letters to Nature, 353. | [4]Michael Gratzel(2003), Review, Dye sensitized solar cells, Journal of Photochemistry and photobiology C: photochemistry reviews, 145-153. | [5]Michael Grätzel(2004), Conversion of sunlight to electric power by nano crystalline dye- sensitized solar cells, Journal of Photochemistry and photobiology A: Chemistry 164, 3-14. | [6]Ravi Kumar Kanaparthi, Jaipal kandhadi, Lingamallu giribabu (2012) Metal free organic dyes for dye sensitized solar cells: recent advances, Tetrahedron, 68, 8383-8393. | [7] Handbook of photovoltaic science and engineering,edited by A. Luque and S.Hegedus, 2003, John-Wiley and sons ltd, 663-696. | [8] Giuseppe Calogero, Jun Ho Yum, Alessandro Sinopoli, Gaetano Di Marco, Michael Gratzel, Mohammed Khaja Nazeeruddin (2012),anthocyanins and betalains as light harvesting pigments for dye sensitized solar cells, Solar energy, 86, 1563- 1575. | [9] Vinoth shanmugam, Subbaiah Manoharan, Sambandam Anandan, Ramaswamy Murugan, (2013), performance of dye sensitized solar cells fabricated with extracts from fruits of ivy gourd and flowers of red frangipani as sensitizers, spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 104,35-40. | [10] Ho Chang , Mu Jung Kao, Tien Li Chen, Kun Ching Cho, Xuan rong Lai (2013), Characterization of natural dye extracted from wormwood and purple cabbage for dye sensitized solar cells, International journal of photoenergy. | [11] Khwanchit Wongcharee, Vissanu Meeyoo, Sumaeth Chavadej (2007), Dye sensitized solar cell using natural dyes from rosella and blue pea flowers, Solar energy materials & solar cells, 91, 566-571. | [12] Simon Mathew, Aswani Yella, Peng Gao, Robin Humphry Baker, Basile F.E.curchod, Negar Ashari Ashtani, Ivano Tavernelli, Ursula Rothlisberger, Md.Khaja Nazeeruddin, and Michael Gratzel, Dye-sensitized solar cells with 13% efficiency achieved through the molecular engineering of porphyrin sensitizers, Nature Chemistry 2014, 6, 242-247. | | [13] Yanrong Shi, Rebecca B. M. Hill, Jun Ho Yum, Amalie Dualeh, Stephen Barlow, Michael Gratzel, Seth R Marder, Mohammad K. Nazeeruddin, A High-Efficiency Panchromatic Squaraine Sensitizer for Dye-Sensitized Solar Cells, Angew. Chem. Int. Ed. 2011, 50, 6619 –6621. |