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# A Brief Review on Natural Photosensitizer Based Dye-Sensitized Solar Cells For Photoelectric Conversion

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**ABSTRACT**

The main purpose of this brief review article is to provide the simple and short knowledge of dye sensitized solar cell technology from the working principles to the commercial application.This paper explains the role of the sensitizer, construction of Dye sensitized solar cell (DSCC) and preparation of electrodes. In DSCC, dye is used instead of metal. Natural dyes are extracted by various parts of plant like fruits, seeds, flower and leaves. Green Parts of plant contain chlorophyll and coloured parts like flower, buds, etc. contain anthocyanin. Both chlorophyll and anthocyanin absorb electromagnetic radiation. Selection of efficient dye plays a key role in enhancement of efficiency of the cell.

**Keywords**: Dye sensitized solar cell (DSCC), Sensitizer, Electrodes, Chlorophyll and Anthocyanin.

## INTRODUCTION

The demand for energy is increasing day by day due to increase in population.The nonconventional fossil resources are depleting and thus will not be enough to cater to this rising demand. Therefore demand for more energy and shortage of energy has become an important area of research in developing and developed countries. Due to the limitation of energy resources, the policies of India should now have been changed. After the USA and China, India has the highest demand for energy. In ancient times the biomass is used for cooking, which represents about 13% of total energy consumption. Large hydro power represents 3% and is growing in developing countries (IEA report, 2008). There are various alternative sources of energy, solar energy is the best and indefinite energy resource on the earth, and it is available for use in direct (solar energy) and indirect (wind energy, hydro power, geothermal, etc.) forms.

The first solar cell was invented by the New York scientist Charles Frittis by coating the selenium on a gold film (R. Eisenberg, D.G. Nocera 2005). Then the traditional one, i.e., silicon based solar cells were used. In the photovoltaic cell, the semiconductor layer produces an electric current by exploiting the photovoltaic effects. Silicon based solar cells are having the disadvantage that the initial cost is very high for the equipment to harness the energy. So, there is an alternative technology known as DSSC which stands for Dye-Sensitizing Solar Cell.

A DSSC works on the principle of photosynthesis in plants. This cell was developed by Gratzel and Brian O. Regan at the Ecole Polytechnique (F. Lausanne, 1991, B, O' Regan, *et al.,* 1991). DSSC is commonly known as GRATZEL'S solar cells. In DSSC, Gratzel used synthetic dyes. Some natural organic dyes extracted from green spinach, algae, and green leaves of tree were also used in DSSCs (S.A Taya, *et al.,* 2013). DSSC is more advantageous over photovoltaic or silicon based cells. They are stable device, eco-friendly, low cost manufacturing, and higher performance efficiency of solar to electrical energy conversion. The actual conversion efficiency of DSSC is 11% (B, O' Regan, 1991), but that can be further improved by the adoption of various technologies.

In DSSC, dye is used instead of the metal. Natural dye is simply extracted by plants, fruits, seeds, leaves, etc. It does not pollute the environment as it is biodegradable and non-toxic. It has very good efficiency to absorb light energy from the visible light, (Abdel-latif, 2013, AS Polo 2006) because the large part of plants contains the green chlorophyll pigment and colored parts like flowers, buds, etc. contains anthocyanin absorbing in the range of 520-550nm wavelength, (Chang H2010, Kumara NTRN, *et al.,* 2013).

Chlorophyll is found in the chloroplast. There are various types of chlorophyll pigments present in plants, i.e. chlorophyll A, chlorophyll B, carotenoids, etc. These two chlorophyll A and chlorophyll B are known as reaction centre and are slightly different from each other in the composition of a single side chain. Many light harvesting complexes (LHC) are present in each chloroplast which absorbed energy of light. The highest absorption of chlorophyll A occurs at 430nm -630nm while it is 450nm -640nm in case of Chlorophyll B.

DSSC mainly includes the Nano particles of $TiO_2$ electrodes which are impregnated on dye surface in a transparent conducting oxide (TCO). The performance of DSSC mainly depends on the $TiO_2$ particles and the absorption spectrum of dye association. The best photosensitized effect occurs by the dye which is extracted by black rice. This is due to the better interaction between the surface molecules of $TiO_2$ porous film and carbonyl and hydroxyl group of anthracyanin molecules present in black rice extract. A dye extracted by the fermentation of manscus (red yeast rice) has been studied as a novel sensitizing dye for DSCC. The dye which is selected for sensitization play a very important role in the enhancement of the efficiency of a DSCC. (Figure 1).

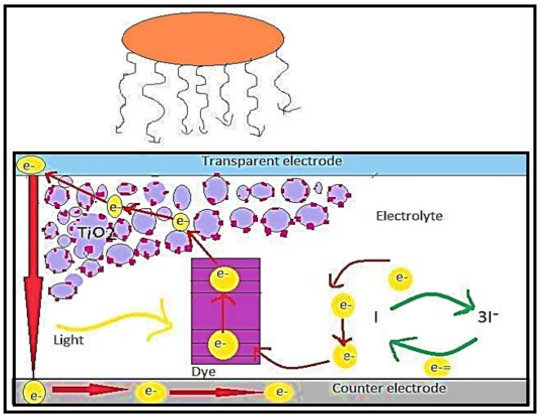


**Fig. 1. DSSC Structure, (Bill Norrington, 2010)**

## Background

DSSC has recently emerged as a progressive research area for solar cells from last decade amazing progress were made on various aspect of DSCC e.g. stability, commercialization and efficiency etc. The first DSCC was developed by or Tsubomura *et al.,* In 1976 using porous zinc oxide (Samy shaat *et al.,* 2017).

Brian O. Regan and Michael Gratzel developed a DSCC in 1991 using black dye and enhanced the conversion efficiency of DSCC by 7.12%. Using Ru based dye (N749) they increased the efficiency of DSCC up to 10%. This led to a great success in the research area. The researchers of EPFL in Switzerland have achieved a new efficiency record of 15% for dye sensitized solar cells. The photo electrochemical conduction (PEC) of DSSCs mixture of different dyes solution was also investigated.

B. Pari *et al.,* (2014) studied the third generation photovoltaic materials and recent advances in $SnO_2$ based DSSC. The third generation of solar cells devices (10.7%) and dye sensitized solar cell (14.1%) has good conversion efficiencies (Yella A. *et al.,* 2011).

It was found in early 2000s that the organometallic complexes of Ruthenium have highest power conversion efficiencies (D. Zhanget *et al.,* 2008). The most enhanced reduction oxidation couple was Iodide/Triodide. In late 1990s the power conversion efficiency reached to 10% and settled to 11.5%. The hydrochemical method has been widely used to prepare $TiO_2$ after the investigation of Gratgel cells and introduced the synthetic method of $TiO_2$ nanotubes in 1998 (T. Kausuga *et al.,* 1998-1999).

The development of solar cell technology is represented in Fig. 2. The four generation of solar cell included: (i) single crystalline silicon solar cell, (ii) amorphous silicon solar cell; polycrystalline silicon solar cell; cadmium telluride solar cells; copper indium gallium diselenide (IGS) solar cell, (iii) sensitized solar cell; DSSC (B,O' Regan, M. Gratgel 1919), Quantum dot sensitized solar cells (QDSSCs) (O. E. Semonin, J. M. Luther, S. Choi 2011, M. Yu, G. W. Fernando 2006), (iv) polymer solar cells; planar heterojunction polymer solar cells (tang solar cell) (C. W. Tang 1986), bulk heterojunction polymer solar cell (BHI) (W. U Huynh, J. J. Dittmer, W. C. Libby, G. L. Whitting 2003), hybrid planar heterojunction solar cells; Bulk heterojunction Tandem solar cell (Fig. 2) (N. S. Saraciftci, Smilowitz, A. J. Heeger, F. Wudi, 1992).

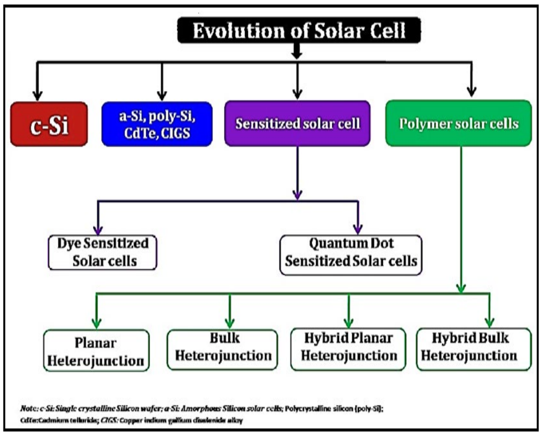


**Fig. 2. Evolution of Solar Cells**

Working of DSSC was explained in various steps by M. Sokolsky, J. Cirak, 1992. Recently, $TiO_2$ has more attention from researchers worldwide due to its conceivable application in environmental safety and energy production (L. Saadoun *et al.,* 2000). This has been largely used in DSSC due to its nanocrystalline mesoporous nature that provides high surface area for dye adsorption. Since the dye plays a very vital role in absorbing the visible region of light and transferring photon energy into electrical energy, much attention has been paid to survey the effective sensitizer.

## Construction of DSSC

### Natural Dye and its Extraction

The coloured pigments present in various part of green plants like fruits, leaves, seed, flowers, buds, etc. absorb visible light and these pigments are called Natural dye. $TiO_2$ is a semiconductor which is white in colour and it does not absorb visible light. So it is necessary to coat the Titania electrode with a dye which can absorb in visible spectrum of light. Naturally, the dye can be extracted from selected plant material such as leaves, flowers, fruits, etc.

Extraction of dye can be carried out from raw plant material in following steps:

1. Washing
2. Grinding
3. Centrifugation
4. Filtration

Acetone is a good solvent to extract pigments from plant materials. The extracted dye can be characterized by various techniques.

### Preparation of electrodes

Two electrodes are present in DSCC, one as cathode and another as anode. A specific glass of 2 mm thickness is used as an electrode in these cells and coating with a transparent conductive oxide ($TiO_2$) on one side (2.5x2.5 $cm^2$). The availability of a conductive slide makes a more efficient solar cell. The non-conducting glass slide can be made conductive with the help of $SnCl_2$ and ammonium difluoride by evaporation method. The characterization of the conducting slides can be done by simple microscopy, determining of resistance with the help of keithley source meter and multimeter, XRD, UV-Visible spectroscopy, etc. The transparency of the substrate helps in passing the sunlight to enter the cell while its conductive surface area collects solar energy.

The negative terminal of DSCC is the anode. The anode essentially ensures a continuous network of $TiO_2$ nanoparticles. The inner surface area of this porous network is thousand times greater than the equivalent flat area and behaves as a "light–sponge" which can trap the sun light. $TiO_2$ is a semiconductor which is white in colour and does not show any sensitivity to visible light. Therefore this anode is soaked with a dye solution. Dye is a photosensitizer and is able to convert the light energy into electric energy.

The cathode of the DSCC is covered with a catalytic material such as platinum. The electrode remains transparent as small amount of catalyst is required. An electrolyte is filled between the space of two electrode and this electrolyte transports the charge through a redox couple. The most common electrolyte used in DSCC is iodide/triiodide solution. To prevent the evaporation of electrolyte solvent, the two electrode are sealed together.

**Working principle**

**Operating principle of dye sensitized solar cell:-**

To increase the surface area of $TiO_2$ for the absorption of sensitizer (dye material) nano particles of $TiO_2$ are placed in the photo electrode. The energy absorbed by the dye, promotes the electrons from the highest occupied atomic orbital (HOMO) to the lowest unoccupied atomic orbital (LUMO). To become more effective, the Homo of dye lies in the band gap of the semiconducting material and LUMO of the dye in the conduction band of the semiconducting material. Meng *et al.,* found that the electrons ejected from the Cynin dye to the Titanium dioxide conduction band minimum (CBM) by 0.1-0.3 ev (Meng *et al.,* 2008). This explains the current understanding mechanism of DSCC and also improves the efficiency and compatibility to optimize their design.

**Electron hole separation, electron injection, and collection**

The integrated bond between the $TiO_2$ and dye helps the excited electrons to inject into the conduction band of the semiconductor; after this they are transported and collected by the anode. In contrast by the photon excitation the hole is generated, remains on the molecule during this process, since the HOMO of dye is separated from all other energy levels of the device.

**Redox reaction at the dye electrolyte interface, and at counter electrode**

To diffuse the hole into $TiO_2$ photo anode, there is no energy source. Therefore, this hole is ultimately filled up by the electrons of electrolyte, so the current is flown between the molecule of the dye and the cathode. The reduction of the triiodide on cathode, regenerates the iodide ion. Thus, the overall mechanism is that the electron flow from anode of the cell to the outer circuit. If there is no voltage loss during regeneration of natural dye, ejection of electron and in diffusion of electron then the potential difference is equal to the energy of incident photon.

**Recombination**

In DSCC, the electrons from $TiO_2$ Nano particles diffuse to the anode by hopping between particles (Baxter *et al.,* 2006). The recombination of photo excited electron with electrolyte is appreciably feasible with each hop because both the rate of recombination and diffusion are the order of millisecond.

Hence, this makes it possible for recombination to limit the cell efficiency. From another point of view nano wire or tube, structured photo electrode provides a direct path (express high way) to the anode, without increasing the rate of recombination, leading to increased diffusion rate and thus increased cell efficiency. Due to the loss of ejected electrons from nano structured wide band gap semiconductor ($TiO_2$) to hole carrier in electrolyte solution ($I_3^-$), a dark current flows in DSCC. Thus, this back reaction must be minimized. The open circuit voltage enhances as the dark current is reduced. The following general equation of solar cell are used to determine the relating open circuit voltage $V_{oc}$ to both the injection current Iinj and dark current Idark.

$$V_{oc} = KB\ T/q\ [\ \ln I_{inj}/I_{dark}+1]$$

$K_B$ = Boltzmann constant, *T* is the absolute temperature of the cell, and q is the magnitude of the electron charge.

**Advantages of DSSC**

**The main advantages of DSCC are as follows:**

**The capability of manufacturing in a simple way:** In the manufacture of DSSC vacuumed system is not required and thus has an excellent advantage in term of production cost (S. Bose *et al.,* 2015). It reduced the expenditure of manufacturing by 1/5 to 1/10 as compared silicon solar cells production cost (S. Suhaimi *et al.,* 2015, S. Yoon *et al.,* 2011, M. Gratgel 2001).

**Thin and flexible structure:** The use of aggregates of tiny particles of photo electric conversion material allow the solar cells to be formed as a flexible thin film.

**Lighter weight:** To minimize the weight, a plastic substrate can be used in DSCC. The other solar cells are not installed in the outer and inner wall, glass plane of building, source of outer panels of vehicles and enclosure of a hand phone and DSCC can be installed.

**Colourable and transparent:** As DSCC is made by the use of natural dye, which consists of a wide range of coloured cells and transparent cells, this makes them to decorate the desire place as window and sun roof (C. W. Tang 1984).

**Environmentally friend and recyclable:** DSCC solar cells have no harmful materials. The materials which are used to prepare DSCC are easily separable and used back. In the view of recycling and reuse frame work of solar cell, DSCC is highly advanced (T M Elagez *et al.,* 2012).

**Challenges**

Low stability and low efficiency are the big challenges for the commercial development of DSSCs; the following steps can be recommended in order to enhance the efficiency of DSCC.

1. Improvement in the formation of the semiconductor to reduce the dark current.
2. To improve the charge transfer rate, developing low volatile and less viscous electrolyte.
3. Improvement in the design of dye to absorb radiation in the NIR region.
4. Improvement in mechanical contact or adhesion between the two electrodes.

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**Conflict of Interest**

The authors don't dispute or have any conflicts of interest.

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