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Recent Progress in Dye Sensitized Solar Cells

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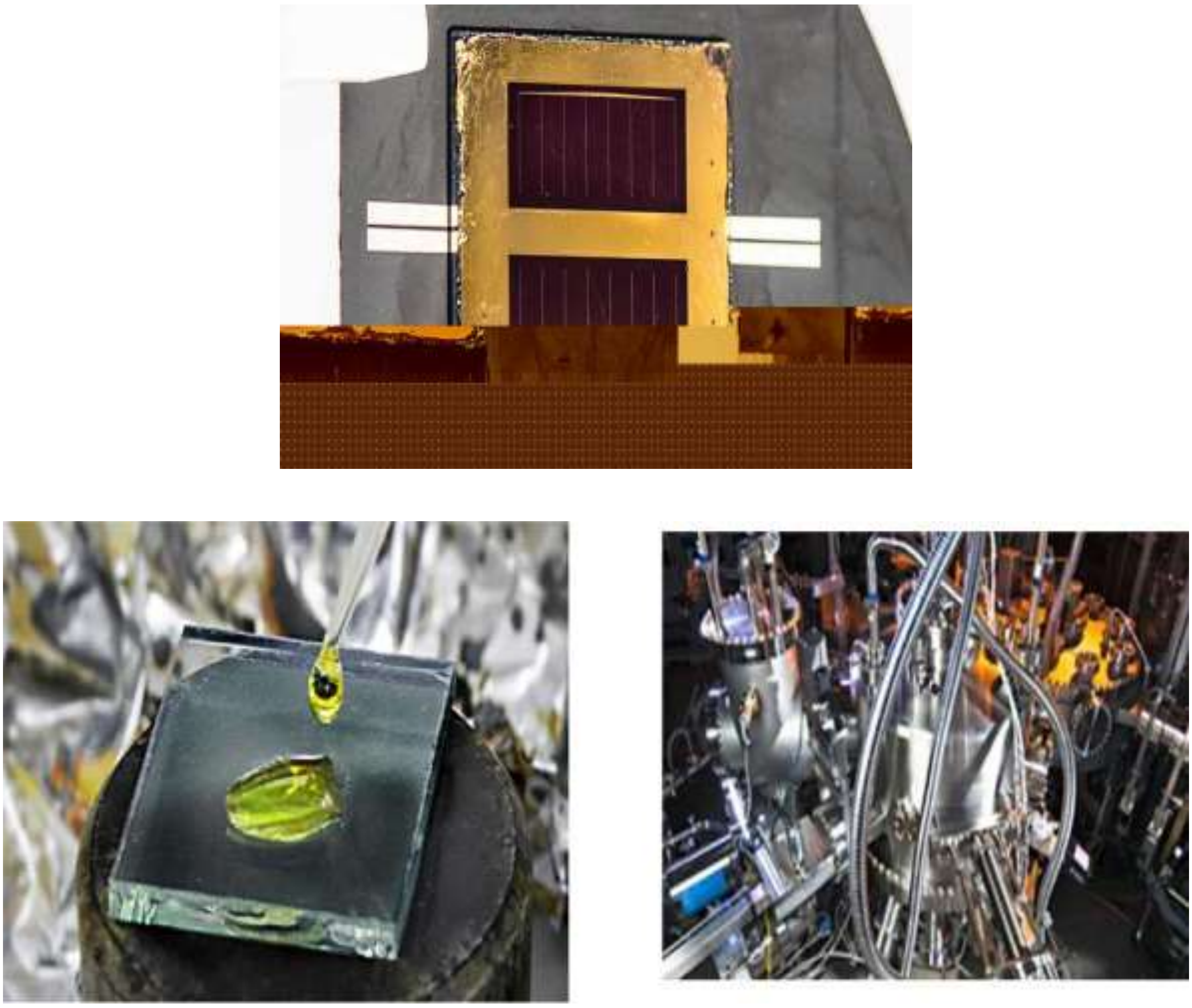
Abstract: The article summarizes the recent trends in solar cells particularly in the field of Dye Sensitized Solar Cell. The DSSC we would refer for short for Dye Sensitized Solar Cell. The Dye Sensitized Solar Cell is the recent trend in the field of solar photo voltaic electricity generation. The Solar Cells captures the solar radiation and he photovoltaic material convert those solar radiations to the usable voltage which could be used for various purpose. The conventional method using in this regard consists of the use of Silicon wafer photovoltaic solar cell which is way too costly to be used. The most efficient way to achieve the objective (cheaper solar energy) is to replace the Silicon from the PV Solar Module (Silicon being the most costly material of the module) with any other chemical or element which is abundantly available in nature and also is very cost effective. Titanium Dioxide ($Ti0_2$) is one major compound which can be used to replace Silicon along with the Ruthenium Dye. Apart from presently being many methods for a generation or harnessing solar energy, the Dye Sensitized Solar Cells or DSSCs have acquired the attention of a much wider section of scientists and engineers working in this field. Due to its greater and wider working capability in the solar UV Spectrum ad future scope of the material and porous structure and semiconducting behavior, the mesoporous titania made Dye Sensitized Solar Cells are widely expected to be used in innovative applications.

Keywords: Renewable Energy, Dye Sensitized Solar Cell, Photovoltaic, Nanoparticle, Photo Catalyst, Solar Cell, Natural Dyes, Sensitizers.

INTRODUCTION

The recent trend and availability of the current deposit of fossil fuels stocks availability within the planet is seeking and urge for the change of power generation need. The environmental impact of the current rate of use of fossil fuels fulfilling our energy and power requirements have an urge for the switch to the non-conventional and renewable source of energy to meet our power requirements [1]. As per an estimation, the energy requirement is to get doubled by the year 2050 because of the rapid population growth and industrialization [2]. The worldwide concern for environmental aspect for major energy production in the country is coal based, which has major environmental impact. Thus, the geothermal energy, hydrothermal energy, nuclear energy, wind energy, biomass energy, etc i.e. carbon free energy production method is getting momentum [3]. However, light from the Sun is the major source of renewable energy as solar energy. Moreover, the efficiency and the cost of the solar energy production is the major barrier in a step toward environmentally friendly energy production method. Among all the renewable sources of energy available to us for the exploitation to meet our energy requirements, Solar Energy seems to be most promising, quiet and clear form of energy with the all the available technologies we possess [4]. The Solar radiations incident on the Earth's surface has the capability to generate and power equivalent to 1, 20,000 TW, which is sufficient to meet all our energy requirements [5]. Thus, all those methods or technologies available to us which can harness the solar energy is of the extreme category of importance to us [6].

The National Renewable Energy Laboratory classifies solar cells basically into the three main categories namely as Organic Solar Cells, Inorganic Solar Cell, Hybrid Solar Cells. The Organic Solar Cells are further classified as Polymer based solar cell and small molecule based solar cell. The National Renewable Energy Laboratory has further classified the solar cells based on the types of materials used. Fig 1 shows the classification of solar cells by the National Center for Photovoltaics (NCPV) categorizes the solar cell based on the chemistry behind the material growth and the physics behind the device operation.



(a) High-Efficiency Crystalline PV **(b) Perovskite and Organic PV** **(c) Polycrystalline Thin-Film PV**

Fig 1: Classification of Solar Cells based on NCPV

Moreover, solar cells can be further classified into three categories based on their development stages or generation of the solar cell be called for ease [7]. The mono- and-poly crystalline Silicon doped with any other element can be categorized as the First generation of the solar cell [8,9]. However, these cells are much costly in fabrication [10]. Amorphous polycrystalline compound semiconductors based thin film PV cells constitute the second generation of the solar cells. However, these cells were cheap comparatively the first generation but showed the efficiency of about only 14% which is even lesser than the efficiency shown by the first-generation solar cells which were as high as 27% [11]. Since, the development of solar cells, researcher have been trying to develop the low-cost solar PV module with significant enhancement of the efficiency. The third generation of solar cell differs from the rest by virtue of the reduced fabrication cost of the module and also it yields higher efficiency level than any other generation of solar cells [12]. The Dye Sensitized Solar cells (DSSC) [13], quantum DOT Dye Sensitized Solar Cell (QDSSC) are the few examples of the solar cell module which fall into the category of the third generation of the solar cell. The pictorial representation has been shown in Fig 2 depicting the relation of PV fabrication cost per square meter with the solar cell module efficiency and the cost per unit power [14].

The year was an improvement of DSSC cell and as well as other forms of a photovoltaic cell have been depicted in the following graphical representation in Fig [3]. The conventional solar cell which we are using based on Silicon falls under the first generation of the Solar cell. The highest efficiency level reached sol far by the crystalline silicon

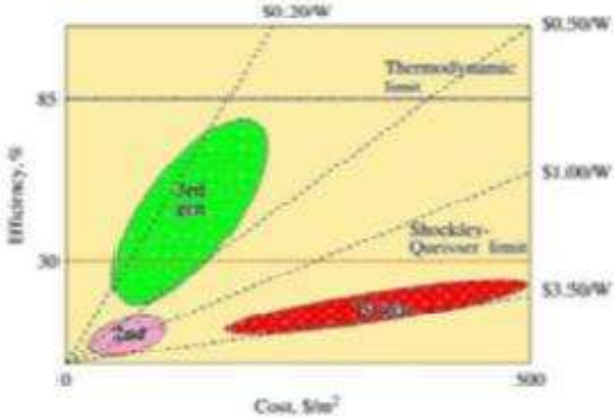


Fig 2. The efficiency cost trade off for the three differnet solar cell technology, wafers, thin -films and advanced thin films [12].

Cells are 25.6% and 20.4% respectively for Mono Silicon and Poly Silicon respectively. The thin film technologies used forms the second generation of solar cells. Amorphous Silicon, CIGS, CdTe are under the second generation with established solar technology and have efficiency 10.1%, 20.5%, 19.6% respectively. Multi Junction (37.9%), DSSC (13%), and Organic solar cell (10.7%) come from the third generation of the Solar cell and have the promising technology to pass Schokley Queisser Limit [15]. The highest level of efficiency achieved by various solar cells is shown in Table 1.

Among the various available models of the promising low-cost solar cells, DSSC which can be fabricated using a known
- vacuum printing system has attracted the greater attention of various academicians and industrial attention

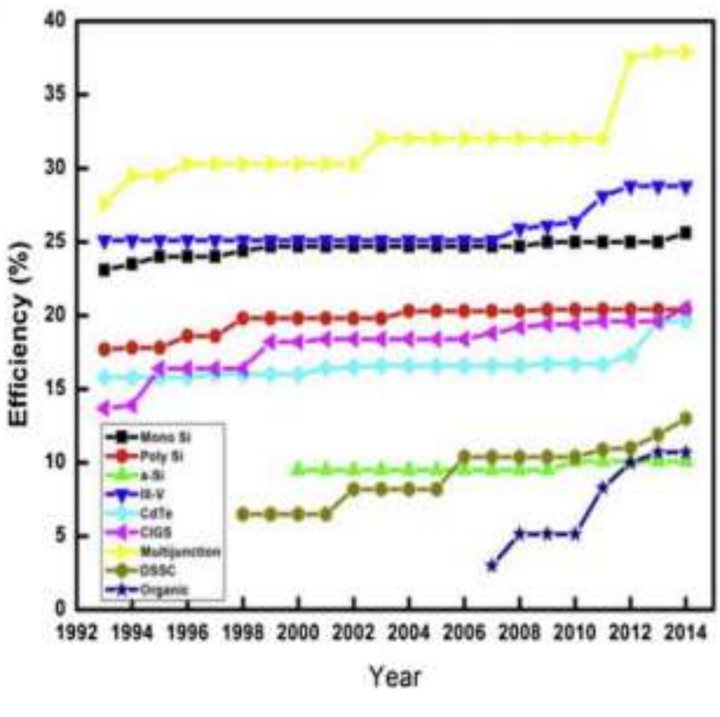


Fig: 3 Efficiency reported for various solar cell

S. no	Classification	Area (cm^2)	VOC (V)	JSC (mA cm^{-2})	FF (%)	h (%)	**Ref.**
1	**Mono Si**	143.7	0.74	41.8	82.7	25.6	[19]
2	**Poly Si**	242.74	0.6678	39.8	80	21.25	[20]
3	**Amorphous Si**	1.001	0.896	16.36	69.8	10.2	[21]
4	**III-V**	0.9927	1.122	29.68	86.5	28.8	[22]
5	**CdTe**	1.0623	0.8759	30.25	79.4	21	[23]
6	**CIGS**	0.9927	0.757	35.7	77.6	21	[24]
7	**Multifunction**	1.021	4.767	9.564	85.2	38.8	[25]
8	**DSSC**	1.005	0.744	22.47	71.2	11.9	[26]
9	**Organic**	0.993	0.793	19.4	71.4	11	[27]
10	**Pervoskite**	1.020	1.074	19.29	75.1	15.6	[28]

Scientists have done lots of research since decades improving the operation mechanism of the battery and battery component optimization etc [15], making the DSSC rapid and steady development. Dye is one of the core parts of the DSSC, whose function is to absorb sunlight, photoelectric and charge transfer to the conduction band, similar to that of photosynthesis process in plants and trees. The performance of dye sensitizer plays the key role in photoelectric conversion efficiency of the complete system.

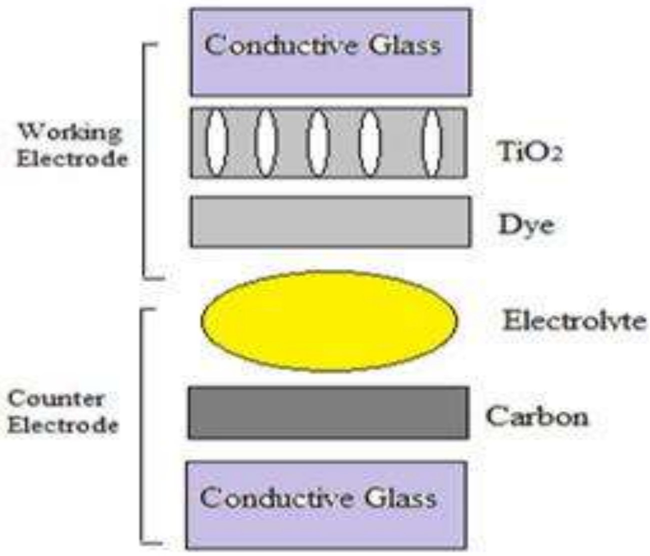


Fig Schematics of DSSC

Structure

There were two conducting glass used. Each of the conducting sides of the glass was coated with the anode and cathode. Here we used TiO_2 as anode and Carbon as Cathode. The working electrode i.e. TiO_2 was soaked in the charge carrier i.e. Natural Dyes. The two plates were assembled into sealed sandwich type cell [fig 3]. A drop of the electrolyte solution was put into the sandwich. The sandwich was then heated for 450^0C for an hour.

Front and counter substrates are coated with a transparent conducting oxide (TCO). Fluoride doped tin Oxide (FTO) is most commonly used. The TCO glass at the counter electrode is coated with few atomic layers of carbon. In order to catalyse the redox reaction with the electrolyte.

Usually, the photo anode is prepared by adsorbing a dye on a porous TiO_2 layer. By this approach, the dye extends the spectral sensitivity of the photo electrode, enabling the collecting of lower energy photons. Due to its crucial role in such systems, considerable efforts have been directed towards the development and improvement of new families of organic dyes and of metal complexes, the most efficient so far been Ru(II) and Os(II) polypyridine dyes, which couple broad spectral sensitivity to almost ideal ground and excited state thermodynamic and kinetic properties. Since the preparation of synthetic dyes normally requires multi-step 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, vegetables, and flowers with minimal chemical procedures.

WORKING PRINCIPLE

The dye is the photoactive material of the DSSC cell and can produce electricity once it is sensitized by solar light. The dye catches the photon of incoming light (sunlight and ambient artificial light) and uses their energy to excite electrons, behaving similarly to chlorophyll as in photosynthesis. The dye injects the excited electron into the Titanium Dioxide. The electron is conducted or carried away by nanocrystalline titanium dioxide (a nano scale crystallized form of the titanium dioxide).

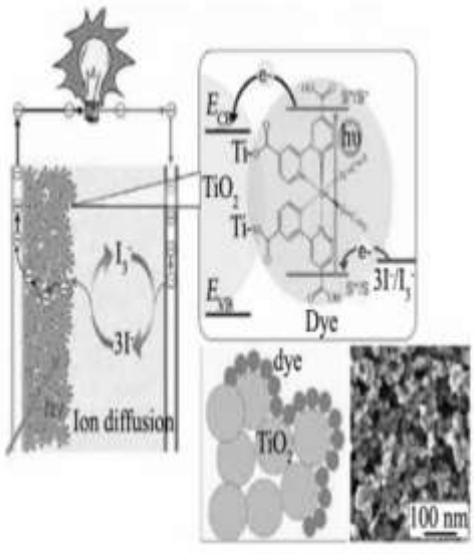


Fig 5: Operation Principle of DSSC [16]

A chemical electrolyte in the cell then closes the circuit so that the electrons returned back to the dye. It's the movement of the electron that creates energy which can be harvested into a rechargeable battery.

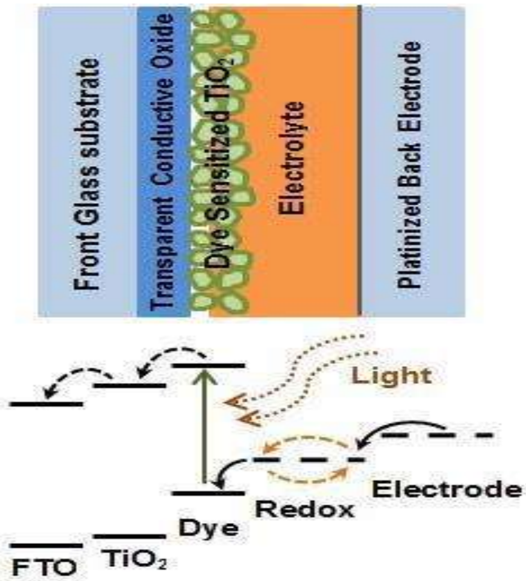


Figure 6: Basic device structure and relative band diagram for DSC

The nonporous TiO_2 film consists of spherical anatase particles of diameter ~20 nm. The presence of oxygen vacancies in the lattice makes it a weekly n-doped material (equivalent carrier concentration 10^{16} cm^{-3}).[16] As the TiO_2 particle diameter is too small for the electric field to build up, the dominant electron transport mechanism is diffusion via trapping and de-trapping.

The electron travels through the outer circuit performing work, reaches the back FTO electrode, and reduces the iodine in the electrolyte. The platinum layer on the FTO acts as a catalyst for the reduction. The dark cathode reaction:

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

The iodine reduction can also occur at the excited dye molecules causing recombination of the photo-generated electrons. For efficient charge transfer, the rate of iodine reduction at the counter electrode has to be orders of magnitude faster than the recombination at the TiO_2/electrolyte interface.

The reduced iodide ion replenishes the highest occupied molecular orbital (HOMO) of the dye - regenerating its original form, and makes it ready for electron generation again. The photoanode reaction:

$$2I^- \rightarrow I_2 + 2e^-$$

This prevents the buildup of S^+, which could lead to the conduction band electrons going back to the dye molecules. The maximum output voltage equals to the difference between the Fermi level of the semiconductor and the redox potential of the mediator.[17] Thus, the device can produce electricity from light without undergoing any permanent physical and chemical change.

Light Intensity and Temperature

The short circuit current shows a linear increase in light intensity due to the presence of more photons and hence more photogenerated electrons. The open-circuit voltage also increases slightly with light intensity. But a decrement in fill factor is observed due to ohmic losses in the conducting glass electrodes.

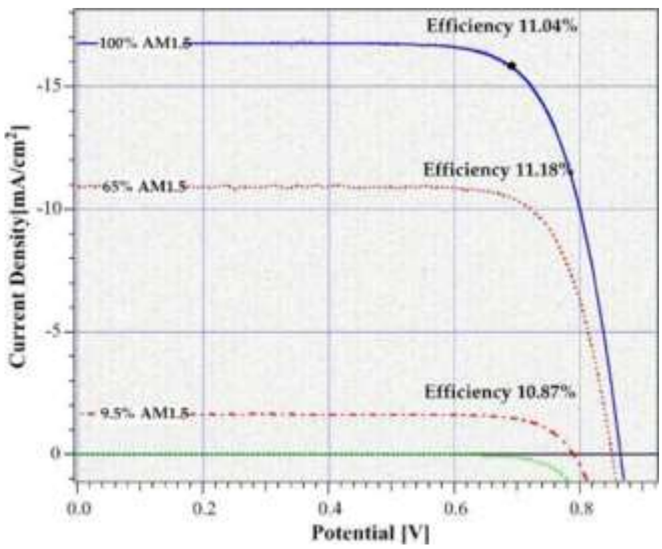


Figure 7: Stable performance at diffuse sunlight is a big plus point for DSC.

Increasing the temperature decreases V_{OC}, while the current rises significantly (5 to 70^oC). The influence on the fill factor is dependent upon the electrolyte solvent. For solvents with high viscosity such as propylene carbonate, the fill factor increases with temperature. The voltage decrease is because of the increment of the dark current with temperature, which implies an increase in the rate constant of triiodide reduction. The quantum efficiency values are not affected within the temperature range. An important observation is that the sensitized charge injection rate is independent of temperature, which implies a quantum mechanical tunneling process. The effect of temperature on the cell efficiency is minor due to the different compensating factors, which is another advantageous feature for DSC.

RESULTS AND DISCUSSIONS

Optimum thickness was found to be critical to the performance of DSC. With the increase of thickness, there were more dye molecules present in the titania layer to absorb the sunlight, hence an increase in current generation was observed. However, with the increase of thickness, it required a longer path for the photogenerated electrons to reach the working electrode thus increasing electron recombination. So, currently started decreasing after an optimum thickness.

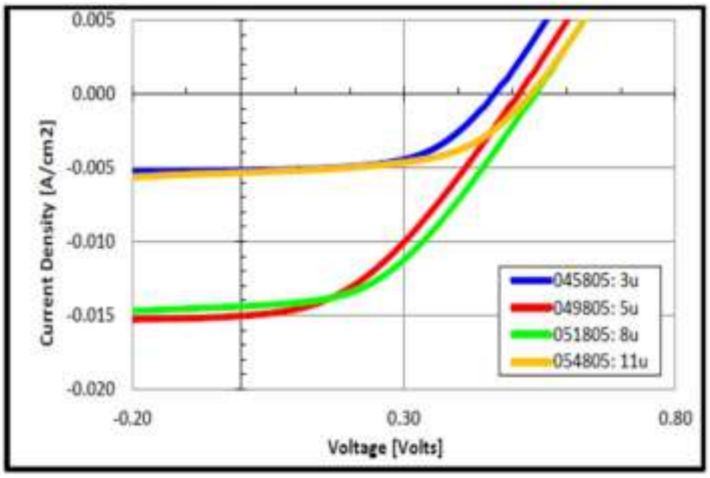


Figure 8: Current – voltage relationship for DSC with varying TiO_2 layer thickness

Table 1: DSC with varying TiO_2 layer thickness

Thickness (um)	ID	Voc (V)	FF	Jsc (mA/cm^2)	Efficiency (%)
3	045805	0.47	0.557	7.2	3.36
5	049805	0.51	0.394	17.05	4.02
8	051805	0.54	0.435	15.4	4.38
11	054805	0.53	0.548	7.34	3.54

Literature suggested a slight decrease in open-circuit voltage with the increase in thickness, but the change in observed voltage for the investigated thicknesses was within the range of experimental error.

RF Sputtered Blocking Layer

A blocking layer of RF sputtered TiO_2 was deposited on clean FTO glass. The sputtering was done with a Titanium target, in presence of O_2 (4.4mTorr) and Ar (6mTorr) at room temperature. Incorporation of an RF sputtered blocking layer decreased both the current and the voltage. With an increase in blocking layer thickness, more decrease is observed.

Table 2: DSCs with different thickness of RF sputtered TiO_2 blocking layer.

Blocking Layer Thickness (nm)	Cell ID	**Voc (V)**	**FF**	Jsc (mA/cm^2)	**η (%)**
0 nm	751110	0.67	0.486	13.96	5.22
20 nm	920120	0.63	0.536	10.77	4.63
50 nm	950120	0.63	0.532	10.39	4.54
100 nm	980120	0.61	0.521	9.96	4.17

APPLICATION OF DYE SENSITIZED SOLAR CELL

Dye is the one of the major role in the DSSC, the main work function of it has to absorb the solar radiation and to transmit the photoelectron to guide a band of TiO_2. The pros and cons of the performance of the DSSC photoelectric conversion efficiency play a decisive and key role. Since, last few decades the researchers and scientists working in this field are working on natural dye sensitizer focused on the chlorophyll, anthocyanin (a pigment found in plants responsible for purple color in them), carotenoid pigment and tannin acid etc.

There are several other pigments which have the ability of dye sensitizers, all have various sort and the extraction method is simple. Scientists have [29] extracted the red cabbage pigment from red cabbage, curcumin and Perilla pigment, Tennakone, etc. [30] extracted of sandalwood from rosewood acid dye Sensitizer.

CONCLUSION

With the constant progress and extensive research in the field of Dye Sensitized Solar Cell, the efficiency of the DSSC is approaching the efficiency level required for the commercialization of the product. However, the platinum used in the DSSC is expensive noble metal which needs to be replaced with something inexpensive and as effective as platinum. The other problem that the DSSC is facing is the liquid electrolyte which gets displaced whenever tilted a bit.

The DSSC is widely used worldwide by researchers with the advantages for its cheap and simple fabrication process which is far ahead of any other kind of solar cell. Though there is some problem faced by the DSSC at present, with the advancement of technology, the DSSC has bound to have a prospect in the practical use.

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