

# Bi facial DSSC

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**Abstract** - New energy is the near future and solar energy plays a vital role in it currently the efficiency obtained from the bifacial solar cells is nearly of 40% and it is hoped to get more with further development in photovoltaic cells; this review is all about combining the ideas of bifacial and dye-sensitized solar cells to increase efficiency.[1] for the improvement of efficiency and feasibility many researches are undergoing on solar cell. This review combines both the advanced technologies that is bifacial and dye-sensitized solar cells in order to increase the efficiency.

**keywords** - DSSC , Bi facial , Thin films , Transparent fabrication.

## I. INTRODUCTION

With bigger population there comes the requirement for larger energy utilization. The way that utilization of hydrocarbon deposits (fossil fuels) assets are agile than they can really be re-established. So there comes the idea of renewable assets for energy utilization. Solar energy is a good alternative solution for the energy requirements globally. Anyway the use of solar energy is still limited by cost. So to overcome this, productive methodologies should be developed. This review brings the ideology of dye sensitized solar cells which has the capacity of converting higher amount of incident solar energy (6%) by trapping photons on front as well as rear surfaces. This module needs a highly stable transparent dye in combination with a transparent electrolyte, transparent electrodes etc. [2] This ideology alongside with promising outcome gives a better future by enhancing the photovoltaic nature of the solar cells. In bifacial solar cell the efficiency on the front side is around 17.0% (100 mW per cm<sup>2</sup>) and the efficiency on the rear side is around 7.1% (42 mW per cm<sup>2</sup>). Thus an enhanced total efficiency of 24.0% is produced. The DSSC provides an efficiency of power conversion around ~ 6%. In this review we study about combining the ideas of bifacial and DSSC. The photons incident on the front side of the device is transmitted and getting reflected it is then reused in the rear side. The usage of transparent electrodes, electrolytes etc helps in the penetration of light energy. As a result the efficiency of power conversion on the front side is increased upto 6.54% and the efficiency on the rear side is increased upto 4.26%. Thus the enhanced efficiency outcome is around 20~40%. This novel bifacial DSSC is a better scheme for generating energy in order to meet the global energy requirements. The ideology of bifacial DSSC module proves to be an expense productive design plan, in this manner making it operated at locations where a high albedo radiation is available. [3-4] This review examines the state of the art of combining the ideas of bifacial and DSSC technologies with an aim of meeting the energy requirements.

SEGMENT 2 is totally committed to silicon based bifacial solar cells.

SEGMENT 3 is totally committed to DSSC technology.

SEGMENT 4 is totally given to consolidated idea of bifacial DSSC module.

SEGMENT 5 is completely devoted to niche applications.

SEGMENT 6 is all about conclusion.

## II. BIFACIAL SOLAR CELL

### 2.1 History

Bi-facial cells are cells which collect photons on both rear and front sides. Since these cells are made up of transparent material they can generate direct current from both the sides unlike conventional cells structure generating only from front side (i.e.) mono-facial cells.<sup>[5]</sup> In 1946 the first patented silicon solar cell was given by Russell Ohl and it was first demonstrated publicly by Fuller, Chapin and Pearson.<sup>[6][7]</sup> The concept of bi-facial cells was first theoretically proposed by a Japanese named Hiroshi Mori in 1960.<sup>[4]</sup> His proposal described a solar cell which had a two-junction p-n-p structure along with contact electrodes where these electrodes were affixed to the two opposite edges.

The practical implementation of bi-facial cells was done by Soviet space programs, in the Salyut 3 and Salyut 5 space station. The usage of bifacial solar cells in the above mentioned space stations was developed and fabricated by Bordina et al.<sup>[5]</sup> In Salyut 3 34% more efficiency was recorded as compared to the conventional type of solar cells. A huge gain of around 17 to 45% was recorded; a generation rate of around (40W per 0.48m<sup>2</sup>) has been given by the bi-facial solar cells placed in Salyut 5 space station.<sup>[6][7]</sup>

### 2.2 Working principle

The functioning standard of bifacial cells is analogous to those mono-facial solar cells. In a mono-facial solar module the light enters the front side of the cell or glass frame (facing the sun). The light energy absorbed from the incident photons is readily being converted to electrical power. In a bifacial solar module, the front side collects the light energy like the mono-facial module and in top of that the backside of the cell also absorbs the light. The light source for the backside is not only from the sun but also from variety of sources like reflection of sunlight from the ground or from the neighbouring modules. This additional light gives more electrons which generates more power. The voltage of the bifacial solar cells also increases with the increase in current

### 2.3 Cell Substrate

In general silicon based bifacial solar cells are used commonly. When the electron in the valance band gets invigorated on contact with photons, these electrons consume the vacant space in conduction band. The energy of these electros is relatively more than the ground state silicon electrons. The electrical conductivity of this natural semiconductor (silicon) is minimum.

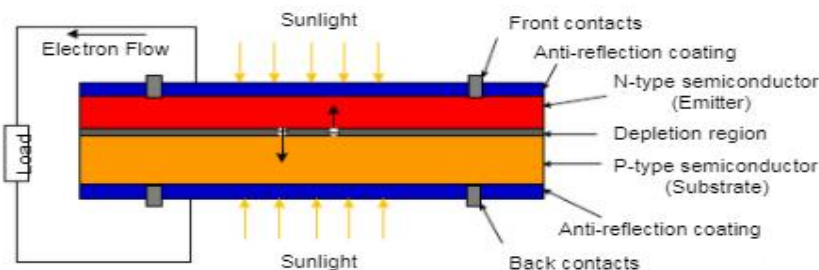
Doping can be done to make maximum number of electrons to move to conduction band from the valance band. Depending on the material used for doping the semi-conductor is classified into two types namely n-type and p-type. When phosphorus is added to the semiconductor it becomes n-type semiconductor where the phosphorous will provide excess electrons. When elements like boron or aluminium are added the semiconductor becomes p-type where more holes are created.

Doping of silicon solar cell with Boron is done so as to make a p-type semiconducting material and it superficial n-type region of 0.5 microns. A p-n junction is formed in between the both and an electrical field is thus created when there is a flow of electron from n-type to p-type. Photocurrent thus obtained is then taken back by contacts on either side of the solar cells. There is no split in the light which is falling away from the p-n junction and since recombination of the electron-hole pair occurs, it ends up in producing no photocurrent.

An unrivaled nature of silicon material should be utilized for bifacial solar cells with the outcome that the photogenerated electric charges, which are close to the rear surface can enhance power generation while they travel to the emitter on the front surface of the cell. This makes a necessity to use transparent encapsulating materials i.e, glass on both the sides of the solar cell.

### 2.4 Preparation of module

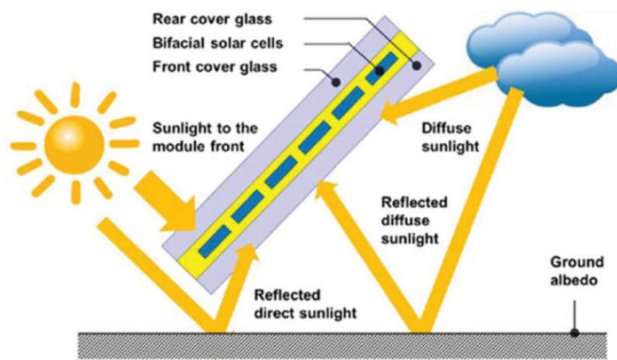
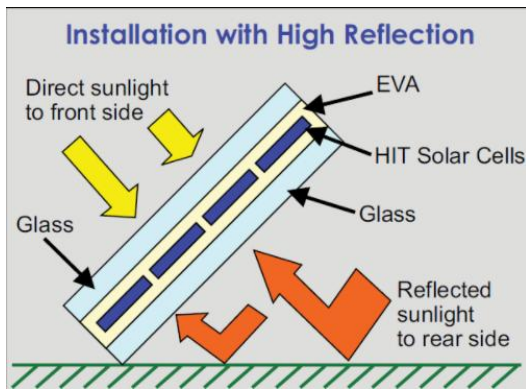
Traditionally silicon wafers are utilized as the cell substrates in the solar cells. Even though different types of materials were proposed and proven as substrates many prefer silicon as substrate. The substrates's thickness is a very crucial in determining the cost of the material, thus if the material is thinner it saves money. But the problem with thin wafers is that it is more of a hassle to handle them and preparation cost is more. The biggest advantage obtained by using the thinner substrate is that they improve the efficiency because of the reduction in the bulk recombination.<sup>[8]</sup>



Bifacial solar cells require two p-n junctions containing different dopants which thereby increase the quantity of high temperature processors during production and it likewise brings about significant expense. Whereas mono-facial cells require only require single p-n junction which can be obtained by only one diffusion step. In this situation co-diffusion can be done to assess the complications in this process. In this process Boron and phosphorous are pre-deposited and doping is carried out on either sides of the solar cells. However, this process demands no cross doping. To decrease the cost another suitable method is been deployed. In this method a p-n junction is build using ion implantation instead of usual diffusion method.

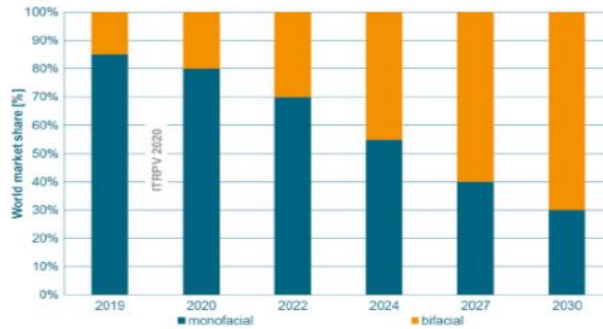
### 2.5 Contacts

The front contacts in bifacial solar cells are mainly silver screen printed, which plays a major is increasing the cost of these solar cells. Research has been conducted to find a replacement of the screen-printed silver contacts. The materials like copper plated contacts, aluminium, or TCOs were found to replace the silver contacts. However, the most cost-efficient way to reduce the amount was by reducing the amount of screen-printing paste through utilizing busbar-less solar cells on the front sides with exceptionally thinner contact wires.'



In comparison with mono-facial cells, the rear side of the bifacial solar cell has a recombination at the metal-semiconductor interface, which is less comparatively. This is done due to former restricting of this interface to that of the rear side surface metal grid. However here passivation silicon surfaces are absolutely need and the area of these silicon surface more than that of the rear surface. To allow sunlight through the rear back surface a ‘finger’ grid is used in place of using a aluminium contact for covering the rear surface. Temperature reduction is important in the manufacturing process.

The course of passivation is acquired generally by thermal oxidation method (SiO<sub>2</sub>), also this process needs an optimisation of 1000°C. In modern methods passivation of silicon surface is obtained by adding silicon nitrate (SiN<sub>x</sub>) on both the sides of the solar cell. Plasma-Enhanced Chemical Vapour Deposition (PECVD), is the method of the mentioned process. This method requires a optimised 400°C. Passivation of silicon can be achieved in lower deposition temperatures like -225°C with the help of Hydrogenated Amorphous silicon (a-Si:H).

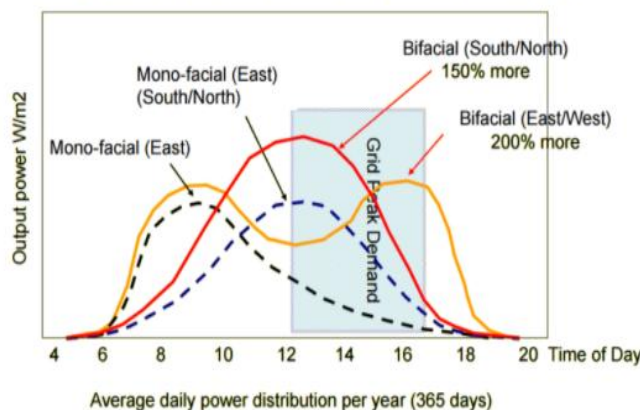


Forecast of the worldwide market shared for bifacial solar cell technology according to the International Technology Roadmap for Photovoltaic (ITRPV) - 11th Ed., April 2020

2.6 Purpose of invention

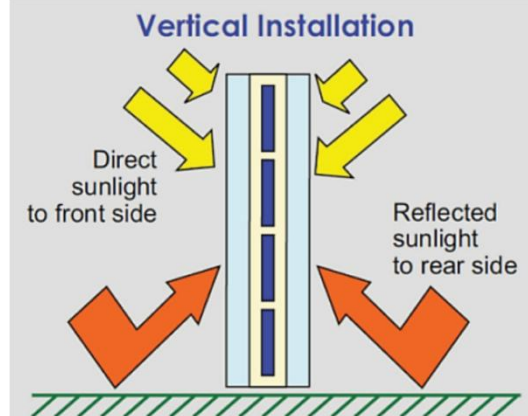
Bifacial cells were initially invented for BIPV applications and to place it in areas where the solar energy generated is comparatively very low due to the presence of diffuse sunlight, where the only light source is very less and the light that gets reflected back from the ground and surrounding objects in that place is taken as a light source for the solar cells. This idea was brought up to place this kind of solar cells in regions which have extreme latitudes and snow-prone areas where we can get an output with the help of diffuse sunlight in that area. However, due to the plateauing peak efficiencies from the screen-printed solar cell and overall huge reduction in the rate of solar glass and making use of the glass encapsulation viable in the recent years has brought much spotlight on bifacial solar cells.

Yearly average of daily power distribution (365 days)



### 2.7 Vertical installation of bifacial solar cells

The light or radiation from the light source or the sun by the bifacial solar module largely depends on the albedo of the objects that are close to the module and to the ground. This particular albedo factor is important for vertical modules, because during summer at the noon the intensity of the sun is the highest but due the vertical installation a small amount of light is received by the module from the direct beam. This type of vertical installation of the bifacial solar panel reduces accumulation of dust and snow since its perpendicular to the ground. It also gives out two peak output during day time. One of the advantages of this east-west module is that it gives greater output, this happens because the lower temperature of this module during the maximum irradiance than that of south oriented module. Through-out the day many networks show peak power production during the noon or midday when the intensity of the sun is at its peak and comparatively much less power production during off-peak period. The vertical module produces power 200% more than any other modules.



### 2.8 Efficiency Parameters

Bifacial technology has helped in reducing LCOE and enhancing the annual yield of PV industry all along these few years. The efficiency of bifacial solar cell can be defined as the proportion of incident light or luminous power (from the light source) to the generated electrical power (from the solar cells). These values are measured separately for both the sides i.e., on both the rear and front side under the condition of one sun or n values of sun. Approximately 1 sun equals 1000W/m<sup>2</sup>.

The bi-faciality factor percentage determined by the ratio of the efficiency of the rear side to the efficiency of front side ideal that they are subjected to same irradiance. The proficiency of the bifacial cells is typically controlled by the efficiency estimations from the front and back sides of the bifacial boards under one sun. This equivalent efficiency is utilized for portrayal of bifacial cells. This equivalent efficiency can be explained as the efficiency of the mono-facial cell which can acquire the equivalent amount of power per area as of bifacial cell at the impacts of the same test applied on both.

$$\text{Bi-Faciality Factor (\%)} = \left[ \frac{\eta_{\text{front}}}{\eta_{\text{rear}}} \right] \times 100$$

The separation rate is also specific to bifacial solar cell that tries to measure the bifacial illumination effect which was predicted by McIntosh et al. It states that the electrical output of bifacial solar cell which is under bifacial illumination would not have to be necessarily equal to the sum of front and rear side electrical output i.e., it may not be merely a linear combination of mono-facial solar cell's characteristics.<sup>[9][10]</sup>

$$\text{Separation rate (\%)} = \left[ \frac{X_{\text{front+rear}}}{X_{\text{front}} + X_{\text{rear}}} \right] \times 100$$

To characterize bifacial solar cell operation further under a simultaneous irradiation on both the rear and front side a term irradiance gain is introduced (g)

$$g = \left[ \frac{G_f + G_r}{G_f} \right]$$

The bifacial 1.x efficiency can be referred as the efficiency obtained by the front side of the solar cell under a certain amount of simultaneous irradiance and the x times of this value on the rear side of the bifacial solar cell. The actual gain of the bifacial cells with respect to the mono-facial cells can be expressed through gain-efficient product. It is the product of g and 1.x efficiency.

$$x = \frac{G_r}{G_f} = g - 1$$

### 2.9 Types and design

Bifacial modules come in various types and designs. There are solar cells without any frame or with frame. There are cells made up of dual glass and others use clear back sheets instead of dual glass. There are monocrystalline and monocrystalline designs and monocrystalline designs are preferred more. In either designs the power produced in the both sides are constant.



There are even models that are not bifacial but are frameless and dual glass with exposes the back side of the cell. The bifacial cells have contacts or busbars on both the faces of the cell

### III. DYE-SENSITIZED SOLAR CELLS

Being potentially cost effective to fabricate and also non-toxic in nature it is a better solution to meet the energy requirements. It depends on the development of semiconductor between a photo sensitized anode and an electrolyte, i.e. photo electro chemical system.

#### 3.1 Background

Because of its imperative role in the field of power production, DSSC has turned into an important scope of research in recent days. DSSC otherwise called Gratzel cells which is named after Michael Gratzel. He began to dig deep about the nanocrystalline semiconductor particles and mesoporous oxide semiconductor films in his laboratory, which made him to come up with a new type of solar cell, based on dye sensitized nanocrystalline films along with Brian o' Regan in 1988. [5]

The technology used in DSSC has been evolved over years. During 1960s it was found that power can be produced by illuminating organic dyes at oxide electrodes in electrochemical cells.[6] An experiment has been directed with chlorophyll extracted from spinach (bio-mimetic or bionic approach) in University of California at Berkeley.[7] This experiment enabled the scientist to demonstrate and discuss the electric power generation through the dye sensitized solar cell in 1972. [8] In 1995, sensitivity of these cells were experimented to know about their high frequency end of light spectrum (blue light and UV). During 1999, new variants of the dyes were developed which had much larger frequency response particularly "triscarboxy-ruthenium terpyridine"  $[\text{Ru}(4,4',4''\text{-(COOH)}_3\text{-terpy})(\text{NCS})_3]$ . This wider frequency response end up with a dye having a deep brown-black colour which is known as black dye.[9]

#### 3.2 Design and structure

Generally, DSSC has a layer of titanium dioxide nano particles which is porous in nature. Like chlorophyll in green leaves, a layer of molecular dye which covers the porous layer helps in the absorption of sunlight. It is known that in trivial alkaline battery both anode and cathode are set inside an electrolyte, comparably here titanium oxide (anode) and platinum based catalyst (cathode) is inundated under an electrolyte solution. One of the most significant part of DSSC is counter electrode, as it is known that counter electrode place a significant role in gathering electrons from external circuit and transfer them to electrolyte so that reduction reaction of redox shuttle can be catalyzed ( $\text{I}_3^-$  to  $\text{I}^-$ ). But due to higher cost of platinum many researchers moved on towards new hybrid doped materials for replacing platinum. Primarily chalcogen compounds of cobalt, nickel, iron are keenly under research. Apart from this, a wide range of other materials are currently under research such as Mesoporous carbons[10], materials based on tin[11], gold based nano structures[12] and lead based nano structures[13]. In 2017 a study determined that ternary oxide of  $\text{NiCo}_2\text{O}_4$  has the greater ability to increase the efficiency of power conversion and electrocatalytic ability.[14]

##### 3.2.1 Construction

Initially the cell designed to have (Gratzel and O'Regan cells) 3 primary parts. The transparent anode which is made up of fluoride-doped tin dioxide ( $\text{SnO}_2:\text{F}$ ), which acts as conductive plate represents the top layer and behind this plate there is a highly porous layer which is extremely high in surface area is covered by a thin layer of titanium dioxide( $\text{TiO}_2$ ). Sintering[15] is a process which chemically bounds  $\text{TiO}_2$ .  $\text{TiO}_2$  is only capable of absorbing a small amount of photons from sunlight[16]. Ruthenium-Polypyridyl Dye which is photosensitive is used as a molecular sensitizers in which the plate is immersed. Due to immersing a thin layer of the dye coating is formed which is covalently bonded (either ester bond, chelating or bidentate bridge linkage) with the  $\text{TiO}_2$  surface. Another plate which is comprised of a thin layer of iodide, which disseminates over the conductive sheet, i.e. platinum metal. By joining and sealing the two plates together the electrolyte being leaked is prevented [17]. After all these steps mentioned above finally the electrolyte is fed into the cells (fills the cells). Since electrolytes are soluble in acetone, the excess electrolyte is wiped out by using acetone, thus completes the cell. After this completed cells are tested and then silver paint is coated on the contacts for the proper electrical connections and further to reduce resistance losses. Testing is required to check parameters of the cells for example the output voltage of the DSSC should be in the range of 0.6 to 0.7 V. In case of short circuit current density it should be around 8 and  $12\text{mA}/\text{cm}^2$  and also under illumination the current value should remain constant[18].

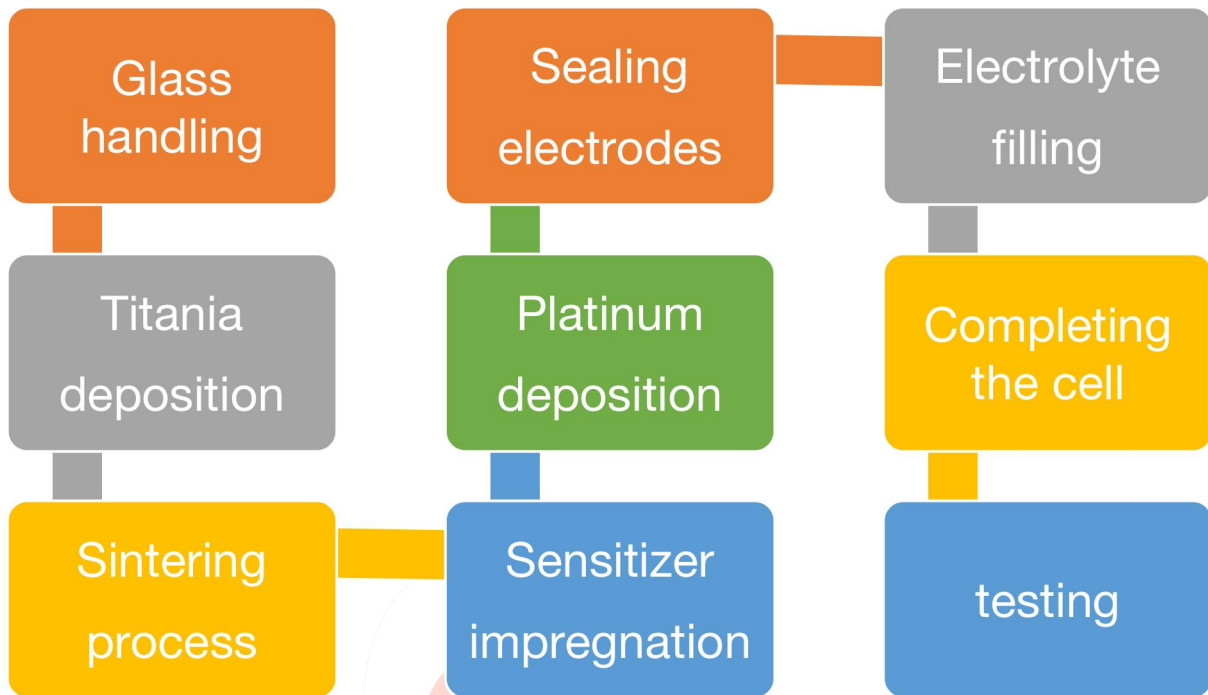


Fig (represents the process involved in making DSSC)

sensitizer a dye should consist of many carbonyl (C=O) and hydroxyl (-OH) groups, and should be ideal of chelating to TiO<sub>2</sub> surfaces. Around 10% conversion efficiency was achieved, by the usage of N3 and N917 dyes. But these chemically engineered dyed are expensive

### 3.3 Working principle behind DSSC

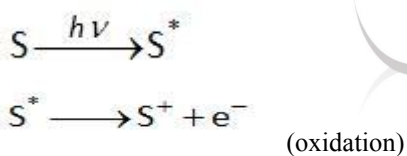
The working mechanism behind the DSSC is completely based on photoelectrochemical process. The various process involved in the conversion of photons (light energy) to electrical energy are as follows.

Step: 1

When sunlight falls on the cells, the photons get absorbed by the photosensitive sensitizer (Ru complex) layer and get absorbed by the TiO<sub>2</sub> layer

Step: 2

Due to the change in temperature the molecules of photosensitizer get excited from lower energy state(S) to higher energy level(S\*). Oxidation of the photosensitizer (S<sup>+</sup>) takes place due to the injection of excited electrons into conduction band of TiO<sub>2</sub> electrode.



Step: 3

By diffusion toward the back contact(TCO) the electrons(injected) in the TiO<sub>2</sub> conduction band get moved between the TiO<sub>2</sub> nanoparticles, so that the at last arrives at the counter electrode.

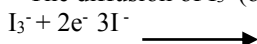
Step: 4

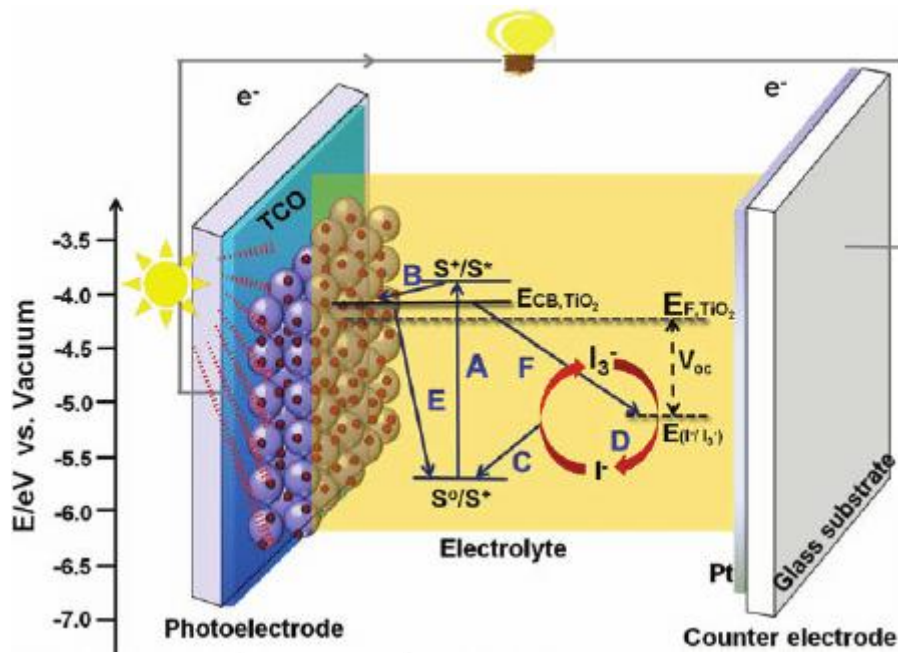
The I<sup>-</sup> ion act as a redox mediator from which the oxidised photosensitizer (S<sup>+</sup>) accepts electrons. Further regeneration of ground state takes place followed by the oxidation of two I<sup>-</sup> ions into elementary iodine and these reacts with I<sup>-</sup> to the oxidised state, I<sub>3</sub><sup>-</sup>.



Step: 5

The diffusion of I<sub>3</sub><sup>-</sup> (oxidised redox mediator) towards the counter electrode takes place where it get reduced to I<sup>-</sup> ions.





Fig() diagrammatic representation of operational principle of DSSC

The four energy levels of the components

- 1) Excited state of photosensitizer
  - 2) Ground state of photosensitizer
  - 3) Fermi level of TiO<sub>2</sub>
  - 4) Mediator's redox potential in electrolyte
- Determines the efficiency of the DSSC.[19]

### 3.4 Power production

The percentage of the total amount of electrical energy produced for the amount the given solar energy is known as solar conversion efficiency,

#### 3.4.1 Influence of binder molecule weight towards power production

The titanic particle of diameter around 7nm is best suitable for DSSC. And from various researches it is suggested that higher the molarity of the molecular binder PEG 20000mol, higher will be the current density production , but however the circuit voltage will be low as compared to PEG 400mol and vice versa.[The voltage and current distribution for PEG400mol and PEG20,000mol.] graph

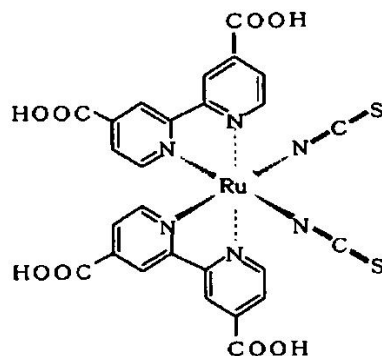
Further it is to be noted that higher molecular weight is required for enhancing binder strength [20], so generally long chain binder is preferred. And good performance of DSSC can be achieved by the usage of higher molecular weight which helps in better interconnected network of TiO<sub>2</sub> particles [21]. And further the power production in case of 20000 mol PEG is about three to four times more as compared to the power production resulted from the using 400 mol PEG.

#### 3.4.2 Influence of colours towards power production

The amount of power produced also depends on the dye used for immersing TiO<sub>2</sub>. Many researches have reported that “black dye” is a superior option for charge transfer sensitizer in DSSC. Initially Gratzel group developed many Ru complex photosensitizers. cis-Di(thiocyanato)bis(2,2'-bipyridyl)-4,4'-dicarboxylate ruthenium(II), was one among them and coaded as N3 or N-719 dye. They have an outstanding ability to absorb solar light and charge transfer sensitizer[22].

[Chem. 3]

N3 dye



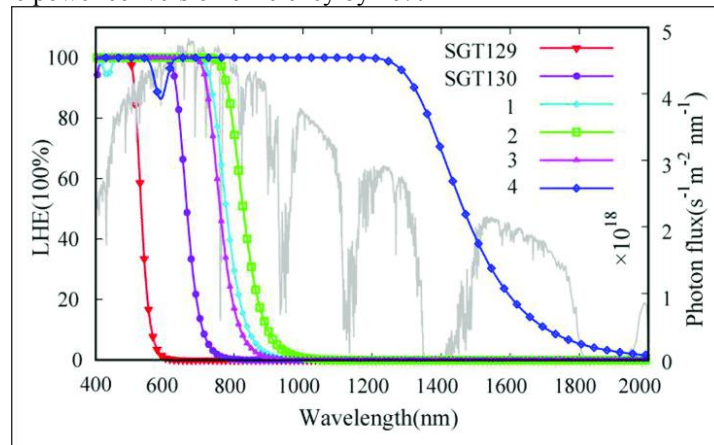
fig() cis-Di(thiocyanato)bis(2,2'-bipyridyl)-4,4'-dicarboxylate ruthenium(II)

The N3 dye has a capability of absorbing light of wavelength ranging 400nm to 900nm. New Ru based dyes for DSSC have been theoretically studied by Monari et al., states. In order to be an excellent s e. So various researches has been undertaken in order to develop a method for extraction of natural dyes. For example, Bahraini henna, Yemeni henna, pomegranate, raspberries, and cherries etc and methanol is used for their extraction process.

One of the important testing that every dyes undergo is of testing their light harvesting efficiency.

$$LHE(\lambda) = (1 - 10^{-A(\lambda)}) * 100$$

Where A (λ) is the absorbance of sample at specific wavelength. The concentration of the dye is directly proportional to the LHE, therefore with increase in concentration of dye the LHE also increases. And some sort of energy relay dyes are also added to in order to increase the power conversion efficiency by 26%



Fig(1) shows the variation of LHE for different wavelength.

### 3.5 New developments

Year	progress
2003	Attempts to increase the thermostability of the DSSC with the help of amphiphilic ruthenium sensitizer along with quasi solid state gel electrolyte. This made cell to withstand heat for 1000h at 80° c[23][24]
2006	The first ever solid hybrid DSSC were reported successfully.[25]
2007	A wide range of organic dyes(low cost) based on porphyrin has been experimented[26]. From the researchersthe efficiency in the order of 5.6% were reported [27].
2009	Researches from Georgia tech developed DSSC with a surface area which is highly effective by using quartz optical fiber.[28][29]
2010	Progress were in electrolyte and platinum, in case of electrolyte the progress resulted in transparent and non-corrosive gel which can increase photovoltage, stability and also cell's output[30]. Platinum was replaced by cobalt sulfide [31].
2012	The concept of nanotechnology is used in order to overcome the major difficulty of liquid electrolyte [32].
2018	Development on nanorods were made, mainly surface plasmon resonances present on gold nanorods, it is reported that increase in concentration of nanorods, the light absorption increased. They found that the efficiency increased from 5.31% to 8.86% [33].

## IV. BI-FACIAL DYE SENSITIZED SOLAR CELLS.

As we discussed about the bi-facial and DSSC's in the previous sections. This section is completely all about the fabrication, mechanism etc of bifacial DSSC's. As mentioned before, the efficiency can be increased by the usage of bifacial and DSSC as compared to conventional design. So by combining the both elite idea the efficiency can be further increased, which will lead a path to meet the global energy crisis. Unlike classical DSSC's bifacial DSSC's with highly transparent materials can produce 50 percent more electrical energy [34].

### 4.1 Design and Structure of bifacial DSSC's.

In order to increase the performance of the cells the bifacial DSSC's are fabricated with highly transparent materials. Rear side of the cell acquires photons due to its transparent property.

### 4.2 Transparency of the solar cell

As per the requirements the materials used should come with transparent property. Many researches have been undergoing to explore the transparent electrode, colourless electrolyte, thin film technology [35]. The arrangement of atoms and electrons decides the transparency of a material. If the energy band gap of the electron matches with the energy with which it absorbs the photons and get excited to higher energy level, then the material is opaque [36]. Whereas for the transparent material the electron's energy band gap is higher than that of the energy of photon, so that light penetrates through the material. A transparent material should be synthesised to build the layers of the solar cells, thereby increasing the transparency of the solar cells without affecting the efficiency [37]. The factors that affects the transparency is of the cells are: a) shape of nano crystals to be synthesised, b) paste producing process, c) penetration of UV light through it, d) thickness of the depositions. A few



transparency theories are going through in order to fabricate transparent solar cells. From the research outcome it is found that FTO or ITO is used as conductor on glass in 90 % of these technologies. They generally has a layer of around 10 ohm/Sq resistance and with the help of thin film technology , thickness less than 20nm is implemented [38][39]. When intrinsic optical losses are taken into consideration , then transparency can be reduced of approximately 15-20% by these layers and so transparency achieved is less than 80% [40].

### 4.3 Technologies

#### 4.3.1 Thin film photovoltaics

One of the most productive technologies is the thin film photovoltaics. Tvp's thickness usually ranges from few nanometers to 10s of micrometers of materials deposited on glass[41] [42].

Transparency is inversely proportional to thickness, hence decrease in thickness brings about an increase in transparency. The strategies followed for the deposition of thin film on the substrate is of chemical bath deposition(CBD) [43] , physical vapour deposition(PVD) or sputtering [44] , electro deposition , screen printing , pulsed laser deposition (PLD) [45] spray and atomic layer deposition [46]. The first thin film reported is of screen-printed thin film. Screen printed technology is usually preferred because of its easy handling and control over thickness and position [47]. In case of DSSC, in screen printing for paste making titanium dioxide nano particles are used widely. Desired quantity of the paste deposited on to the frame then swept with constant velocity so that the paste flows from screen to substrate eventually and in turn the left part of the screen gets separated from the substrate so that only thin layer of deposition remains and get dried [48]. During the experimentation in year 2007 the researchers detailed that, out of 3 commercially available TiO<sub>2</sub> nanoparticles pastes (P25, ST21, and ST41) P25 was the most transparent while ST21 was hazy and ST41 was completely opaque or white [49]. P25 resulted with a thickness of 17micrometer and light transmission was around 60% [50].

#### 4.3.2 Near infra-red transparent cells

While every research were based on producing thin films , with an average transparency less than 30% , a different idea has been implemented by Richard Lupnt , which is based on change of dye's molecule for the absorption of UV and NIR wavelengths (650-850nm), they just focused on absorption of wavelengths rather than the active layer's thickness. Transmission of visible light more than 65% and absorption of near infra-red spectrum is made possible with transparent organic heterojunction PV. Here chloro-aluminium phthalocyanine (ClAlPc) go about as sub-atomic organic donor and C<sub>60</sub> behave as sub-atomic acceptor [51]. Anode utilized here is coated with Bathocuproine (BCP), Indium-tin-oxide, (ClAlPc), MoO<sub>3</sub> and C<sub>60</sub> and the cathode is coated with Ag with thermal evaporation. So the principle point of this process is to make absorption of UV and NIR wavelengths and transmission of visible light.

#### 4.3.4 Polymer solar cell

It is inefficient to use only the transparent conducting material, so the transparent solar cell is combined with transparent conducting material has taken under note. These are the sort of organic or plastic solar cell. These cells uses organic electronics i.e , conductive organic polymer. The molecules used here are cheap thus low production cost is achieved for larger volume. Further these molecules absorbs in NIR spectrum. Two electrodes are used and an active region is kept between them. The active region containing polymer heterojunction which acts as an electron donor and PCMB (fullerene derivative) behaves as an electron acceptor. The electrodes are coated with silver nanowire metal oxide. For combining of active region and electrodes (AgNW ) , TiO<sub>2</sub> sol-gel is used as an adhesive(glue) . At 50nm wavelength and transparency the efficiency is increased around 66% [52]. Other alternative methods are also taken into account, with the usage of polymers like PBDTTT-C-T, PC71BM, PTBT:PC71BM different transmittance and efficiencies were reported [53].

#### 4.3.5 Perovskite solar cells

Hybrid organic and inorganic compounds are known as perovskite structured compound , here mostly lead or tin halide materials. These materials usually have lower band gap when contrasted with photons. Methylammonium lead halides, all inorganic caesium lead halide (CsPbX<sub>3</sub>, X = Cl, Br, I) are some perovskite materials which are simple and cheap to manufacture[54]. Perovskite materials have high absorption coefficient, so that complete visible spectrum can be absorbed by the thin film of 50nm. In general perovskite solar cells are used to power – low powered wireless electronics. Further the cation used in these cells should have radii around 1.60Å -2.50Å. The most commonly studied perovskite cells are Methylammonium lead trihalide (CH<sub>3</sub>NH<sub>3</sub>PbX<sub>3</sub> X=Cl, Br, I) and Formamidinium lead trihalide (H<sub>2</sub>NCHNH<sub>2</sub>PbX<sub>3</sub>), which evidently showed a suitable bandgap of around ~1.55 and 2.33ev and ~1.48 and 2.2ev respectively. In DSSC, Perovskite used as transport layer of p type hole and absorber

Methods :

Dip coater:

The coral natured TiO<sub>2</sub> nano structures are utilized as photoanode and for counter electrodes transparent polyaniline (PANI) films are used. Since PANI and TiO<sub>2</sub> have similar energy band gap , TiO<sub>2</sub> thin films are deposited using a dip coater. The reported outcome is of 70% for transmittance , 8.22% for DSSC's efficiency [55].

Sputtering deposition:

Sputtering process is used for the deposition of thin film of TiO<sub>2</sub> nano particles on the surface of FTO. Sputtering is the process of deposition of metal on a surface with the help of fast ions to eject particles of it from a target. Sputtering is followed by annealing which is done at 450 °C at suitable conditions for 30mins , annealing process makes the TiO<sub>2</sub> layers to exhibits higher optical transmittance [56].

Quantum dot solar cell:

These cells have outstanding opto-electronics properties. The quantum dots are the semiconducting particles which are also known as artificial dots.

## V. TRANSPARENT COUNTER ELECTRODE

### 5.1 Pt- Mo<sub>2</sub>C counter electrode.

Strong metal support interactions are used to fabricate these electrodes. Here Pt nanoclusters have high dispersity on Mo<sub>2</sub>C, so that the front-rear efficiency was achieved around 0.75%. In general these electrodes work based on the electrocatalytic principle. The strategy used to increase the transparency in counter electrode is of reducing the amount of light absorbing electrocatalytic materials by thinning and patterning them [57][58]. But these methods may lead to insufficient number of catalytic sites which in turn reduces the activity of transparent counter electrodes. In order to overcome this problem Strong Metal Support Interactions (SMSI) is adapted with the high potential of reducing the dosage of catalysts without disturbing the activity and stability of the catalyst. Further in SMSI reaction interface possess large area. The sole purpose of SMSI in DSSC includes activation of high transparent Pt-Mo<sub>2</sub>C counter electrodes for DSSC [59][60].

### 5.2 Ru-N-doped template free mesoporous carbon counter electrode:

The widely preferred counter electrode for DSSC is Pt, because it satisfies most of the requirements. The minus point is that of cost, so various alternatives are being studied and has been developed. Diverse amount of conductive polymers, alloys, carbon and its composite materials were used as counter electrodes [61][62]. Although thinning of polymer layer exhibits transparency the major problem arises with stability, since their stability is less [63][64]. So carbonaceous materials are used which are highly stable and of less cost. These materials like wise exhibits good catalytic properties, great conductivity and primarily low charge transfer resistance, but catalytic property is not up-to the level for the manufacturing of transparent counter electrodes. Hence different composites of carbonaceous materials with extremely high catalytic properties are utilized. Nitrogen (N) doped porous carbon is widely use since nitrogen N atom increases conductivity and electronic interaction between metal and carbon. Further studies revealed that Ru and N-doped carbon exhibited superior performance. In order to increase the surface area of composite material Ru and N doped template free mesoporous carbon (Ru-N-TMC) was developed. This counter electrode is prepared by direct stabilization of ruthenium(III) acetylacetonate [Ru(acac)<sub>3</sub>] with poly(butyl acrylate)-b polyacrylonitrile (PBA-b-PAN). Ultra low charge transfer resistance ( $R_{ct}=0.034\text{ohm/cm}^2$ ) is noted from Ru-N-TMC, and average visible transmittance was around 42.25% (380nm to 750nm)[65]. It also showed high power conversion efficiency of about 11.42% which was noted to be 10.13% for front and 8.64% for rear. Based on the loading amount of Ru-N-TMC, three different semi-transparent semiconductor materials are used i.e; Ru-N-TMC-x (x= 0.04,0.05 and 0.06).

### 5.3 Platinum and Molybdenum alloyed transparent electrodes.

One of the pertinacious objectives in power generation using bifacial DSSC is of designing a cost effective counter electrode without any deficiency of photovoltaic performances and power output of the process. Thus to lift up the power output, by electrochemical method platinum and Molybdenum alloyed transparent counter electrodes were fabricated. These counter electrodes have high charge transfer ability, high electrocatalytic activity and maximum power conversion efficiency of around 6.75% for front and 2.89% for rear side irradiation. The upgraded productivity alongside improved force yield, quick start-up, numerous beginning capacity, straightforward readiness, and low Pt measurements features the likely utilization of the low cost straightforward Pt-Mo compound counter electrodes in bifacial DSSCs [66]. The important rule to be considered before the fabrication of alloy counter electrode is of choosing the precise transition metal with unfilled d orbital.

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