International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 1, January 2017)

Dye Sensitized Solar Cells- A Review

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I. INTRODUCTION

The depleting trend of the current energy systems, and concerns about pollution leading to environmental degradation, has aroused much interest in alternative renewable energy sources. Among all the sources of renewable energy like wind, hydro, biofuels, biomass solar energy have attracted a great interest as a solution to this problem because of its abundance and non-polluting[1-2]. As a result, the conversion of solar energy into different forms has been the core of research for the recent past years. Solar energy conversion devices that convert sunlight into electricity are gaining importance by the researchers and industrials as future energy candidates [3-4]. The conventional solid state silicon based solar cells with conversion efficiency of about 25% have dominated the photovoltaic market from last many years but are yet to become popular for mass applications as the manufacturing of these silicon based solar cell are highly expensive [5-6]. Therefore necessity for developing low cost devices for harvesting solar energy was, therefore very much desirable. Since 1991, following the illustration of dye sensitized solar cell (DSSCs) by Micheal Gratzel at EPFL, have open up the new perspective for the researchers all over the world. DSSCs have been considered as one of the most promising photovoltaic technologies because they are generally made from inexpensive components, and have simple designed structure [7-8]. Moreover there are certain advantages of DSSCs over traditional solar cells as in DSSCs electrons and holes are transported in two different phases TiO_2 and electrolyte respectively and chances of recombination become low. Hence DSSCs can even work in low illumination or diffused light and do not require ultra fine materials for their manufacturing [9].

A DSSC is composed of a nanocrystalline porous semiconductor electrode, sensitizer, counter electrode and an electrolyte containing iodide and triiodide ions. In DSSCs dye plays an important role by harvesting solar energy and converting into electrical energy with the aid of semiconductor photoanode. Therefore dye as sensitizers is important component of DSSCs which helps in determining the efficiency of the cell. Numerous metal complexes and organic dyes have been utilized as sensitizers by far; the best studies example is the Ruthenium-bipyridyl dyes which shows a high conversion efficiency of about 11% reported by Gratzel group [10-11]. The major drawbacks of these ruthenium based dyes are its rarity, high cost and complicated synthesis.

Therefore, alternative organic dyes such as natural dyes have been studied intensively. In nature, some fruits, flowers, etc. show various colors due to presence of several pigments that can be easily extracted and employed in DSSCs. Therefore, unlike artificial dyes, the natural ones are abundantly available, easy to prepare, low in cost, nontoxic, environmentally friendly, and fully biodegradable [12-14].

Among the various types of widely-investigated wide band gap semiconductor material like TiO_2, ZnO, SnO_2 etc for DSSCs, titanium dioxide (TiO2) has been considered the most active photocatalyst due to its low cost, chemical stability and comparatively high photocatalytic efficiency [15-16]. Basically, ns-TiO_2 can only utilize 6% of the total solar irradiation in photocatalysis due to the large band gap of anatase ns-TiO_2 (3.2 eV) but doping techniques can shift the activity of ns-doped-TiO_2 from the UV region to the visible light region which can improve the efficiency of DSSCs [17]. Electrolyte is another important parameter for determining the efficiency of the dye sensitized solar cells. But temperature sensitivity of liquid electrolyte cause serious problem in the working of DSSCs and it makes the large scale production difficult and causes substantial problems to bring DSSC onto the market [18]. At low temperatures, the electrolyte can freeze, thus rendering the solar cell completely unusable. At high temperatures, the liquid electrolyte expands, making sealing the solar panels a major problem. To overcome these problems, many research groups have been searching for alternatives to replace the liquid electrolytes, such as inorganic or organic hole conductors, ionic liquids, polymer and gel electrolytes [19-20].

Thus the present review article highlights recent progresses in dye sensitized solar cell in pursuit of the high conversion efficiency. Especially, this article focuses mainly on the nanoscale surface modification with various materials, light-harvesting management with scattering layer, new types of solid polymer electrolyte replacing liquid electrolyte for the stability of the cells and replacement of costly platinum based counter electrode with cheap materials in order to reduce the cost of DSSCs.

II. STRUCTURE AND OPERATING PRINCIPLE OF DSSCS

The basic structure of Dye sensitized solar cell is composed of four components first a photoanode, which is made up of a wide band gap semiconductor second dye molecule third is an electrolyte with tri-iodide and iodide redox couple and fourth a conductive substrate coated with a catalyst (Pt, Carbon etc) as cathode.

The mechanism involved in the working of dye sensitized solar cells is first of all the dye molecule is attached on the surface of mesoporous TiO_2 (Wide band gap semiconductor). On illumination, the dye molecule absorbs photons of wavelength corresponding to the energy difference between its highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) [21].

Then the absorbed electrons are injected into the conduction band of semiconductor oxide (the nearby TiO_2 nanoparticles) after that the electrons by diffusing through the nanoparticle network comes to the current collector (anode) and subsequently passed through the external circuit processed to the counter electrode (cathode) performing electrical work. Meanwhile the dye also injects holes to the hole conductors and transport to the counter electrode, and with the outside circuit which finishes loop [22-23].

The proposed set of reaction sequence occurring in DSSCs is shown in the table below where S is molecule of the sensitizers, E_{hv} (Photon energy), A (anode).

Reaction Equation	Event Description
$E_{hv} + S \longrightarrow S^*$	Dye Excitation
$S^* \longrightarrow E_{hv} + S$	Dye Relaxation
$S^+ + A^- \longrightarrow S + A$	Dye Regeneration
$S^* + TiO_2 \longrightarrow e^*_{TiO2}\ S^+$	Electron Injection
$S^+ + e^*_{TiO2} \longrightarrow TiO_2 + S^*$	Dye Recombination
$e^*_{TiO2} + A \longrightarrow A^-$	Electrolyte Recombination
$e^*_{TiO2} + FTO \longrightarrow e_1$	Current Collection
$e_1 + A \longrightarrow A^-$	Electrolyte Reduction

III. PHOTOANODE

Photoanode the first basic component of DSSCs is generally made up of wide gap nanoparticle oxide semiconductor material like ZnO, SnO_2, Nb_2O_5 and TiO_2 etc. Among all TiO_2 have gain a lot of importance as semiconductor material for photoanode of DSSCs due to its low cost, chemical stability. Fabrication of TiO_2 photonaode is also important in respect of influence of microstructure, particle size, porosity and pore size distribution on the photovoltaic characteristics of a cell. Significant efforts have been given to the TiO_2 photoanode in the hope of further enhancing the performance of solar cells by improving electron transporting and gathering efficiency. Incorporation of conductive materials such as single, double or multi walled carbon nanotubes or graphene in TiO_2 is another promising approach that could dramatically enhance the photovoltaic performance of DSSCs by providing the affordable composite photoanode materials [24-25]. H. Chang etal. used TiO_2-CNT (Carbon nanotube) composite material as photoelectrode for enhancing the efficiency of DSSC. The photoelectrode was prepared using electrophoretic deposition method to mix the Degassa P25 TiO_2 nanoparticles with TiO_2-CNT powder for deposition on the indium tin oxide (ITO) conductive glass.

They reported that MWCNT can effectively increase the short circuit current density which enhances the cell efficiency. Experimental results show that photoelectric conversion efficiency increases to around 41% by using TiO_2-CNT photoelectrode from 3.45% to 4.87% [26]. To enhance the electron transfer for improving the efficiency of dye sensitized solar cells researchers are focusing on replacement of TiO_2 nanoparticles with one dimensional nanostructures in the form of TiO_2 nanotubes which delimits the electron transport in the nanocrystal boundaries of TiO_2 and the electron recombination with the electrolyte during the electron migration process [27]. Lin et al fabricated front side illuminated DSSCs based on open end TiO_2 nanotube with conversion efficiency of 5.32% [28]. Another group reported the use of TiO_2 one dimensional nanotubes treated with $TiCl_4$ which have shown the efficiency of about 7.48% which indicates it to be a potential candidate for photoanode of dye sensitized solar cells [29]. A new approach is adopted for preparing flexible Ti-foil based photoanode composed of a composite TiO_2 film with TiO_2 nanotubes (TNT) and TiO_2 nanoparticles (TNP) by dipping-rising-hydrolysis. This method allows direct placing of TiO_2 nanoparticles into TNT and TiO_2 nanoparticles grows internally from the base of the TNT to occupy it completely.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 1, January 2017)

This solve problem of incomplete filling of TNP into TNT. A DSSC containing TNP and TNT prepared by this method shows a conversion efficiency of 6.45% which is much higher than that (4.21%) of a DSSC with untreated TNT [30].

TiO_2 also suffers from oxygen vacancies which results in the formation of surface defects states. These surface states cause recombination of electrons injected in the conduction band of TiO_2 with the I_3^- in the electrolyte and their trapping and de-trapping of electrons. To avoid this problem Hyung J. Kim et al., modify the surface of nanostructured TiO_2 with hydrogen plasma treatment using low temperature radio-frequency plasma enhanced chemical vapor deposition system for improving the efficiency of DSSC. It is well known that plasma treatment is very effective technique for surface modification as it leads to strong interactions between the plasma containing electrons, ions, radicals and neutral molecules. It also improves the hydrophilic property of nano-structured TiO_2 and thus leads to enhanced degree of dye adsorption. They reported the improved efficiency of about 6.94% which is 21% higher than without plasma treatment of TiO_2 [31].

To enhance the light harvesting properties of TiO_2 from UV region to the visible region doping it with oxides of earth abundant metals and friendly metals is another option. Lu et al. studied the effect of Niobium (Nb) doped anatase TiO_2 on the performance of DSSC. It was revealed that doping of Niobium (Nb) has a positive effect on the photocurrent and this positive effect can be attributed due to the enhance electron injection and increased charge transfer kinetics [32]. Moula et al, studied the performance of devices based on titania nanocrystals, bismuth doped titania nanocrystals and bismuth doped titania graphene nanocrystals. The clear enhancement in efficiency can be seen from 0.88% to 4.02% for bismuth doped titania nanocrystals and bismuth doped titania graphene nanocrystals in comparison to titania nanocrystals. The improvement in photo efficiency can be realized due to increment in broad electronic adsorption spectra which resulted in improved efficiency for the studied DSSCs [33].

Zinc oxide (ZnO) is another important class of semiconductor material that is being used in DSSCs as photoanode because of wide and direct band gap (Eg ~ 3.37 eV at room temperature) and low cost porous material [34]. But ZnO shows high resistivity owing to low carrier concentration therefore ZnO-based DSSCs tend to exhibit lower energy conversion efficiencies than to those based on TiO_2 [35]. Researchers are working to enhance the efficiency of DSSCs based on ZnO so Sakai et al reported that the performance of ZnO porous electrodes can be enhanced using surface treatment carried out by immersion in cold aqueous $TiCl_4$ solution that resulted in TiO_2- coated ZnO (Z/T) electrodes [36].

Mahmood et al synthesized boron-doped ZnO film as photoanode for the fabrication of DSSC. They reported the high conversion efficiency of about 7.2% with the use of boron doped ZnO which facilitated the fast movement of electrons towards the electrodes and also function as light scattering centers [37]. A new type of anode was prepared using tri-functional Nb_2O_5 nano-islands deposited on the indium tin oxide (ITO) conductive substrate and used for the fabrication of the cell. It was found that use of Nb_2O_5 reduces the sheet resistance of ITO glass which suppresses the charge loss and helps in enhancement of the conversion efficiency of the cell which was found to be 5.81% [38].

IV. Sensitizers

The overall cell performance of the dye sensitized solar cells depends upon the choice of the photosensitizer. There are certain criteria which a dye molecule should fulfill in order to act as photosensitizers for the DSSCs. As the primary steps of photon absorption and subsequent electron transfer processes depends upon the characteristics of dye molecule so ideally a dye molecule should absorbs light photons in whole of the visible and near IR regions of the solar spectra. The dye molecule should have certain types of groups like carboxylates, sulphonates and phospahates which help in proper adsorption of dye to the semiconductor for efficient transfer of electrons from dye to the semiconductor. The dye molecule should be thermally, chemically and photostable for better performance of DSSC [39-40]. Generally, Ru-polypyridyl-complex e.g. cis-dithiocyanato bis (4,4`-dicarboxy-2,2`-bipyridine) ruthenium (II) commonly called N3 dye developed by Prof. Gratzel and coworkers, have been employed for efficient DSSCs [41-42]. Ruthenium based dye though responsible for high efficiency of the DSSCs but suffers from some of the drawbacks like ruthenium based complexes are poisonous, rare in nature and require long synthetic routes for the preparation. In addition to overcome such drawbacks of the conventional Ru-complex sensitizers, metal free analogs in the form of organic dyes have also been investigated in DSSCs. There are certain advantages of organic dyes like they have larger absorption coefficients due to intramolecular π-π^* transitions and there are wide variety of structures easy to modify [43-44].

Novel dyes comprising a triphenylamine donor thiophene conjugate bridge with different number of anchoring groups were synthesized and employed in dye sensitized solar cell. The butoxy group present in the dye is responsible for the suppression of charge recombination which helps in the improvement of the efficiency of the cell. The conversion efficiency of 7.4% was obtained with the aid of above dye [45].

Four new types of organic dyes (F1-F4) comprising the triarylamine or fluorene unit as an electron donating group and cyanoacrylic acid as the anchoring group in the molecular framework were synthesized by Lai and coworkers and utilized in DSSC. They reported that changing the donor moiety alter the energy levels of HOMO and LUMO which enhances the electrochemical data of the dye which helps in enhancing the photon-to current conversion efficiency upto 80% and the DSSC device based on these dyes shows overall light to electricity conversion efficiency of about 4.74% [46]. Further to enhance the performance of the organic dyes co-sensitization strategy is applied. A novel pyrenoimidazole- based organic dye, 5C, and a squaraine-based organic dye, SQ2, were used for the co-sensitization the photoanode of DSSCs. With the co-sensitization technique the absorption spectrum becomes more broaden and intense and as the result this highest power conversion efficiency of 6.24% was reached for the DSSC [47]. Five bithiazole-based organic dyes D1-D5 containing different electron donor moieties (thiophene, fluorene, carbazole and triarylamine) in the molecular framework were synthesized and studied in DSSCs. The bithiazole based dye with carbazole donating group showed the highest conversion efficiency of about 4.65% [48]. Researchers also synthesizing metal free organic dyes with new donor-π-acceptor like triarylamine as donor and furan, thiophene and benzene as π linkers. Use of these types of donors brings changes in the HUMO-LUMO energy levels which enhances the spectral response range. The comparative study of these donors shows that with furan the cell efficiency was 6.10% followed by thiophene and benzene with cell efficiency 5.92% and 4.97% respectively [49].

Though organic dyes are cheaper and have reported to reach high conversion efficiency However, synthetic organic dyes have often presented problems as well, such as complicated synthetic routes and low yields. The use of natural pigments may be a convenient alternative to ruthenium complexes and synthetic organic dyes, despite the lower efficiency because they are easy to obtain. Therefore, unlike synthetic dyes, the natural ones are available, easy to prepare, low in cost, non toxic, environmentally friendly and fully biodegradable [50-51]. The anthocyanin and betacyanin dyes are natural pigment responsible for the red and blue colors of many fruits, leaves and may serve as photo protective agents, antioxidants and osmotic regulatory. Moreover their absorption spectra have favorable overlap with the solar spectrum [52-53]. Some of the plants like Rhododendron flowers dye have shown the conversion efficiency of about 0.57%. The dye obtained from the flowers of Perilla has shown the conversion efficiency of 0.50%. The dye obtained from the fruits of Mangosteen pericarp was found to be efficient with conversion efficiency of 1.17% [54].

Four natural dyes extracted from the leaves or flowers of the plants namely teak, tamarind, eucalyptus and crimson bottle brush was also studied for the DSSCs it was found that the conversion efficiency varied from 12-27% for the above studied plants [55]. Park et al reported the photovoltaic efficiency of dye sensitized solar cell using gardenia yellow as natural photosensitizers the photoefficciency was found to be 0.35% [56]. Thought the natural dyes does show enhanced efficiency but their cost effectiveness and environmentally begin make them a viable candidate as dye molecule for DSSCs. To improve the spectral response for the dyes cocktail dye are also prepared in which different types of dyes are mixed. By mixing the different dyes increases the absorption spectrum which covers the whole UV-Visible spectra.

V. ELECTROLYTE

Another important aspect of dye sensitized solar cells is electrolyte apart being a conducting medium in DSSCs it also regenerates the dye as the light is converted to electricity by dye, it losses the electron and acquire positive charge, the electrolyte then gives its electron to the dye and regenerates it so that the cycle is repeated again and again. In general there are certain criteria which materials should fulfill to acts as an electrolyte like it should have high conductivity (~10^{-3}S/Cm), highly stable, chemically inert and does cause desorption of the dye from the photoanode [57]. Depending upon the state electrolyte can be of three types' liquid electrolyte, quasi solid electrolyte and solid electrolyte. Most of the dye sensitized solar cells are composed of liquid electrolyte with conversion efficiencies of 11-12% [58]. Basically the liquid electrolyte is composed of redox couple, organic solvent and additives. Although DSSCs based on liquid electrolytes have achieved record conversion efficiency but they suffer from certain disadvantages which delimits its practical usage. For example, the high volatilities and solvent losses during long term operations. Thus work has been done to replace liquid electrolyte with inorganic or organic hole conductors, ionic liquids, polymer and gel electrolytes [19-20]. Recently, the interest of researchers in quasi solid state and solid state dye sensitized solar cells has aroused immensely. The advantages of using polymer gel electrolyte includes good contacting and filling property with TiO_2 film and also show high ionic conductivity by trapping solvent in polymer cages [59].

In order to improve the conductivity of the electrolyte different types of ionic liquids are also being added. Liquid electrolyte was composed of NaI, I_2 and 4-tert-butylpyridine in γ-butyrolactone. The fabricated DSSCs sowed the efficiency of around 3.19% [60].

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 1, January 2017)

A new ionic liquid (IL) 5-mercapto-1-methyltetrazole 1-methyl-3-propylimidazolium salt PMIT with di- 5-(1-methyltetrazole) disulfide (T2) as the organic redox couple is adopted for application in dye sensitized solar cell. The studied ionic liquid showed some prominent features like better light transmission and meets the requirement for building integrated photovoltaics. In addition it was found to be non-corrosive to the photoanode. The IL dye sensitized cells shows high efficiencies of 4.30% [61]. Quasi solid state dye sensitized solar cell was fabricated using polymer gel electrolyte based on Poly (acrylic acid) and poly (ethylene glycol) by soaking in liquid electrolyte. Ionic liquid imbibed polymer gel electrolyte was used for the fabrication of DSSCs with Poly (hydroxyethyl methacrylate/glycerol) polymer and 1-butyl-3-methylimidazolium chloride as ionic liquid. The conversion efficiency of 7.15% was achieved [62].

Xu et al, fabricated efficient solid state dye sensitized solar cell based on an organic hole transport materials with organic dye. The fabricated cell achieved the conversion efficiencies of 5.4% under one sun [63]. To solve the packing challenges in DSSCs solid state hole transporting materials are also used with ZnO-TiO_2 nanoarrays. The obtained conversion efficiency was 5.65% [64]. Chen et al used Polyvinyl-butyral (PVB) based nanocomposite polymer for DSSCs. Solid polymer electrolyte (SPE) films made up of PVB were soaked in liquid electrolyte and used in the device. The prepared SPE conductivity was found to be in the range of 10-3 S/cm and the overall conversion efficiency was found to be 5.46% approximately 94% that of corresponding liquid electrolyte. The device long term stability was tested over 3000 hours [65]. Another research group reported the PEO (Poly ethylene oxide) composite polymer electrolyte with Montmorillonite (MMT) clay as solid electrolyte for DSSC. The addition of MMT filler enhances the conductivity of PEO polymer in the range of 10-3 S/cm. The device fabricated with this polymer electrolyte shows the efficiencies of 3% [66]. Lianos and co-workers used the silica based gel polymer electrolyte the device fabricated with the use this gel polymer electrolyte showed the efficiency of 5.4% [67]. Dong et al prepared interconnected block polymer by the oligomerization of poly (oxyethylene)-segmented diamine and 4, 4′-oxydiphthalic anhydride, followed by a late-stage curing to generate amide-imide cross-linked gels. The gel-like copolymer was used to absorb a liquid electrolyte and it has been found that gel like structure can easily holds the liquid electrolyte which helps in improving the overall conductivity of the electrolyte. This elastomeric copolymer was used as the matrix of a polymer gel electrolyte (PGE) for a dye-sensitized solar cell (DSSC), which shows extremely high photovoltaic performance (soaking for 1 h in the electrolyte).

In particular, the PGE containing 76.8 wt% of the liquid electrolyte renders a power conversion efficiency of 9.48% for its DSSC, with a short-circuit photocurrent density of 19.50 mA cm−2, an open-circuit voltage of 0.76 V, and a fill factor of 0.64. The outstanding performance of the gel-state DSSC, superior to that (8.84%) of the DSSC with the liquid electrolyte, is mainly ascribed to the suppression of the back electron transfer through the PGE. Such efficient polymer gel electrolyte can helps in enhancing the efficiency and long term stability of DSSCs [68].

VI. COUNTER ELECTRODE

Counter electrode yet another vital component of DSSCs. The purpose of counter electrode is to complete the circuit and reduce triiodide to iodide at the FTO/electrolyte interface for this the surface of counter electrode should be activated with suitable catalyst. In addition to that counter electrode catalyst should have high chemical stability towards the electrolyte [69-70]. Based on these requirements the most commonly used catalyst is Platinum. But despite the fact that Platinum is most suited catalyst for the counter electrode it suffers from the major drawback of excessive cost [71]. Therefore excessive use of Pt is a technological problem which if resolved can solve the problem of DSSCs cost. Therefore researchers are working in this direction and other materials like carbon, conducting materials are also used in DSSCs and they are found to work reasonably well. Composites of few layered graphene and Platinum nanoparticles with different loading of Pt were used as counter electrode. DSSCs formed using the composites showed improved performance compared to conventional Pt electrode. Composite with 27% loading of Pt shows 45% higher efficiency (η = 2.9%), greater short circuit current (J (sc) = 6.67 mA cm (-2)), and open circuit voltage (V (oc) = 0.74 V) without any loss of the fill factor (FF = 58%) as compared to the cells fabricated using Standard Pt electrodes. The better catalytic activity of these composite materials is also reflected in the stronger I(-)(3) reduction peaks in cyclic voltammetry scans [72]**.** Yoon et al Photovoltaic performance of dye-sensitized solar cells having counter electrodes of different activated carbons (coconut shells (CC), pine trees (PN) and coals (CL)) was compared with each other and also with the performance of DSSC having conventional Pt counter electrode. The DSSCs with CC and PN activated carbon counter electrode exhibited good performances due to their large surface area. Brunauer-Emmett-Teller (BET) values of CC and PN are 1, 111.32 m2 g(-1) and 963.03 m2 g(-1), respectively. In contrast, DSSC with the CL counter electrode showed a negative performance for its small surface area. The BET value of CL is 754.12 m2 g(-1).

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 1, January 2017)

The good photovoltaic performances of these DSSCs were found to be related to the excellent electrochemical catalysis of the activated carbons on the redox of the iodide/tri-iodie complex, as shown by AC impedance spectroscopy [73]. Mesoporous-graphitic-carbon-supported HfO2 (HfO2-MGC) nanohybrids were investigated as new type of counter electrode for DSSCs. The new HfO2-MGC as a CE in DSSCs showed a surprisingly high efficiency of 7.75 % for the triiodide/iodide redox couple and 3.69 % for the disulfide/thiolate redox couple, greater than the Pt electrode in the corresponding electrolyte system, which opens up a possibility for its practical application [74].

VII. Fabrication Of DSSCs

There are several methods like screen printing, doctor blading, spray coating, spin coating etc for the preparation of porous TiO_2 photoanode for DSSCs. First, the nanocryatalline TiO_2 powder is mixed homogeneously in an aqueous and non aqueous medium with organic binders. Then the obtained paste is coated over the FTO glass. Then the TiO_2 film is dried followed by sintering where organic additives are burnt out of the film and TiO_2 particles get adhered properly together for the better conduction of the electrons through the film. The sintered film is soaked in dye for a long time at room temperature to allow large amount of dye to be adsorbed over the surface of TiO_2 film.

After that the major problem that arises in the fabrication of DSSCs is addition of electrolyte. Sealing methodology plays an important role because it is the electrolyte which should be protected from the external environment and leakage. Also the moisture permeation into the cell should be restricted. Hence to ensure better performance and longevity of the cell effective sealing is necessary. The most widely used material for sealing is slurry. Slurry is the ionomer thermoplastic resin in which the ions are neutralized. Nowadays generally polymer electrolyte film is used in the place of liquid electrolyte to avoid sealing difficulties. Usually, thermoplastic sealants are introduced to the DSSCs by sandwiching the polymer film between the electrodes and then applying heat and pressure simultaneously. The whole assembly of the film consists of TiO_2 photoanode with dye and a platinized FTO substrate cathode. The two electrodes were sealed together by the slurry on all the four sides of the TiO_2 film. The electrolyte was injected into the gap through the hole made on the cathode while the air was sucked out through another hole on the cathode. The holes in the cathode are filled by slurry again. Now the fabricated cell is ready for the study of cell performance measurement.

VIII. Performance Characteristics Of Cell

The power conversion efficiency of the cell of the solar cell is defined as:

PEC= Jsc X Voc X FF/Pin

Where Jsc is short circuit current density, Voc is open circuit voltage, FF is fill factor and Pin is incident input power.

These are the factors which completely determine the efficiency of the device. A typical I-V characteristics curve determines all the three characteristics of the cell. Short circuit current density (Jsc) is the maximum photo current density which can be extracted from the device at short circuit conditions. The Jsc is directly related to the external quantum efficiency.

Fill factor describes the squareness of the I-V curve it is defined as follows

Ff= Jm x Vm/Jsc x Voc

Where Jm and Vm are the maximum power point current density and voltage respectively.

Open circuit voltage is the maximum voltage obtained when there is no current flow and it corresponds to the energy difference between fermi levels of the semiconductor and redox energy level of the redox couple. The product of the current density and the voltage gives the power per unit area of the cell and it takes a maximum value at a particular point on the J-V curve. The origin of Voc in organic-inorganic hybrid solar cells remains thus far largely unexplored. Few reports have shown link between the diagonal band gap and Voc. One report investigating hybrid polymer/TiO_2 solar cells suggests that the Voc is dependent on the ionization potential or HOMO energy level of the polymer.

Current understanding at the very least suggests the maximal theoretical Voc of organic-inorganic hybrid solar cells is determined by the diagonal band gap of the heterojunction. The requirement to maximize the diagonal band gap for Voc is in conflict with the desire to minimize the band gap of the individual isolated materials, such that light absorption can be maximized. Understanding this trade off is necessary for the designed optimization of materials use hybrid solar cells.

IX. Conclusion

In this review article we have discussed so many works that has been carried out for improving the individual component and design and fabrication of DSSCs to make the commercialization of DSSCs in reality. Dye sensitized solar cells (DSSC) have been widely investigated as a next generation solar cell because of their simple structure and low manufacturing cost and this is the driving force for development of DSSCs. The advancement has been taken in photonaode materials different types of nanocomposites materials have been synthesized to improve the structure of photoanode. Titania nanotubes (TNTs) have a demonstrated potential yet the reliable fabrication of photoanodes based on TNTs has to be simplified.

TiO_2 one dimensional structures proved to show better performance in DSSCs and they allow easy transfer of electrons from dye to the photoanode to the outer circuit. Doping of TiO_2 with different metal oxide is another important approach that improved the spectral response of TiO_2 which helps in the improvement of efficiency of cells. Further work is required to examine newer quasi-solid or solid electrolytes that do not compromise with the performance of DSSCs. Dye molecules have also been modified with different types of moiety and anchoring groups that form bonds with the TiO_2 surface for easy transport of electrons to the TiO_2 surface. Further to reduce the cost of DSSCs platinum catalyze counter electrode have been replaced with carbon or graphene catalyze electrodes which are cheap and have no adverse effects on the efficiency of the DSSCs. In summary, DSSCs offer sufficient challenges for any materials scientist for further research and fruitful commercialization of this exciting new technology.

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