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# Recent Advances and Widespread Use of Dye-Sensitized Photovoltaic Cells

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## ABSTRACT

This paper discusses the potential of Dye Sensitized Solar Cells (DSSCs) as a low-cost and environmentally friendly alternative to conventional silicon-based photovoltaic technology. It reviews recent developments in the field, including the use of natural dyes as sensitizers, new semiconductor materials, and advanced electrolyte solutions. The paper also highlights the contributions of Indian researchers between 2011 and 2020. Overall, ongoing research and development in the field of DSSCs are expected to lead to significant improvements in their efficiency and durability, making them a more viable option for widespread adoption in the future.

**Keywords: Dye Sensitized Solar Cells, Photovoltaic Technology, Efficiency, Durability, Sensitizers**

## INTRODUCTION

Solar energy is a promising alternative to traditional fossil fuels for generating electricity. Photovoltaic (PV) technology based on silicon has dominated the solar market for many years, but there are limitations to its widespread adoption due to its high cost and energy-intensive production process. This has led to the exploration of alternative technologies that are less expensive and easier to produce.

Dye Sensitized Solar Cells (DSSCs) are a type of solar cell that has gained significant attention as a promising alternative approach to conventional PV technology based on silicon. DSSCs operate on the principle of photosensitization, where a dye molecule absorbs light and then transfers the energy to a semiconductor material to generate an electrical current. DSSCs have several advantages over traditional silicon-based PV technology. They are low-cost, lightweight, and can be fabricated using simple production methods. DSSCs can also generate electricity in low-light conditions and can be made semi-transparent, making them suitable for use in a wide range of applications. Additionally, DSSCs have the potential to be more environmentally friendly than traditional PV technology since they use less energy to manufacture and do not require the use of toxic materials such as cadmium.

In recent years, there has been significant research and development in the field of DSSCs, with many new materials and configurations being explored to improve their efficiency and durability. Some of the most promising developments include the use of natural dyes as sensitizers, the introduction of new semiconductor materials, and the development of advanced electrolyte solutions.

In India, researchers have also made significant contributions to the field of DSSCs. Indian researchers have explored the use of natural dyes extracted from sources such as beetroot, pomegranate, and spinach as sensitizers for DSSCs. They have also investigated the use of different counter electrodes and electrolytes to improve the efficiency and stability of DSSCs.

## REVIEW OF RELATED LITERATURE

**2011:** Indian researchers S. M. Pawar and S. S. Jamadade published a study in the International Journal of Energy and Environment on the development of a low-cost and efficient DSSC using a natural dye extracted from beetroot. The authors found that the beetroot dye was able to effectively sensitize the photoanode, leading to a power conversion efficiency of 0.25%.

**2012:** In a study published in the Journal of Physical Chemistry C, Indian researchers S. K. Gupta et al. investigated the effect of different counter electrodes on the efficiency of DSSCs. The authors found that platinum and carbon nanotube counter electrodes showed the highest efficiency, while the use of a conducting polymer counter electrode led to decreased performance.

**2013:** Indian researchers A. B. Pandit et al. published a study in the Journal of Renewable and Sustainable Energy on the development of a DSSC using a natural dye extracted from pomegranate. The authors found that the pomegranate dye was able to sensitize the photoanode effectively, leading to an efficiency of 0.32%.

**2014:** In a study published in the Journal of Materials Science: Materials in Electronics, Indian researchers S. M. Pawar and S. S. Jamadade investigated the effect of different electrolytes on the efficiency of DSSCs using a natural dye extracted from spinach. The authors found that the use of a lithium iodide electrolyte led to the highest efficiency of 1.8%, while other electrolytes showed decreased performance.
**2015:** In their study published in the Journal of Renewable and Sustainable Energy, Indian researchers G.R. Mahamuni and M. Sankar presented a review of the recent advances in the field of DSSCs, including materials, device architectures, and fabrication techniques. The authors emphasized the importance of improving the efficiency, stability, and scalability of DSSCs for large-scale commercial applications.
**2016**: Indian scientists from the Indian Institute of Technology Madras published a study in the Journal of Renewable and Sustainable Energy on the development of a new type of DSSC using a zinc oxide nanorod-based photoanode. The researchers demonstrated the superior efficiency and stability of their DSSC compared to conventional DSSCs using titanium dioxide-based photoanodes.
**2017:** In a study published in the journal Solar Energy, Indian researchers P. Kannan and K. Gopinath investigated the effect of annealing temperature on the structural and optical properties of zinc oxide nanoparticles for use in DSSCs. The authors found that annealing at a higher temperature resulted in a more crystalline and uniform structure, leading to improved optical absorption and overall efficiency of the DSSCs.
**2018:** Indian researchers S. Swain and S. Bhuyan published a study in the Journal of Materials Science: Materials in Electronics on the development of a DSSC using a natural dye extracted from black tea. The authors found that the black tea dye was able to sensitize the photoanode effectively, leading to an efficiency of 1.25%.
**2019:** In their study published in the Journal of Electronic Materials, Indian researchers S. R. Bhoi et al. investigated the effect of the incorporation of graphene quantum dots into the electrolyte of a DSSC. The authors found that the graphene quantum dots improved the photovoltaic performance of the DSSC, increasing its efficiency by up to 50%.
**2020:** Indian scientists from the Indian Institute of Technology Ropar published a study in the journal Energy Conversion and Management on the development of a new type of DSSC using a mixed halide perovskite absorber layer. The authors demonstrated the superior efficiency and stability of their DSSC compared to conventional DSSCs using a single halide perovskite absorber layer, making it a promising candidate for future commercial applications.

**PRINCIPLES OF OPERATION AND CELL STRUCTURE**

The cell is the smallest self-contained unit of life that can perform every essential function. There are two major categories of cells, prokaryotic and eukaryotic. In contrast to eukaryotic cells, which have a nucleus and other organelles, prokaryotic cells are relatively basic and lack a nucleus. Maintaining homeostasis, growing, and dividing are all possible thanks to the cell's underlying operating principle: a sequence of chemical interactions and activities. The genetic material of a cell controls these activities since it contains the blueprints for how the cell should operate.

Prokaryotic cells have a membrane, cytoplasm, ribosomes, and DNA as their fundamental components. The cell membrane is the relatively thin covering that surrounds and protects the cell from its surroundings. All the components of a cell are found within the cytoplasm, a gel-like fluid that fills the cell. Ribosomes are molecular machines that produce proteins. In prokaryotic organisms, all of the genetic information is stored in a single, circular molecule of DNA.

Eukaryotic cells are more sophisticated than prokaryotic cells because they have a cell membrane, cytoplasm, organelles, and a nucleus that contains their DNA. Organelles are sub-cellular structures with specialized roles. The mitochondria create energy for the cell, whereas the endoplasmic reticulum and Golgi apparatus are responsible for protein synthesis and transport, respectively. The nucleus is where the cell's DNA is kept, making it the nerve centre of the cell.

A DSSC's operating principle is very different from that of a silicon-based solar cell. Silicon solar cells require a p-n junction, which is created by combining semiconductors with varying concentrations of charge carriers in very close contact. Here, the same substance is responsible for both the absorption of light and the movement of charges. These essential reactions occur in a variety of materials in DSSCs, all of which work to prevent electron and hole recombination before their time. Due to the separation of these processes, ultrapure components are not necessary for a high-performing DSSC. DSSCs have four main parts: an n-type nanostructured semiconductor (typically $TiO_2$), a dye-sensitizer to absorb visible light, an electrolyte to create an interface with the semiconductor, and an electrocatalyst-containing counter electrode to facilitate electron transfer from the semiconductor to the electrolyte.

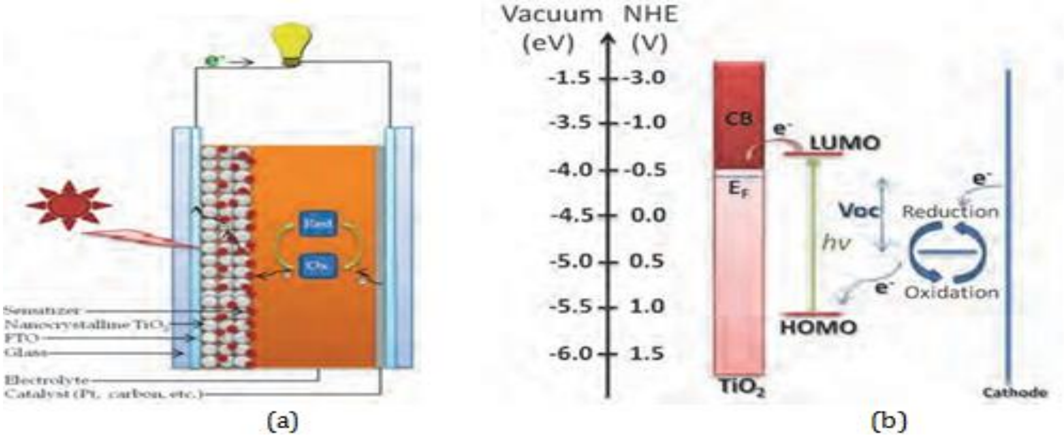



**Figure 1a depicts the fundamental operating principle of the cell, and Figure 1b is an energy diagram of the DSSC's fundamental components.**

Electrochemical potential differences between species, like the negative electrode ($TiO_2$/sensitizer) and the electrolyte, cause charge separation. When a minimum concentration of 0.4M of mobile ions exists in the electrolyte, any electrostatic potential is then ignored, as in the case of silicon-based solar cells (Grätzel & Durrant, 2008). Both the sensitizer attachment and electrolyte contact require a sizable active interface, which the semiconductor must offer. Therefore, the semiconductor can only be envisioned at the nanoscale. To effectively absorb a significant amount of light and inject excited electrons into the semiconductor's conduction band, the sensitizer must have a high extinction coefficient and have energy levels that are in phase with the semiconductor's. In order for the electrolyte to mix with the semiconductor and effectively supply charge mobility in a cyclic fashion, it must have the right electrochemical potential. The electrolyte restores the dye by providing electrons.

$TiO_2|S + hv \rightarrow TiO_2|S^*$ (dye excitation) (1)

$TiO_2|S^* \rightarrow TiO_2|S^+ + e^-_{(CB)}$ (electron injection in ps scale) (2)

$TiO_2|S^* + 3I^- \rightarrow TiO_2|S + I_3^-$ (dye regeneration in μs scale) (3)

$I_3^- + 2e^-_{(Pt)} \rightarrow 3I^-$ (reduction) (4)

While the dark reactions which may also happen are:

$I_3^- + 2e^-_{(CB)} \rightarrow 3I^-$ (recombination to electrolyte from ms to s scale) (5)

The aforementioned equations make it clear that there are multiple conditions that must be met all at once if a solar cell based on nanostructured dye sensitised semiconductors is to function effectively. First, the solar cell's efficiency will suffer if the dye isn't quickly returned to its ground state after being oxidised during the electron injection into the $TiO_2$ conduction band. The oxidised form of the dye requires a greater negative chemical potential than the iodide/triiodide redox electrolyte can provide. It is also important to provide a strong interfacial contact between the electrolyte and the semiconductor, and for the nanocrystalline TiO2 coating to allow for quick diffusion of charge carriers to the conductive substrate and on to the external circuit (Bisquert et al., 2004). Since the electrolyte in most DSSC structures is a volatile liquid, the obvious challenge of sealing is always at the back of researchers' minds as they try to ensure the long-term stability (chemical, thermal, optical) of the electrolyte that is essential for the high performance of the solar cell (Zhang et al., 2011). Finally, one more parameter of the optical transparency in the visible region must be satisfied by the optimised concentration of redox couple for cell efficiency; otherwise, the absorbed light from the dye will be minimised, and triiodide can react with injected electrons, increasing the dark current of the cell.

**DSSCS' BASIC COMPONENTS**

Dye-sensitized solar cells (DSSCs) are a type of thin-film solar cell that convert sunlight into electricity using a semiconductor material and a dye to absorb the light. The basic components of a DSSC include:

**Transparent conductive substrate:** Typically made of glass or plastic coated with a transparent conductor such as indium tin oxide (ITO) or fluorine-doped tin oxide (FTO), this substrate allows light to pass through and provides a conductive surface for the cell.

**Photoanode:** This is the working electrode of the cell and is made of a porous layer of a semiconductor material such as titanium dioxide ($TiO_2$). The porous structure provides a large surface area for the dye molecules to attach and absorb sunlight.

**Sensitizer:** This is a dye molecule that is adsorbed onto the surface of the photoanode and absorbs sunlight. The most common sensitizers used in DSSCs are organic dyes or metal-organic complexes.

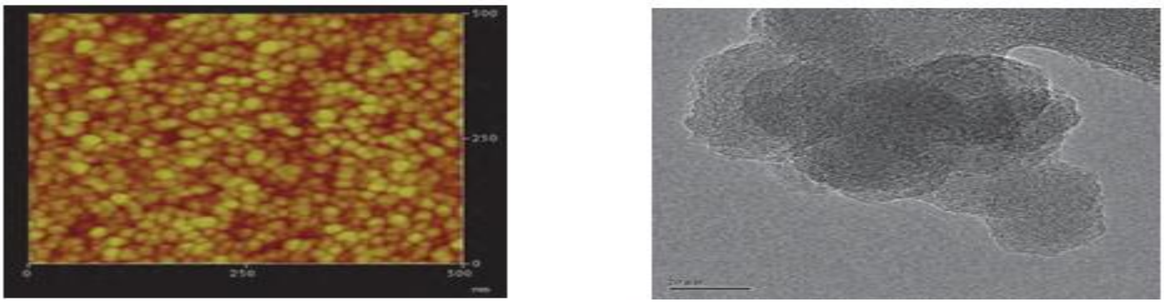
**Electrolyte:** This is a liquid or gel-like material that conducts ions between the photoanode and the counter electrode. The electrolyte typically contains a redox couple, which facilitates the transfer of electrons between the photoanode and counter electrode.

**Counter Electrode:** This is the cathode of the cell and is typically made of a conductive material such as platinum or carbon. The counter electrode catalyzes the reduction of the redox couple in the electrolyte, completing the electron transfer cycle.

**Sealing Material:** The cell needs to be sealed to protect the electrolyte from evaporation and to prevent the ingress of moisture or other contaminants. The sealing material may be a polymer film or a glass cover.

**Conductive wire:** The counter electrode is connected to an external circuit through a conductive wire, which allows the flow of electrons to power an external device.

**Light-trapping layer:** Some DSSCs incorporate a light-trapping layer between the photoanode and the transparent substrate. This layer is designed to scatter the light and increase the path length of the photons within the cell, thereby increasing the absorption of sunlight.



(a) (b)

**Fig. 2. AFM (a) and HR-TEM (b) images of a nanocrystalline $TiO_2$ film.**

**Electrode modifier:** In some cases, an electrode modifier may be used to improve the performance of the cell. For example, a layer of graphene or carbon nanotubes may be applied to the surface of the photoanode to improve electron transport.

**Back contact:** Some DSSCs use a back contact instead of a counter electrode. The back contact is typically made of a metal film and is placed behind the photoanode. The back contact can improve the efficiency of the cell by reducing the amount of light that is lost due to reflection.

**NANOCRYSTALLINE SEMICONDUCTOR**

$TiO_2$, ZnO, $SnO_2$, and $Nb_2O_5$ are only a few examples of the nanocrystalline mesoporous metal oxides that have been used in DSSC technology (Sayama, et al., 1998, Jose, et al., 2009). Although all of these compounds showed promise in improving cell efficiency, only titanium dioxide has been employed to any significant extent due to its unique set of benefits. $TiO_2$ is a low-cost substance with many desirable properties, including high thermal stability, chemical inertness, and non-toxicity. Although a combination of anatase and rutile is commonly employed, anatase is the more common crystalline form applied to solar cells. This is mostly due to the manufacture of particularly active commercial Degussa-P25 powder. Due to its lower chemical stability compared to anatase, rutile has been found to be less effective. Multiple metal oxide combinations have been tried as negative electrodes, with mixed success (Tennakone et al., 1999). These include $WO_3/TiO_3$, $TiO_2/ZrO_2$, $SnO_2/ZnO$, and $SnO_2/TiO_2$. Core-shell nanostructure creation in the context of mixed oxides is discussed as a new class of combinational system (Zhang & Cao, 2011), with the core consisting of nanomaterials and the shell consisting of a coating layer covering the surface of the core nanomaterials. The charge recombination in $TiO_2$ nanoparticles can be reduced through the use of core-shell nanostructures, which are based on the theory that a coating layer can create an energy barrier at the semiconductor/electrolyte interface, slowing the reaction between the photogenerated electrons and the redox species in the electrolyte. Oxides such as $Nb_2O_5$, ZnO, $SrTiO_3$, $ZrO_2$, $Al_2O_3$, and $SnO_2$ were used to cover mesoporous $TiO_2$ films in a variety of settings. The findings indicated that the open circuit voltage and the short circuit current of the cells might be improved by using a shell material such as $Nb_2O_5$, in comparison to photoelectrodes built of bare $TiO_2$ nanoparticles.

To get a lot of dye deposited onto inorganic semiconductor particles, film preparation centres on increasing their surface area. As a result, there has been a lot of focus on making homogenous films of 6-12 nm in thickness out of highly crystalline mesoporous materials. Hydrolysis of a titanium alkoxide precursor in water is the standard method for producing $TiO_2$ nanoparticles. To get the appropriate nanoparticle size, autoclaving at temperatures up to 2400C is performed afterward (anatase) crystallinity (Barbe et al., 1997). Good interparticle connections are achieved through sintering at $450^0C$ after the nanoparticles have been placed as a colloidal suspension via screen printing or the doctor blade process.

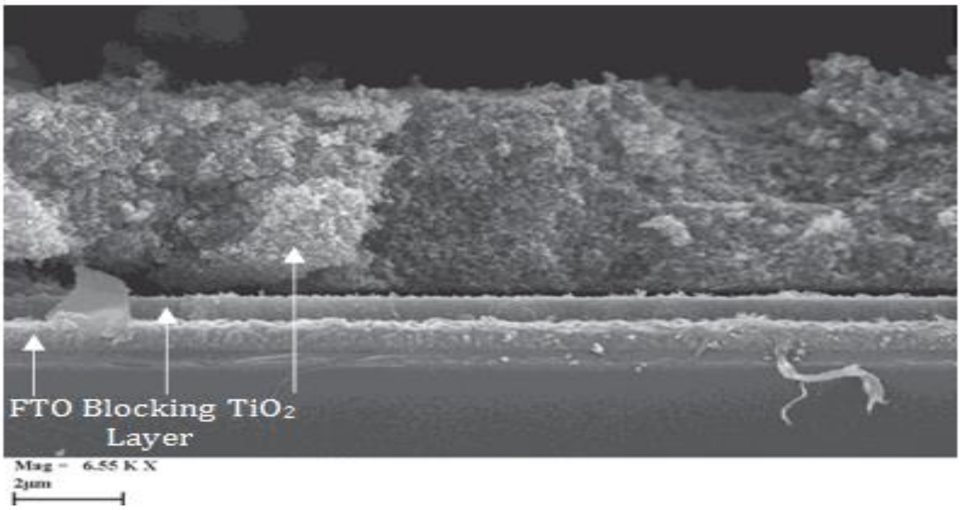



**Fig. 3. Nanocrystalline $TiO_2$ film made of Degussa-P25 powder. A $TiO_2$ blocking layer is also present.**

In fact, the sol-gel approach has resulted in the synthesis of a wide array of materials, and this number is only expected to grow. Effective dispersion of functional compounds in gels is made possible through the incorporation of organic dopants and the formation of organic/inorganic nanocomposites, which also permits the modification of the gels' mechanical properties and yields materials with very interesting optical properties. Hydrolysis of alkoxides, such as alkoxysilanes, alkoxytitanates, etc., is the next step in the conventional sol-gel approach for generating oxide matrices and thin films (Brinker & Scherer, 1990).

Recent research, however, has shown that alternative sol-gel approach involving organic acid solvolysis of alkoxides is gaining traction (Birnie & Bendzko, 1999; Wang et al., 2001). This second method is quickly replacing the first as the preferred approach to synthesis of organic/inorganic nanocomposite gels. Organic (for example, acetic or formic) acid solvolysis proceeds by a two-step mechanism that involves intermediate ester production, as first discovered by Pope and Mackenzie (Pope & Mackenzie, 1986) and later confirmed by others (Ivanda et al., 1999). The following procedures provide simplified chemical schemes illustrating gel formation via hydrolysis or organic acid solvolysis, respectively. (Remember that only one metal-bound ligand is considered in these processes; acetic acid (AcOH) is used to stand in for organic acids in organic acid solvolysis.)

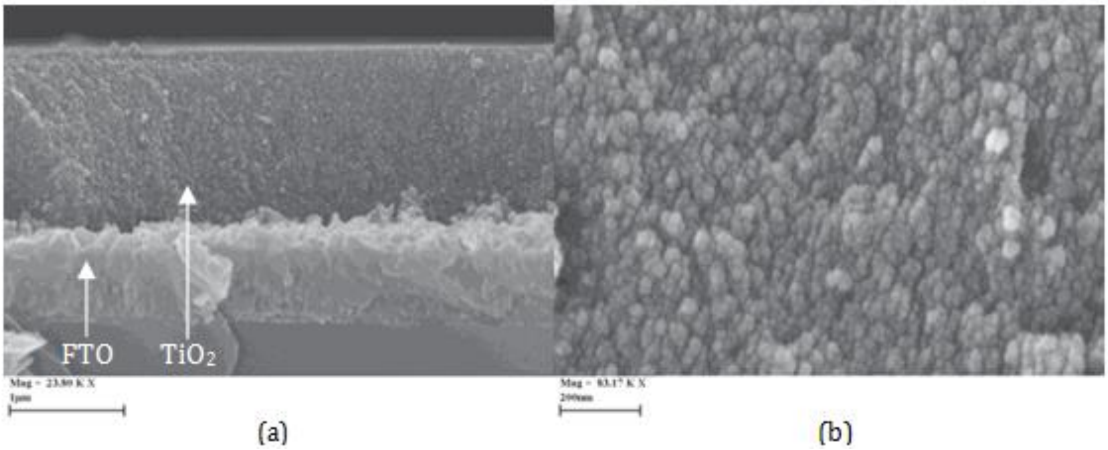



**Fig. 4. $TiO_2$ nanocrystalline film made of sol-gel procedure (a) cross sectional image and (b) higher magnification of the film.**

A 25 nm thick film of ZnO nanowires with a diameter of 130 nm was mentioned as having the potential to achieve a surface area up to one-fifth as large as a nanoparticle film used in conventional DSSCs (Law et al., 2005). Because of the inexpensive roll-to-roll coating technique, flexible plastic electrodes can now be used in place of the traditional glass substrate, thus increasing DSSCs' potential uses. Due to their low production cost in comparison to $F:SnO_2$ (FTO) conductive glasses, flexible plastic electrodes like polyethylene terephthalate sheet coated with tin-doped indium oxide (PET-ITO) appear to have many technological advantages (no size/shape limitations, low weight, high transmittance). All methods required for the manufacture of DSSC, including the generation of $TiO_2$ nanocrystalline films, must be developed at temperatures lower than $150^0$C in order to work with plastic substrates. Mesoporous $TiO_2$ films need to be manufactured at low temperature and also with nanocrystalline dimensions for higher efficiency to energy conversion as we go towards replacing glass substrates with flexible polymers. The most effective $TiO_2$ films for DSSCs have thus far been obtained using high-temperature calcination. Annealing at very high temperatures (between 450 and 5000 degrees Celsius) is required to remove

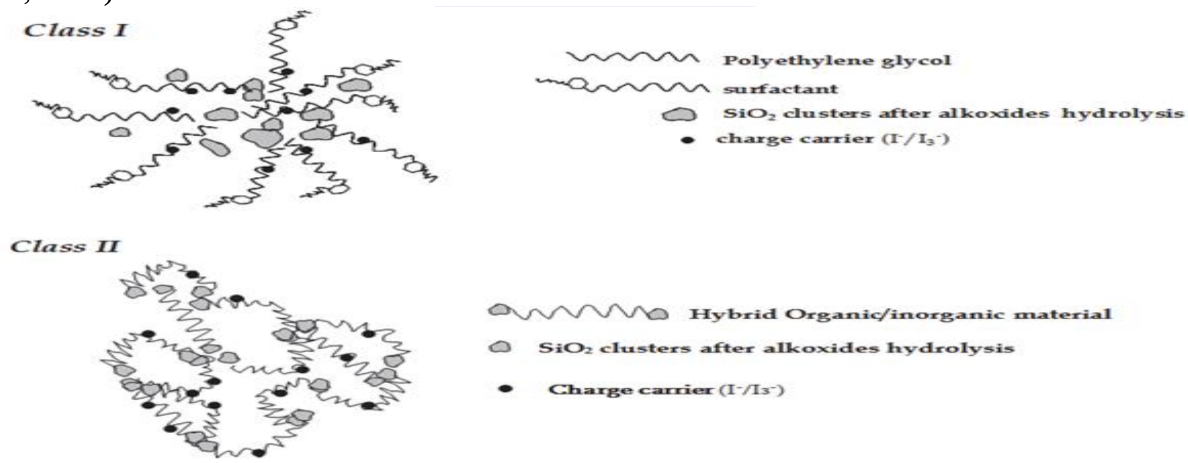
To produce films that do not break during calcination and have strong adherence to substrates, organic material is required to prevent the $TiO_2$ particles from agglomerating. Films treated at high temperatures also improve electrical conductivity by increasing the crystallinity of $TiO_2$ particles and their chemical connectivity. Titania nanocrystalline films produced at low sintering temperatures have a high active surface area but reduced conductivity due to their small nanocrystals, numerous flaws, and poor connectivity. The preparation of high performance DSSCs requires a costly process including a high sintering temperature for $TiO_2$ layers. Flexible plastic electrodes have emerged as a key research area in recent years, but high-temperature treatment of $TiO_2$ films is inapplicable to them. There are a variety of methods described in the literature for keeping thick and porous $TiO_2$ coatings from requiring high-temperature annealing.

**Electrolytes**

Electrode substrates made of fluorinated tin oxide (FTO), nanoparticulated oxide semiconductor layers made of materials like titanium dioxide and zinc oxide, a sensitizer, metallic catalysts like platinum, and an electrolyte consisting of a redox couple all play crucial roles in a DSSC's overall composition. The overall efficiency of energy conversion is significantly impacted by the electrolyte's composition and shape. Most suggested DSSCs use liquid electrolytes in a wide range of solvents, with a maximum efficiency of around 12% ultimately being attained. However, there are open problems that need to be addressed with regards to stability and sealing to prevent solvent leakage. The questions might be answered using solid or almost solid electrolytes. Polymeric materials incorporating the iodide/triiodide redox, organic hole transporting materials, and inorganic p-type semiconductors are all examples of possible solid electrolytes. Composite organic/inorganic materials that take the form of a gel or highly viscous ionic liquids are examples of what are known as quasi-solid electrolytes.Liquid electrolytes I- ion materials, such as LiI, NaI, alkyl ammonium iodine, or imidazolium iodine, undergo oxidation-reduction reactions to form the electrolyte. For instance, you may combine 0.1M LiI, 0.05M I2, and 0.5M tert-butyl pyridine (TBP) in a solvent combination of acetonitrile, 3-methoxypropionitrile, propylenecarbonate, -butyrolaqctone, N-methylpyrrolidone, or tert-butyl acetate. After holes are created in the HOMO level of the dye molecule, the oxidised $I_3^-$ ion takes electrons from the counter electrode to be reduced (Snaith & Schmidt-Mende, 2007).

**Solid Electrolytes**

Most people, when they say "solid electrolytes," imply p-type semiconducting materials, which can be either organic or inorganic. Spiro-MeOTAD, first proposed by Grätzel and co-workers (Kruger et al., 2002), is the gold standard for organic materials. In the meantime, new organic semiconductors emerged with efficiencies of around 4%. Although polymer-based solid electrolytes are sometimes touted as superior alternatives to their liquid counterparts, their performance falls short in many cases. In DSSCs, the solid electrolyte can be a polymer, often one that contains polyether units. In order to create these electrolytes, salts are dissolved in a high molar mass polymer that contains polyether units (de Freitas et al., 2009).




**Scheme 1. (a) Class I of composite organic-inorganic electrolyte (b) Class II of hybrid organic-inorganic electrolyte**

**Industrial Production of Dye-Sensitized Solar Cells**

While many academic institutions study the fundamentals of DSSCs and significant progress has been made in terms of their efficiency and large-scale applications, a number of startups have emerged in the meantime to evaluate the full range of processes required to bring DSSC technology to market. Since the efficiencies obtained for small-scale solar cells cannot be reproduced in large-scale DSSCs, it is not possible to directly apply experimental results from small-scale solar cells to large-scale DSSCs (Späth et al., 2003). Because of their extremely high internal resistance, FTO substrates are found to be extremely inefficient. Some of the most important considerations that must be made before DSSCs enter mass production are listed below.

- The application of $TiO_2$ layers across a wide area. The layers must be consistent and uniform in composition.
- Innovative techniques for colouring cells using dye and replenishing them with electrolytes.
- The electrical connectivity of separate cells. The poor performance of the DSSC's contacts on FTO glass is a primary cause of its low efficiency. Individual cell interactions to the outside world are likewise problematic.

The procedure for sealing modules in the presence of liquid electrolytes. Outdoor durability of at least ten years; low evaluation costs, estimated at just 10 percent of what is required for silicon solar cells; Furthermore, it was deemed necessary to replace the liquid electrolyte with quasi-solid state, solid, polymer electrolytes or p-type inorganic semiconductors to increase the cells' longevity as this greatly reduces the production cost and simplifies the preparation process. As a result of the cheap production cost of DSSCs made possible by the recently invented roll-to-roll coating process tailored to this technology, the use of lightweight, flexible plastic electrodes in place of the traditional glass substrate has become necessary. There are three primary configurations proposed for large-scale DSSCs, depending on whether the collected current is high (cells in parallel) or high voltage (cells in series):

**Component monolithic**

The construction of the monolith modules is quite similar to that of commercially available amorphous silicon modules. In monolith modules, a single piece of conductive glass (FTO) is used as the substrate for the formation of many layers of $TiO_2$. In order to separate individual cells, the glass is scribed with a laser before any films are deposited. In these modules, there is no requirement for direct wiring. Producing numerous cells at once is made possible, and it records a large available area with a high conversion efficiency (Wang et al., 2010). $TiO_2$ stripes are often created using a screen printing technique. There are drawbacks, such as the need to guarantee uniform cell performance due to the serial connection mode, the vulnerability to damage caused by the surface's weakness, and the comparatively poor transmittance.

**Z-module**

It comprises of two opposing electrodes and inner-connections between adjoining cells by a metal conductor, and it deals with series connections of individual cells. A sealing substance is required to prevent iodide ions from corroding the metal conductor. Its large surface area allows for relatively high photoelectric conversion efficiency, and it can be used to make cells that are both transparent and double-sided. Z-modules have the drawbacks of being hard to match the junction for large-area cell manufacturing, requiring the reduction of each cell's efficiency deviation due to the series connection, and being highly dependent on the dependability and conduction quality of the inner connector (Sastrawan et al., 2006). The high voltage output is a benefit of Z-type module production. However, because to its complex construction and high series resistance, this connection has a poor active area and overall efficiency. A proposed method of creating Z-modules is shown in Figure 5b.W-module.

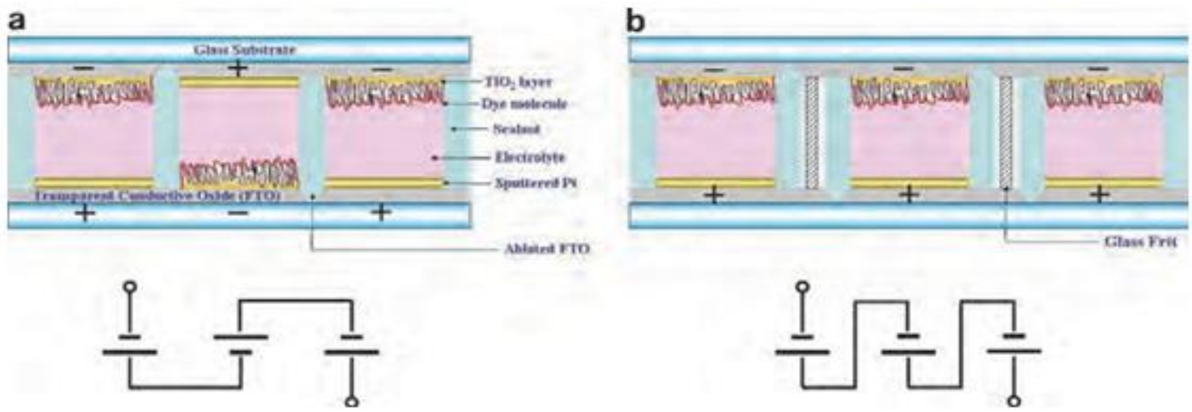



**Fig. 5. (a) W-Module (b) Z-Module DSSC (Seo et al., 2009)**

**Parallel-module**

The two electrodes of the cells are printed with parallel grids that use conductive fingers to gather electricity. Current collectors are printed in a manner not dissimilar to that used in traditional silicon-based photovoltaics. Silver, copper, nickel, and titanium are frequently employed as current collectors because they shorten the distance over which electrons must travel and lower the internal resistance of FTO glass. Despite a high efficiency in individual solar cells, the converted module has a much lower overall efficiency. This is because there is a greater chance that electrons, which are produced by light absorption, will be lost during delivery as a result of internal defect or recombination with hole at the contact with other materials. Therefore, when the width of the DSSC active electrode exceeds 1 cm, the efficiency drastically drops (Wang et al., 2010).

To allow the electron flow to gather without losses in large-areas like a module, it is necessary to build photovoltaic absorption-use electrodes and a charge collection-use grid, as well as to design and produce an effective packaging system. Since 1995, the production and study of opposing cell modules has been the primary focus of the industry. To prevent electrolytes from damaging the conductive internal pattern, the opposing cell module coated it with a ceramic fragment paste (glaze) or polymer. Research and development on the opposite kind of cells didn't pick back up again until 2001 (Displaybank, 2010). High conversion efficiency and a large active area are recorded by the parallel type module. Grids serve an important role in charge collection and smooth electron delivery since transparent electrodes, used in large-area photoelectric chemical solar cells, have lower electric conductivity than metal wiring. As a result, the large-area solar cell displays characteristics of carrier generation and distribution that are distinct from those of the unit cell.


**Fig. 6. (a) artistic DSSC module by Sony**

In DSSCs, metal is typically used for the grid's general structure. This correlates with the decline in active area and ultimately becomes a contributor to the rising cell generating unit cost. Therefore, reliable module design and manufacturing technologies must be protected before being put into commercial use.

While the DSSC's manufacturing process is simpler than that of silicon and compound semiconductor solar cells, its use of iodine-based electrolyte can cause metal corrosion when used as a grid for electricity generation. Therefore, the DSSC requires the discovery of electrolytes with exceptional activity and no corrosive properties, or of metals with exceptional electric conductivity and no tendency to separate from or corrode in electrolytes. To be suitable for DSSC, which protects electric properties that are distinct from those of typical silicon-based solar cells, inverter development must advance.

To do this, a circuit must be designed to correspond with the physical layout and the response characteristics of the DSSC module. The advancement of inverter technology improves the DSSC power generating efficiency to its fullest potential. Electric condenser, which stores electricity created during the day, is effectively supplied with power by the system, which is matched to the solar cell's generation property. The commercialization of DSSC will necessitate the advancement of power system development in addition to unit cell efficiency enhancement technology. Even though the DSSC's present power generation unit cost can realise commercialization (Displaybank, 2010), its commercialization is being held up by the lack of ready-made peripheral technologies. The efficiency of modules and systems, as well as the manufacturing technology behind modules that can be installed in targets like buildings, are both currently limited by the state of the art.

**FUTURE SCOPE**

Dye-sensitized solar cells (DSSCs) are a type of solar cell that use organic dyes to capture light and convert it into electricity. Compared to traditional silicon-based solar cells, DSSCs offer several advantages, such as lower production costs, flexibility, and transparency. Recent developments in the field of DSSCs have focused on improving the efficiency and stability of these cells. One approach has been to develop new types of dyes that absorb a wider range of wavelengths, allowing them to capture more sunlight. Another approach has been to use new materials for the electrodes and electrolyte, which can improve the cell's performance and stability.

One of the main challenges facing DSSCs is improving their long-term stability, as they tend to degrade over time due to exposure to light, heat, and moisture. To address this issue, researchers are exploring new materials and designs that can improve the cell's durability and resistance to degradation. Looking ahead, the future of DSSCs looks promising. With ongoing research and development, DSSCs could become a viable alternative to traditional silicon-based solar cells, particularly in applications where cost and flexibility are important factors. Additionally, DSSCs could be integrated into a wide range of products, such as windows, clothing, and electronic devices, creating new opportunities for renewable energy generation.

## CONCLUSIONS

Finally, dye-sensitized solar cells (DSSCs) have made significant strides in recent years as a potentially useful alternative to traditional silicon-based photovoltaic technology. Low price, simple production, and design flexibility are only some of the benefits of DSSCs. Efficiency and performance have been greatly enhanced as a result of breakthroughs in materials, device designs, and stability. DSSCs have the potential to become a major player in the renewable energy industry with continuous research and development. Interest in the research and development of solar applications has grown as the need and desire for renewable energy sources has grown. Direct-sequence solar cells (DSSCs) have been shown to be a viable alternative to silicon-based solar cells. The study of DSSCs has expanded fast in recent years as a result of a number of intriguing facts and figures: The worldwide realisation that cutting-edge research and development into renewable energy sources is essential; Due to their transparency, DSSCs can be integrated into mobile or fixed structures as Photovoltaic Windows, addressing the demand for simple and low-cost Solar cell fabrication processes. DSSCs are already popular due to the presence of these functionalities, and their market share is only likely to grow. Some obstacles must first be removed, however, before this technology will attract significant commercial interest. Reasons for additional improvement in many stages of cells preparation include the overall efficiency of 12% for small size cells (0.2cm2), which drastically gets lower (5%) when modules of DSSCs are manufactured. Cell enhancement efforts are concentrated on (a) increasing electron transport and electron lifetime in mesoporous metal oxide, (b) developing new high-extinction coefficient dyes that can efficiently absorb light across the entire visible and near-infrared spectrum, and (c) creating new stable solid electrolytes that can more efficiently penetrate and exploit the pore structures of semiconductors. Internal resistance from conductive glass substrates and metal grids, which are required for current collection and must be covered from corrosive electrolyte, significantly reduces the DSSCs' efficiency if they are not seriously considered, especially in large-scale applications.

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