# Review of Dye-Sensitized Solar Cell (DSSCs) Development

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## ABSTRACT

**Energy consumption is increasing yearly all over the world due to the increase in population and demand of energy. The world largely depends on a hydroelectric energy supply, thermal electric energy supply which is all non-renewable energy resources. Nevertheless, non-renewable energy resources are rapidly decreasing per year due to increasing rate of energy consumption. The quest for the discovery of another abundant resource of energy has attracted many scientists into development of renewable energy technologies like photovoltaic energy which are the technology that convert solar radiation into electricity. For the past several years, different photovoltaic devices like inorganic, organic, and hybrid solar cells have been invented using different methods for different application purposes. Moreover, high conversion efficiency of silicon solar cells, the high cost of module and complicated production processes involved in the production restricted commercialization of photovoltaic solar cells as a means of electricity supply. Among all organic solar cells, Dye-Sensitized Solar Cells (DSSCs) are the most efficient, low cost and easily implemented technology. This review paper focuses on clarifying the technological meaning of the structure of DSSCs, Various types of DSSCs materials, working electrode and working mechanism of DSSC, transparent and conductive substrate, nanocrystalline semiconductor film electrode, photosensisitizer (dye), electrolyte, carbon layer electrode, zinc oxide (ZnO) layer, zirconium dioxide ($ZrO_2$) layer, benefits of DSSCs and application, the efficiency and challenges for research and development of DSSCs to upgrade the current efficiency.**

## 1. INTRODUCTION

The energy consumption of the world is increasing on daily basis [1-3]. There is no doubt that the stored fossil fuel mainly used for energy generation is depleting every year and call for another source of energy [4, 5]. The sun is a natural source of energy created by God in abundant and is clear and renewable [6]. Harnessing the power of the sun can improve our way of life, reduce our dependence on fossil fuels or other types of energy sources and stimulate our economy by creating new jobs [7]. Sustainable and renewable resources of energy such as, Solar thermal, Wind Energy (Air), Gravitational Potential Energy (water or Hydro-electric Energy), Tides Energy and Biomass Energy are all good sources of energy but solar cell which is also known as photovoltaic cell is one of the promising options of renewable energy and the most efficient [8, 9]. Among different categories of solar cell, the dye sensitized solar cell (DSSC), which was invented by Professor Michael Gratzel in 1991 [10], is the most promising inexpensive technology for harnessing sunlight radiation. Dye-sensitized solar cells (DSSCs) are cheaper alternatives to the conventional silicon solar cells and belong to thin film family [11, 12]. Dye-Sensitized Solar Cells (DSSCs) are efficient, low cost with simple manufacturing procedures [13]. Solar radiation could be best harnessed, converted to electricity using Dye-sensitized solar cell (DSSCs) technology that is the combination of natural dye as a photo sensitizers. Dye sensitized solar cell would be a good light harvesting channel because of the product of a dye with moderate extinction and a photoanode of high surface area (~1200 times the area of a flat electrode). The combination of dye with moderate extinction, photoanode of high surface area with area of a flat electrode allows for ample absorbance over the majority of the visible spectrum with room for improvement in the red wavelengths [14]. The basic components of dye sensitized solar cell are photoanode consisting of monolayer of sensitizer (dye) absorbed onto a mesoporous semiconductor oxide (typically $TiO_2$) [15]. In conventional solar cell system, semiconductor assumes both the task of light absorption and charge carrier. In dye sensitized solar cells, the functions of light absorption, electron transport and hole transport are separated into different materials [16]. Light is absorbed by the sensitized dye, Electron transport takes place in a porous $TiO_2$ structure, while hole transport occurs in a liquid redox electrolyte and charge separation takes place at the interface between photon induced electron and the dye moving into the conduction band of the solid [17].

### 1.1. Dye Sensitized Solar CELL (DSSCs) Structure

A typical example of Dye sensitized solar cell (DSSC) consist of different layers of components, including substrate, transparent conducting layer, $TiO_2$ nanoparticles, dyes, electrolyte, photo electrode and counter electrode covered with sealing gasket. The block diagram of DSSC is shown in **Figure 1**.

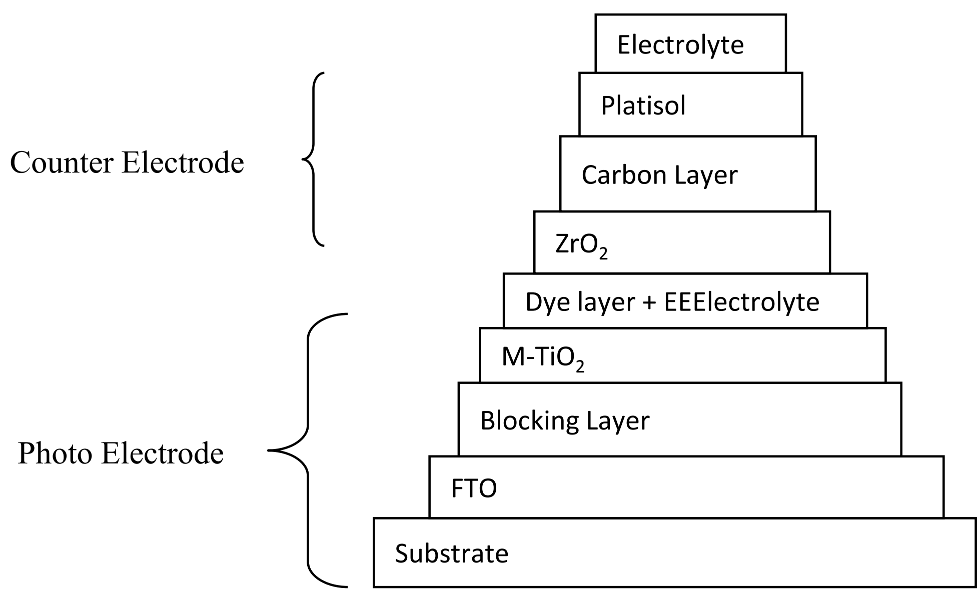


**Figure 1. Block diagram of monolithic dye sensitized solar cell (DSSC) layers.**

The main components in dye-sensitized solar cells, including semiconductor films, dye sensitizers, mesoporous $TiO_2$ layer, redox electrolyte, conducting substrate and counter electrode.

## 1.2. The Working Electrode

The working electrode is a mesoporous film of $TiO_2$ nanoparticles (size ~20 nm) with a thickness of about 10 µm, on a Fluorine-Doped Tin oxide (FTO) coated glass substrate. Dye-molecules are absorbed at the surface of $TiO_2$. The $TiO_2$ framework acts as electron acceptor and transport medium [18].

### 1.2.1. A Redox Electrolyte

This is a solution containing a suitable redox couple in a high concentration, as well as some additives that improve solar cell performance. The most common redox couple used in DSC is iodide/tri-iodide.

### 1.2.2. A Counter Electrode

This is an electrode with good catalytic activities for electron transfer to the redox electrolyte. The counter electrode is used for the regeneration of the electrolyte. The oxidized electrolyte diffuses towards the counter electrode where it receives electrons from the external circuit. A catalyst is needed to accelerate the reduction reaction and platinum (Pt) is considered as a preferred catalyst due to its high exchange current density, good catalytic activities, and transparency. The performance of the counter electrode depends on the method of platinum (Pt) deposition on TCO substrate [19].

The illustration Showing Electron Cyclic Movement in Photo Electrode and Counter Electrode Connected Together of DSSC is shown in Figure 2.

The Electron Cyclic Movement involving Photo Electrode and Counter electrode connected together was demonstrated in Figure 3.

### 1.2.3. Transparent and Conductive Substrate

Substrates necessarily are high transparent (transparency > 80%) substrates that permit the passage of optimum sunlight to the effective area of the cell. Its electrical conductivity should also be high for efficient

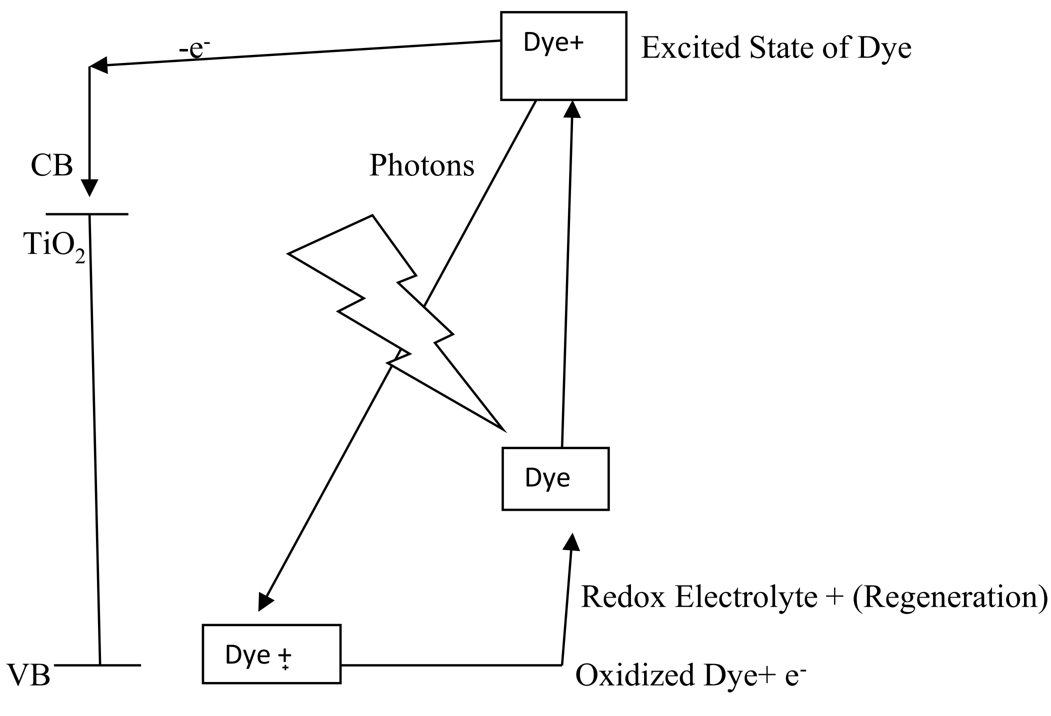


**Figure 2. Energy level movement at conduction-valence band gap.**

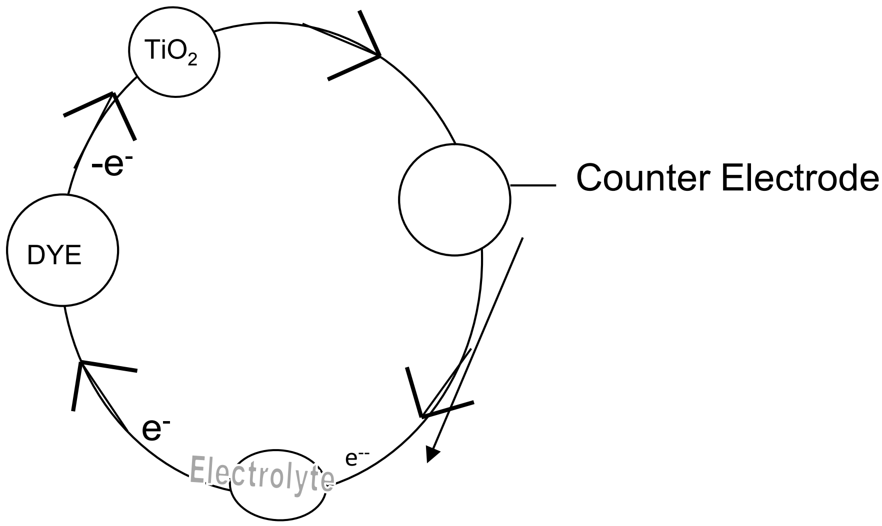


**Figure 3. Electron cyclic movement in photo electrode and counter electrode connected together.**

charge transfer and to decrease energy loss. These two characteristics of substrate dictate the efficiency of DSSCs [20]. Mainly, FTO (fluorine tin oxide, $SnO_2$) and ITO (indium tin oxide, $In_2O_3$) are used as the conductive substrate. ITO and FTO substrates consist of soda lime glass coated with indium tin oxide layers and fluorine tin oxide, respectively. ITO films have a transmittance of above 80% and sheet resistance of 18 $\Omega/cm^2$, while FTO films show a transmittance of about 75% in the visible region and sheet resistance of 8.5/$cm^2$ [21]. Dye sensitized solar cell (DSSCs) are typically constructed with two sheets of conductive transparent materials, which help a substrate for the deposition of the semiconductor and catalyst, acting also as current collectors.

#### 1.2.4. Nanocrystalline Semiconductor Film Electrode

Semiconductor oxides used in dye-sensitized solar cell are $SnO_2$, $Nb_2O_5$, $TiO_2$, ZnO and $ZrO_2$. Zinc oxide may serve as the carrier for the monolayers of the sensitizer using their high surface and the medium of electron transfer to the conducting substrate or as a diaelectric material in the case of zirconium oxide ($ZrO_2$) separating one layer from the other. Due to low-cost price, abundance in the market, nontoxicity, and biocompatibility, and as it is also used widely in health care products as well as in paints production, $TiO_2$ becomes the best choice in semiconductor till date [22]. Titanium dioxide ($TiO_2$) films are deposited on the surface of glass substrate such as metal foil, flexible polymer film and conducting glass. The semiconductors deposition processes are done with various methods and thermal treatment of various degrees are given to the grown films to allow the semiconductor materials deposited on the substrate settle on it [23].

#### 1.2.5. Photosensitizers (Dye)

Organic dye serve as photosensitizers that absorbs photon energy in dye sensitized solar cell (DSSC) even at visible light range, whose proprieties will have much effect on the light harvesting efficiency and the overall photoelectric conversion efficiency. The ideal sensitizer for dye-sensitized solar cells should absorb all light just below a threshold wavelength of 920 nm and firmly grafted to the semiconductor oxide surface and inject electrons to the conduction band with a quantum yield of unity [24]. The purpose of dye is to absorb light even at room temperature and exchange electrons to the conduction band of the semiconductor. It is chemically bonded to the porous surface of the semiconductor [24]. An efficient photosensitizer has the following characteristics:

1) They absorb excellently in the visible region (400 nm to 700 nm);

2) Adsorb strongly on the surface of the semiconductor;

3) They have high extinction coefficient;

4) They are stable in its oxidized form allowing it to be reduced by an electrolyte;

5) They are stable enough to carry out ~108 turnovers, which typically correspond to 20 years of cell operation;

6) They possess more negative LUMO than the conduction band of the semiconductor and more positive HOMO than the redox potential of the electrolyte.

In general, dyes are divided into two groups namely:

1) Synthetic.

2) Natural Dyes.

**1) Synthetic Dyes**

Ruthenium(II) polypyridyl complexes are most commonly used as sensitizer in DSSC due to its high stability, excellent redox properties, broad absorption spectrum in the visible light region [25]. They have good photoelectric properties, but have some drawbacks such as high cost, scanty resources of Ru and biological toxicity. Therefore organic dyes, for example chlorophyll, coumarin, polyene, merocyanine, indoline and anthocyanins, have been tested as sensitizers.

We have three classes of photosensitizers; they are: metal-free organic sensitizers, natural sensitizers and metal complex sensitizers [26].

**i) Metal Complex Sensitizers**

Metal complex sensitizers are made up of Anchoring Ligands (ACLs) and Ancillary Ligands (ALLs). The photosensitizers adhesion to the semiconductor is highly dependent on the properties of ACLs. Ancillary Ligands (ALLs) can be used for the tuning of the overall nature of sensitizers, polypyridine complexes of metal ions possess very high Metal to Ligand Charge Transfer (MLCT) bands in the visible region [27].

**ii) Metal-Free Photo Sensitizers**

Metal free organic sensitizers can be used to replace the expensive ruthenium based sensitizers and to improve the electronic properties of devices. Even though, the efficiency of these sensitizers is still low when compared to devices based on ruthenium-based dyes, the efficiency and performance can be improved by the proper tuning of the designing components.

**2) Natural Sensitizers**

Natural dyes have also been used in dye sensitized solar cell (DSSCs) as a photosensitizer due to their low cost advantage, easy extraction, nontoxicity in reaction, and the environmentally friendliness [28]. Natural dye colorants from chlorophyll, betalain, carotenoid and anthocyanin have been employed as photosensitizers in DSSC [29]. These can be found in flowers, fruits and vegetables.

### 1.2.6. Electrolyte

The purpose of the electrolyte is to reinforce the dye (regenerate the dye) after it injects electrons into the conduction band of the semiconductor. Electrolyte layer in dye sensitized solar cell (DSSCs) acts as a charge passage medium to transfer positive charges toward the counter electrodes. The life time stability of DSSCs strongly depends on the properties of electrolyte. Thus, the electrolyte must have the following characteristic [30].

1) Excellent electrical conductivity and low viscosity for faster diffusion of electrons.

2) Good interfacial contact with the nanocrystalline semiconductor and the counter electrode.

3) Electrolyte should not be the cause of desorption of the dye from the oxidized surface and the degradation of the dye.

4) Electrolyte should not absorb light in the visible region. The oxidized dye is reduced back by its ground state by donor electron that is present in the iodide electrolyte which allows the dye in an oxidized state to absorb photon.

Three classes of electrolytes used in DSSCs are: solid state electrolytes, liquid state electrolytes, and quasi solid state electrolytes.

**1) Solid-State Electrolyte**

Over the years we discover that liquid electrolyte sometimes dry out of DSSCs layer where it was deposited and this have become one of the main problem of using liquid-electrolyte in the development of DSSCs. This action drastically minimizes the life time and stability of the developed solar cells. Solid state electrolytes have been developed for upgrade performance in DSSCs. For this reason, solid state electrolyte replaces the liquid electrolyte with a p-type semi-conductor [31].

**2) Liquid Electrolytes**

Liquid electrolytes are classified into two types: organic solvent based electrolytes and room temperature ionic liquid electrolytes (RTIL) based on the solvent used.

**3) Organic Electrolytes**

The DSSC is a photo-electrochemical solar cell that requires a suitable electrolyte containing an adapted and electrochemically suitable redox couple. The iodide/tri-iodide redox couple (I-3) has given the best overall results so far [32].

### 1.2.7. Carbon Layer Electrode

Carbon layers have special characteristics. It serves as electrode in the cell. These characteristics include cheap material, printable to be a non vacuum processing, flexible and stable against corrosive chemicals. The annealing process is necessary for the carbon electrode in order to be used in DSSCs. For the DSSCs, the high-temperature-annealed carbon counter electrodes have been fabricated because of the utilization of electrolyte, which can dissolve the polymers in the low-temperature-processed carbon layers.

### 1.2.8. Zinc Oxide (ZnO) Layer

Zinc oxide (ZnO) is photoanode material which can transport the electrons to conducting substrate by providing the surface chemisorbed excited dye to its conduction band. Zinc oxide (ZnO) is commonly used as electron transporting/selective layer in place of $TiO_2$ within DSSCs.

### 1.2.9. Zirconium Dioxide ($ZrO_2$) Layer

Zirconium dioxide layer acts as an insulator that separates the photo anode from the counter electrode in monolithic cell. The common method used for the deposition of the Zirconium oxide ($ZrO_2$) on the substrate is by screen printing method. After screen printing of Zirconium oxide ($ZrO_2$), it would be annealed at 500˚C to allow the paste to settle on top of the mesoporous layer. This layer acts as a neutral boundary between the counter electrode and photoanode part of the DSSC.

## 2. WORKING MECHANISM OF DYE-SENSITIZED SOLAR CELL

DSSC is composed of five elements which include; two transparent conductive substrates, nanostructure titanium dioxide layer, platinum layer, dye molecules and electrolyte. Transparent conductive substrates are coated with a thin layer of $TiO_2$ and platinum nanostructures respectively. The mechanism of this type of solar cell is a replica of the processes involved in photosynthesis cycle of a plant [33].

By absorption of light, the dye molecule is excited from ground state to excited state as described in **Figure 2**. This leads to electrons being transferred into the conduction band of the semiconductor layer. The oxidized dye is reduced back by its ground state by donor electron that is present in the iodide electrolyte which allows the dye in an oxidized state to absorb photon [34]. The electrons are accepted by the electrolyte, catalyzed by the platinum on the counter electrode, and recombine with tri-iodide into di-iodide again. This process leads to the conversion of sunlight to electrical energy.

The dye absorbs photon energy from the visible light ($hv$) and immediately causes the electron to be excited from the HOMO stage to the LUMO stage of the dye. The photon energy generated by the excitation of electron migrated from the LUMO state of the dye to the conduction band of $TiO_2$ [35]. In photosynthesis, light is converted into chemical energy. Photons with different energies in sunlight strike on the cell and penetrate into the dye layer since both the fluorine-doped tin oxide (FTO) layer with glass substrate and the $TiO_2$ nanocrystals are transparent to visible light. The hole which was generated by photon excitation remains on the molecule during the process since the HOMO of dye is separated from all other energy levels. The hole eventually filled up by electrons from electrolyte ions. At the same time, reduction of oxidized dye by iodide produces tri-iodide. The tri-iodide diffuses to a counter electrode and accepts electrons from external load, regenerating the iodides, and then the overall process will provide electron flow from the working electrode to the outer circuit. The general chemical reactions, which take part in all the processes, described as follow [36]:

Equations (1)-(7) illustrated what happened when anthocyanin dye (O) absorbed a photon energy from visible light and excite an electron from HOMO state to LUMO State and the excited electron migrated into the conduction band.

$$\text{Anode}: h\upsilon + \text{O} \rightarrow \text{O}^* \tag{1}$$

where $h\upsilon$ is the incoming photon and $\text{O}^*$ is the excited anthocyanin dye. The excited dye will inject electrons into the conduction band of $TiO_2$ according to the equation shown in (2)

$$\text{O}^* \rightarrow \text{O}^+ + \text{e}_{\text{cb}}^-\left(\text{TiO}_2\right) \quad \text{Injection Process} \tag{2}$$

The excited dye will be oxidized. The oxidized dye molecules will be reduced by an Iodide ion which in turn becomes a tri-iodide ion following the equations given by:

$$2\text{O}^+ + 3\text{I}^- \rightarrow \text{I}_3^- + 2\text{O} \quad \text{Regeneration} \tag{3}$$

$$\text{Cathode}: \text{I}_3^- + 2\text{e}^- \rightarrow 3\text{I}^- \tag{4}$$

$$\text{O}^* + \text{e}_{\text{cb}}^-\left(\text{TiO}_2\right) \rightarrow \text{O}^+ + \text{e}_{\text{cb}}^-\left(\text{TiO}_2\right) \tag{5}$$

$$\text{I}_3^- + 2\text{e}_{\text{cb}}^-\left(\text{TiO}_2\right) \rightarrow 3\text{I}_3^- + \left(\text{TiO}_2\right) \tag{6}$$

$$\text{Cell}: 2\text{e}^-\left(\text{pt}\right) + h\upsilon \rightarrow 2\text{e}^-\left(\text{TiO}_2\right) \tag{7}$$

where O represents dye sensitizer.

In principle, the energy conversion efficiency of a DSSC is the product of the short-circuit photocurrent, $J_{sc}$, the open-circuit photovoltage $V_{oc}$, as well as the fill factor [37] [38].

$$\eta = \frac{P_{out}}{P_{in}} = J_{sc}V_{oc}\frac{FF}{P_{in}} \tag{8}$$

$$FF = \frac{(VI)_{\max}}{J_{sc} \times V_{oc}} = \frac{P_{\max}}{J_{sc} \times V_{oc}} \tag{9}$$

$$P_{\max} = I_{\max} \times V_{\max} \tag{10}$$

where $\eta$ is the efficiency, $J_{sc}$ is short-circuit photocurrent, $V_{oc}$ is open-circuit photovoltage, *FF* is fill factor, $P_{\max}$ is maximum power point, $I_{\max}$ is maximum current, and $V_{\max}$ is maximum voltage. In general, working principles of DSSCs are distinct from other classes of solar cells as the three key processes, *i.e.*, light absorption and the subsequent generation of electric charges, electron transport, and hole transport are directed through three materials, thereby making them highly interfacial devices [39].

This is the voltage drop across the diode (p-n junction) when photo generated current, $I_{ph} = 0$, that is, at night when there is no illumination at all. The open-circuit voltage, $V_{oc}$, is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the biased behavior of the solar cell junction with the light-generated current. The short-circuit current is the current that passes through the solar cell when the voltage across the solar Cell is zero (*i.e.*, when the solar cell is short circuited). The Short circuit current is represented by the symbol "$I_{sc}$". The short-circuit current is the largest current which may be drawn from the solar cell [40]. This is the ratio of the maximum power that can be delivered to the load to the product of $I_{sc}$ and $V_{oc}$.

The Fill Factor (*FF*) is a parameter that measures the quality and maximum power in a solar cell. The "fill factor", is represented by the abbreviation "FF" and is a parameter which, in conjunction with $V_{oc}$ and $I_{sc}$, determines the maximum power from a solar cell. It is calculated by comparing the maximum power to the theoretical power ($P_T$) that would be output at both the open circuit voltage and short circuit current together. The short-circuit current and the open-circuit voltage is the maximum current and voltage respectively from a solar cell [41]. In practical fill factors ranges from 0.5 to 0.82 and it would be represented in percentage. Graphically, the *FF* is a measure of the "squareness" of the solar cell and is also the area of the largest rectangle which will fit in the *I-V* curve. The fill factor can also be calculated using Equation (11).

$$FF = \frac{J_{np} \times V_{np}}{J_{sc} \times V_{oc}} \tag{11}$$

where

$J_{np}$ is the maximum current density corresponding to $V_{np}$;

$V_{np}$ is the maximum voltage corresponding to $J_{np}$;

$I_{sc}$ is the short circuit current;

$V_{oc}$ is the open circuit current;

$J_{np}$ and $V_{np}$ are the optimum photocurrent and voltage that can be extracted from the maximum power point of the *I-V* characteristics.

## Efficiency of DSSC Solar Cell

Power conversion efficiency is represented by the symbol "$\eta$" and *is* defined as the percentage of incident irradiance $P_{in}$ (light power per unit area) that is converted into output power. The output power depends on the load but the maximum output power is used for calculating efficiency. According to [42] the conversion efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$FF = \frac{J_{np} \times V_{np}}{J_{sc} \times V_{oc}} \tag{12}$$

where

$J_{np}$ is the maximum current density corresponding to $V_{np}$;

$V_{np}$ is the maximum voltage corresponding to $J_{np}$;

$I_{sc}$ is the short circuit current;

$V_{oc}$ is the open circuit current;

$J_{np}$ and $V_{np}$ are the optimum photocurrent and voltage that can be extracted from the maximum power point of the *I-V* characteristics and

$$\eta = \frac{J_{np} \times V_{np}}{P_{in}} \times 100\% = \frac{J_{sc} \times V_{oc} \times FF}{P_{in}} \times 100\% \tag{13}$$

where $\eta$ is the efficiency;

$V_{oc}$ is the open-circuit voltage;

$I_{sc}$ is the short-circuit current;

*FF* is the fill factor;

$P_{in}$ is the incident light intensity;

The input power for efficiency calculations is 1000 $W/m^2$ or 100 $mW/cm^2$.

This is also expressed as the ratio of the electrical power output $P_{out}$, compared to the solar power input, $P_{in}$, into the PV cell. The efficiency of a solar cell depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another [43]. Terrestrial solar cells are measured under AM1.5 conditions and at a temperature of 25˚C. Power conversion efficiency is important since it determines how effective the space occupied by a solar cell is being used and how much area must be covered with solar cells to produce a given amount of power.

## 3. RESEARCH AND DEVELOPMENT CHALLENGES IN DSSCS IMPROVEMENT

The progress report on DSSCs development shows that the major challenges encountered in DSSCs development is the problem of "low conversion efficiency". Many researchers have attempted to resolve this problem, by increasing the surface area of $TiO_2$ of photo-electrodes used in the DSSC [44].

Low efficiency and low stability are the major challenges for the commercial deployment of DSSCs [26]. The main causes of low efficiency in DSSCs are:

1) Low red and near-IR absorption.

2) Low extinction coefficient requires high surface area.

3) Only $I^-/I_3^-$ redox couple has slow recombination kinetics, but it has unnecessarily large over potential.

4) Poor contact between the electrodes.

5) Degradation of electrolyte properties due to UV absorption of light.

6) Poor quality encapsulation of the two main units of DSSC (Photo electrode and counter electrode) causes leakage of the electrolyte and therefore contributes to the poor conversion efficiency of the cell.

Improving the environmental stability of cells is the most important issue in studying these cells [45]. Stability refers to the performance of individual processes or the entire solar cell development processes at any time relative to the initial time. Good stability leads to long lifetimes of the DSSC [46]. The critical issue regarding to stability and robustness of DSSCs are

1) Liquid electrolyte is undesirable, but solid state hole conductors give lower efficiency.

2) Achieving DSSC module lifetimes of more than 20 years requires 108 turnovers for dye molecules and high quality encapsulation to prevent leakage of the electrolyte and ingress of water [47].

3) $I^-/I_3^-$ is corrosive.

## 4. BENEFITS OF DSSCS

Dye-sensitized solar cells have the following main advantages.

**1) Lighter Weight**

The weight of solar cells and panels can be minimized by the use of plastic substrates instead of glass substrate and silicon materials. Because of this reason, dye-sensitized solar cells can be installed in locations where appearance is important that other solar cells cannot be installed [48].

**2) Low-Light Conditions**

$DSSC_S$ work even under infrared region of spectrum (low-light conditions) to generate current. DSSCs are therefore able to work under cloudy skies without any direct sunlight, whereas traditional silicon designs solar cell cannot function without exposing under intensity sunlight, such as under faint light in the morning and evening and when indoors.

**3) Recyclable and Environmental Friendliness**

The components materials of dye-sensitized solar cells do not have harmful substance. The materials could be easily separated and get back to use, which is an advantage of recycling over solar cell panels [49].

**4) Simple Production Methods**

The various production methods involved in Dye-sensitized solar cells are simple, they don't require vacuum system for manufacturing, and that makes the production cost very cheap. It reduces manufacturing cost by 1/5 to 1/10 as compared to silicon solar cells production cost [50].

**5) Transparent and Colorable**

The use of organic dye allows wide selection of colored cells and transparent cells. The transparency and varied color of DSSCs could be useful for decorative purposes in making window and sunroof [51].

**6) Flexible and Thin Structure**

By using aggregates of fine particles of optical conversion materials, the solar cells can be formed as a flexible thin film.

**7) No Need of Incident Angle and Intensity of the Sunlight**

Compass machine is not required here to find the incident angle and the best position for the intensity of sunlight as required in traditional solar cell installation.

## 5. RECENT ANALYSIS AND DEVELOPMENT IN DSSC

The previous researcher's did not do much in using profilometry analysis to investigate the thickness of the spectral and functionability of the fluorine doped tin oxide film (FTO). In the recent research carried out by Nwokoye and Okoye [52] titiled Profilomatry Analysis of Flourine Doped Tin Oxide (FTO) Film Mesoporous (M-$TIO_2$) Film using Organic Dye from Senna Plant as a Photosensitizer, profilometry analysis was carried out to confirm whether the FTO layer is working or not before adding other layers that made up the monolithic DSSC. Profilometry analysis can also use to measure the thickness and area of the spectral line involved in the developed cell. The dye sensitized solar cell developed from fluorine doped tin oxide (FTO) film and mesoporous films showed 1.7 times of photovoltaic current than those from the nanocrystalline films in the same thickness. It was deduced that the high current present in the cell is as a result of efficient transportation of electrons due to far less grain boundaries of fluorine doped tin oxide(FTO) film and the mesoporous $TiO_2$ structure and by the fast diffusion of electrolytes with the high uniformity in the mesopore size.

Power Voltage Characteristics of Fabricated Dssc Incorporating Multiple Organic Dyes as Photosensitizer was studied using Hall Effect equipment and the four point probe [53]. The electrical properties of photo electrode in this work indicate the suitability of a film in facilitating electron injection and transport through the photo electrode. The Hall Effect measurements involved the measurements of the Hall voltage ($V_H$) and current ($I_n$) for constant applied magnetic field ($B_Y$). The Hall Voltage was measured in a perpendicular direction to the magnetic field and to the direction of an electric current flowing through the semiconductor using Hall Effect meters that provide current and magnetic fields and clamp which support probes and the film. Using Hall Effect meters to investigate the electrical characterization embodied in a developed film will help to reveal the old and new electrical properties that have been existing in a given developed nanostructurte. The type of charge carrier present in the fabricated FTO down to block layer dyed $TiO_2$ films were confirmed as P-Junction semiconductor type of Charge carrier using Hall Effect measurement.

## 6. CONCLUSION

Understanding the basic structure and frame work of dye-sensitized solar cells will help the researcher to develop an interest in nanotechnology development. In the recent time, dye sensitized solar cells development is main fulcrum of nanotechnology science. There has been a continuous effort in searching for affordable organic solar energies among which dye-sensitized solar cells (DSSCs) thus far demonstrate the highest energy conversion efficiency, and have been regarded as the most prospective technology in the near future. The overall interest of DSSC research is to generate electrical energy using organic dye and semiconductor materials. The scientist interest in the development of dye-sensitized solar cells are because of the facts that DSSC are; environmentally friendly, low production costs, easy of fabrication, its raw materials are locally made, Colorable, transparent, its lighter weight property, DSSCs work even under infrared region of spectrum (low-light condition) to generate current, when charge carrier mobility is low and recombination becomes a major issue redox couple iodide/triiodide set up in the system is there to re-energized the weak optical properties involved in the cycle, apart from its low efficiency output which is the main reason why many research are going on, all are the advantages of dye sensitized solar cell compared to traditional silicon designs solar cell which cannot function without exposing under intensity of sunlight.

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## CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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