

# Solar Cells: A pathway through solar energy nanomaterials

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## ABSTRACT

Photo voltaic devices generate electricity directly from sun light via an electronic process that occur in semiconductor. Multiple thin film layers are contained by thin film solar cells. The thickness of thin film layers are very less. Thin film cell functioning and structure is similar to that of normal silicon wafer cells. Semiconductor is considered as the photovoltaic cell's basic component. When semiconductor is doped with phosphorus it results in generation of free electrons in large amount while doping with indium, gallium or boron results in development of vacancy which is known as hole. Photo voltaic cell is formed with the combination of p type and n type materials. In the absence of light, only few atoms get excited and moves across the junction. Due to this, across the junction there exists a small voltage drop. Whereas in presence of light, more atom get excited and moves across junction which result in large current at the output. Furthermore, a rechargeable battery is used to store this current and depending on the needs, it can be utilized for various applications. This chapter focus on the fabrication and structure of different types of solar cell. Challenges and future scope of various solar cells are also discussed.

**Keywords** – Dye-sensitized solar cell, nanomaterials, organic solar cell, perovskite solar cell, lead free perovskite.

## 1. INTRODUCTION

Nanotechnology is by all accounts the route by which photovoltaics can be created, regardless of whether in inorganic or organic solar cells. Nanomaterials are made by using chemical methods which offer high efficiency enhancement. Physical and chemical properties like melting point, surface-to-volume ratio changes, when material changes from bulk to nano size particles. Various shape of nanoparticles are nanowires, nanopillars, nano cones, quantum dots etc. These are attracting an increased attention for their potential applications in emerging energy. Consumption of electricity is exponentially increasing day by day. In current time most part of electricity is generated by coal (1). This electricity generated by burning of excessive coal which result in serious problem like environment pollution and global warming. Due to these reasons renewable energy is necessary for our environment and society. Harvesting solar energy has the potential of delivering cleaner and affordable energy among various renewable energy resources. Further, it tends to be utilized for viable applications, for example, thermoelectric, photocatalytic and PV. Among them, PV technology is viewed as one of the most promising technique since that has the capacity to change sun energy into electrical energy. Solar cell is a technique which is CO<sub>2</sub>-free and does not require any fuel. Solar

panels are also of low cost and eco-friendly. It could well be that in future, solar cell will become the most energy production device in the world. In this chapter various type of solar cell are discussed such as dye sensitized solar cell, organic solar cell, quantum dot solar cell and perovskite cell. The power conversion efficiency (PCE) obtained are still low as nearly 14.3% for ruthenium complexes-based dye sensitized solar cell, 25% for metal halide perovskite-based solar cell and 16.6% for quantum dot solar cell (2).

## 2. METHODOLOGY

### 2.1 Fundamentals of Solar Energy Conversion

*2.1.1. Solar spectrum:* Light rays coming from the Sun are in the form of electromagnetic waves which constitute the Solar spectrum. These electromagnetic waves lies in infrared, visible and ultraviolet frequency bands.

The solar spectrum consists of the following bands:

**Infrared bands:** In this band wavelengths are too long and lies between 780 nm and 1 mm.

**Visible band:** Visible light wavelengths are measured in nanometers and range between 380 and 750 nanometers.

Ultraviolet band: Ultraviolet (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light in the range 10 nm to 400 nm (3).

2.1.2. *Air Mass*: Air mass is measure of how much proportion of atmosphere that the light must pass through before striking the earth. It is represented by MA

MA= 1. when sun is at zenith (directly above head).

MA = 2, when zenith angle is 60°

MA = 0, just above the earth's atmosphere.

2.1.3 *Solar Energy Conversion Technologies*: There are basically three solar energy harvesting technology

Photovoltaic: In this direct conversion of light into electricity take place.

Concentrating Solar Power (CSP): In this thermal energy is used to drive the electric turbines. Solar radiation provides the heat energy or thermal energy.

Solar Heating and Cooling: Thermal energy is used to provide hot water and air conditioning (4).

## 2.2. Photovoltaic Parameters

In Photovoltaic (PV) devices electricity is generated directly from sunlight. This conversion of light into electricity occur via electronic process that occurs in semiconductors. Photons from sunlight strike the surface of semiconducting material and ionize it. The electrons move from valence band to conduction band and finally electrons move in one direction and constitute an electric current. Efficiency of device is not 100%. Most of the energy from sun either reflected or used as heat energy. Only small portion of solar energy is used in production of electricity in the device. Various parameters used in solar cell are discussed below (5).

2.2.1. *Short-Circuit Current Density*: The short-circuit current  $I_{sc}$  is the current that flows through the external circuit when the voltage across the cell is zero. The electrodes of the solar cell are short circuited.  $I_{sc}$  depends on the incident photon flux. The short-circuit current density describe the maximum current delivered by a solar cell.

2.2.2. *Open-Circuit Voltage*: It is the maximum voltage deliver by solar cell when there is no current flow

through the external circuit. It is denoted by  $V_{oc}$  that depends on the photo-generated current density and can be calculated as,

$$V_{oc} = \frac{nkT}{q} \ln (I_L / I_0 + 1)$$

where  $V_{OC}$ =Open circuit voltage

$I_0$  =Dark saturation current

$I_L$ -Light generated current

$n$ =Ideality factor

$kT/q$ =Thermal voltage

2.2.3. *Fill Factor (FF)*: Fill factor is measure of quality of solar cell. It is defined as the ratio of the maximum power to the product to the open circuit voltage ( $V_{oc}$ ) and short-circuits ( $I_{sc}$ ), and is given by  $P_{max} = V_{OC} I_{SC} FF$ , where  $V_{OC}$ =Open circuit voltage

$I_{SC}$ =Short circuit current

$P_{max}$ =Maximum power

$FF$ =Fill factor

## 2.3. Nanomaterials and Their Classification

Nanomaterials

Nanomaterials are those materials which can be classified on the basis of dimension whose range varies from 1-100 nm. Various properties such as electric, optical, thermal and magnetic are strongly dependent on the size of nanoparticles. It has been observed that there is a drastic change occur in the optical properties of the nanomaterials with the decrease in size of nanoparticles below Bohr radius.

Classification of Nanomaterials

Nanoparticles can be classified on the basis of their morphology, composition and dimension. Nanoparticles are classified as 0-D, 1-D, 2-D and 3-D on the basis of their dimension.

Zero Dimensional (0-D) Nanomaterials

In 0-D nanomaterials all dimensions are measured within nanoscale range. Quantum dot is an example of 0-D materials.

### One Dimensional (1-D) Nanomaterials

In 1-D nanomaterials one dimension is outside the nanoscale. Nanotubes, nanorods and nanowires are example of 1-D nanomaterials.

### Two Dimensional (2-D) Nanomaterial

In 2-D nanomaterials two dimension are outside the nanoscale. Graphene, nanofilms, nanolayers, and nanocoating are example of 2-D materials.

### Three Dimensional (3-D) Nanomaterials

These materials not confined to nanoscale in any dimension. Bulk powders, Bundles of nanowires, and nanotubes are example of 3-D materials (6).

#### 2.3.1. Effect of Crystallite Size on Various Properties of Nanomaterials:

**2.3.1.1. Electrical Property:** Electrical property of the nanoparticles varies is inversely proportional to resistivity. Electrical conductivity, degree of localization and carrier concentration varies with crystalline size. With the decrease in crystalline size electrical conductivity, carrier concentration decreases and degree of localization increase.

**2.3.1.2. Thermal Properties:** This is observed that thermal conductivity of the nanoparticles decreases with decreases in crystallite size of the nanoparticles.

**2.3.1.4. Optical Properties:** Optical properties of the nanomaterials arise due interaction among the nanomaterials and incident radiation. The band gap energy of nanomaterials increases with decrease in crystalline size of nanoparticles (7).

## 3. FABRICATION TECHNIQUES OF THIN FILM SOLAR CELLS

### 3.1 Physical Vapour Deposition

Physical Vapor Deposition (PVD) is a process used to deposit thin layers of material. The range of deposited material varies from few nanometer to several micrometer. PVD processes are environmentally friendly. In this process vaporisation of the material occur from a solid source under high temperature or gaseous plasma. The vaporized material get deposited onto substrate and finally condensation process occur onto substrate to generate thin film. In the entire process, there exists no chemical reaction. Different PVD technologies are used to generate and deposit

material. Thermal evaporation and sputtering are two different PVD process, in thermal evaporation source material get vaporized by heating under vacuum condition while in case of sputtering bombardment of accelerated gaseous ions creates vapours from the source target. Sputtering is plasma-assisted technique. Due to condensation process the resulting vapour phase get deposited onto the desired substrate (8).

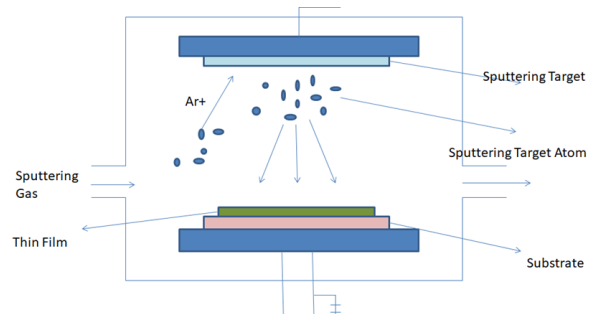


Fig. 1. Schematic illustration of the Physical Vapour Deposition

### 3.2 Chemical Vapour Deposition

Chemical vapor deposition (CVD) is a process in which vapour get deposited on the solid material due to occurrence of chemical reaction occurring on the surface or in the vicinity of a normally heated substrate. In this process reactants are transferred to deposition region by forced convection. The main gas stream is used to transfer the reactant to the substrate by the process of diffusion. Adsorption of reactant occur on the surface of substrate. At the surface of substrate chemical decomposition and other chemical reaction occur and desorption of by-products from the surface take place. There exists formation of film coatings within the CVD reactor among substrates' heated surface. Distinct coating layers are formed on the substrate. CVDs are basically of two type based on the operating pressure (9).

(i). Atmospheric Pressure CVD (APCVD)

(ii). Low Pressure CVD (LPCVD)

APCVD work at atmospheric pressure while LPCVD work at sub atmospheric pressure. Pressure of 10-1000 Pa is used as operating pressure in LPCVD. LPCVD coatings exhibit excellent uniformity and high purity. Vacuum system is not required in APCVD which result in low operating cost. (10).

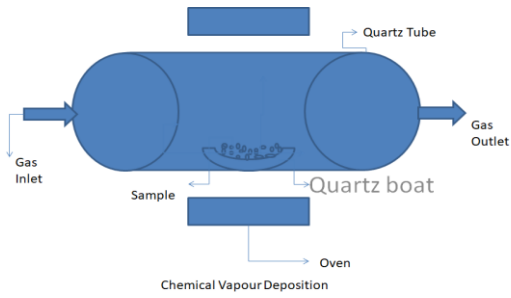


Fig. 2. Schematic illustration of the Chemical Vapour Deposition

### 3.3 SOL-GEL

A sol is described as the polymers' or colloidal particles' stable dispersion in a solvent. There may exist crystalline or amorphous particles. A sol particle exists in liquid phase whereas an aerosol particle exit in gas phase. A gel is semi rigid solid that is formed by evaporation of solvent from the sol. Furthermore, a gel comprises of 3-Dimensional continuous network that in a colloidal gel confines to a liquid state. A polymeric sub-structure is comprised by the particles in a polymer gel that consists of sub-colloidal particles' aggregates. Hydrogen bond or vander Waals forces are utilized by the sol particles for interaction among them. By using the linking polymer chains, formation of gel can also be done(12). This particular process is irreversible. If there is involvement of other interactions than it may result in gelation process reversibility. Through in this process the compound is put in a solvent to carry it back in a regulated way as a solid. The production of Sol-gel can also be used to manufacture materials in various shapes, including dense powders, thin fibers and porous structures as well as the evaporative action of the gel may result in shrinkage of the capillary muscles, a breakdown of the fluid network and the creation of xerogel. This system will ensure strong stoichiometric regulation and decreased temperature of sintering. Repulsive forces must be established in order to counter the interactions of van der Waals forces. Refusion between the particles decreases and agglomeration is avoided by an adsorption of charged species on the surface of the particles, particularly essential for colloidal structure. Through the adsorption of a thick layer of organic molecules, particles cannot approach each other, thus decreasing the van der Waals forces interaction (13).

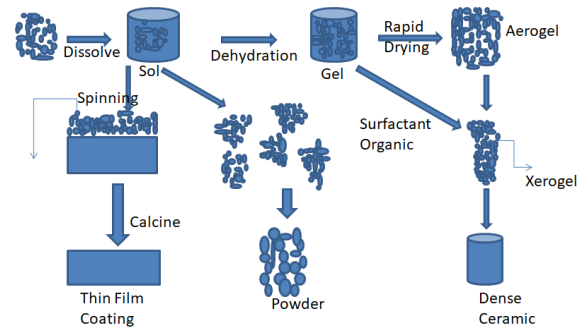


Fig. 3. Schematic illustration of the Sol-Gel Process

### 3.4 Spin-Coat

For the thin films' application, spin coating is being utilized from past many years. Spin coating is a quick and simple strategy to produce thin and homogeneous film. These films produce with solvent having low boiling point. In short, a solution is put on the substrate to be coated, which is then spin at generally around 3000rpm speed so as to spread the liquid. A spin coater machine is used for coating thin film. In the deposition process a syringe is used to put the solution on the substrate. Spin coater machine rotated at desired speed so that liquid is to be deposited. Solution fall on the substrate drop by drop using syringe. Solution spreads from centre to periphery by using spin coater. The subsequent stage is the point at which the substrate is quickened up to its last rotational speed. This stage is typically portrayed by forceful liquid ejection from the substrate surface because of its rotational movement. The thickness of the final film and other characteristics may depend upon the surface tension, amount of solids, viscosity etc (14).

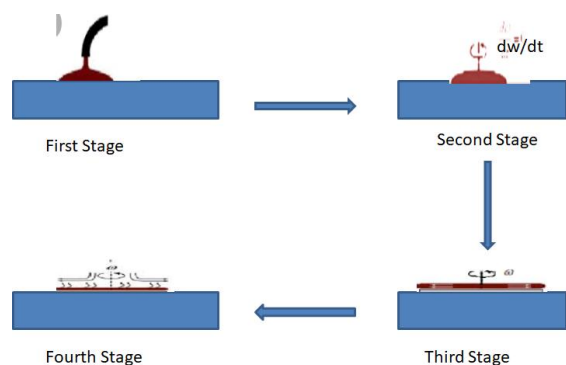


Fig. 4. Schematic illustration of the Spin-Coating Process

### 3.5 Molecular Beam Epitaxy

Molecular Beam Epitaxy (MBE) is a technique which based on ultra-high vacuum (UHV). MBE has developed into one of the most commonly employed technologies for the processing and development of epitaxial metal structures, insulators and superconductors. Epitaxy is the process of growing a thin crystalline layer on a crystalline substrate. Epitaxial layer is always thinner than the substrate. Epitaxial films are mainly of two type, homoepitaxy and heteroepitaxy. In Homoepitaxy, substrate & material are of same kind and in heteroepitaxy, substrate & material are of different kinds. The theory primarily consists of atoms or clusters of atoms formed from a solid source. The molecular or atomic beams interact with the surface of a heated crystalline substrate. Sublimation of solid source materials provides an angular distribution of atoms or molecules in a beam. Atoms freely moves until they finds correct position in the crystal lattice to bond(11).The atoms move into a UHV environment and affect the surface of a hot substrate, so that they can diffuse and finally become part of the growing film. RHEED (Reflection High Energy Electron Diffraction) is used to monitor the growth of the crystal layers. Monitoring of the residual gases and checking source beams for leaking, mass spectrometer are used. Since in MBE process low growth temperature and growth rate are important then certain specific demands such as system control and doping profiles are needed.

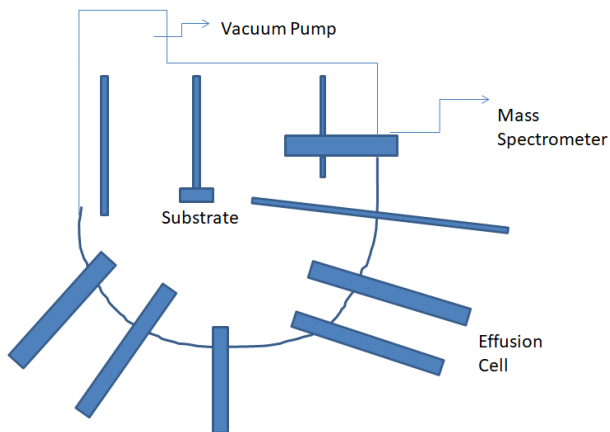


Fig. 5. Schematic illustration of the Molecular Beam Epitaxy

### 3.6 Molecular Beam Epitaxy

Chemical Bath Deposition (CBD) method possessed a better commercial value in comparison to sputtering, thermal evaporation as well as other chemical method. Commercial production, convenience, simplicity, large

area scaling, and replicability, it gets more attention from researchers. For preparing the thin film with the help of CBD method utilizes simple equipment such as stirrer and hot plate. CBD method prepared thin films are uniform and pin-hole free as rather than atoms, ions are considered as primary building blocks. For preparing the nanocrystalline materials in the form of thin film with particle aggregation's degree, particle composition and better controlled particle shape/size, CBD method is considered as an economical method. For altering the thin film's properties, the CBD's preparative parameters can be easily controlled. Generally, there are 3 steps for formation of thin film: i) ionic/molecular/atomic species' creation (ii) these species' transport by a medium and iii) species' condensation. The CBD operates on the desired compound's controlled precipitation's principle from a constituents' solution. Only when the solubility product is exceeded by ionic product, precipitation is noticed in the solution. During a normal CBD procedure, substrate is submerged in a solution that contains an added base, the metal ions ( $M^+$ ) and chalcogenide source ( $X$ ). Furthermore, metal ion's hydrolysis is controlled by addition of a complexing agent. Complex species' formation is used to control the free metal ion concentration. To obtain well adherent, uniform thin film through CBD method, the rate of chemical reaction plays very important role. The growth kinetics of film depends upon various factors such as temperature, pH, and complexing agent and so on (15).

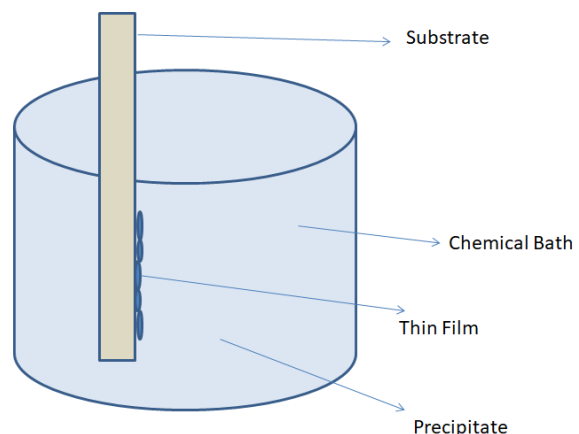


Fig. 6. Schematic illustration of the Chemical Bath Deposition

### 3.7 Molecular Beam Epitaxy

Electrodeposition is the process in which a material is deposited on the conducting surface from a solution that contains ionic species. This processing method is

utilized to add material's thin films to the object's surface for changing its external properties like to enhance decorative quality, enhance abrasion resistance, and enhance corrosion protection or basically for depositing a layer. Electrodeposition can be utilized for plating simple semiconductors, alloys and metals. Normally, it comprises of 3 electrodes that are counter, reference, and working. The electrodes are attached to a device through which deposition process is controlled and is known as potentiostat. The electrodes are put in a vessel that contains a liquid that is has a dissolution of ionic species in it like water with dissolved copper ions. The operating electrode is the surface that should be plated. To complete the electrical circuit, counter electrode is utilized and as the potentiostat's fixed reference point, reference electrode is utilized. Therefore, an electrical field is spread over the working electrode in such a manner that the ions are granted electrons in solution such that they become uncharged components or compounds that tend to bind to the working electrode surface rather than stay dissolved in solution. The power or capacity of the electric field is calculated toward the reference electrode, but the real current passes between the counter and working electrodes (16).

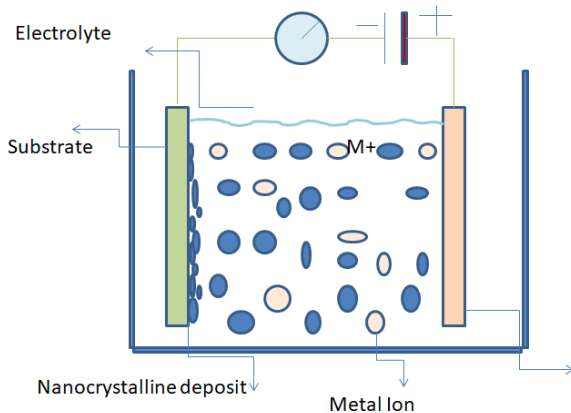


Fig. 7. Schematic illustration of the Electrodeposition Method

## 4. ROLE OF NANOPARTICLES IN SOLAR CELL

### 4.1 Role of nanoparticles in Dye - Sensitized Solar Cell (DSSCs)

i) For dye-adsorption of photoelectrode film's large surface area is required.

ii) Nanoparticles are used for deriving the core shell structures that helps in developing a coating layer that reduces the charge recombination.

iii) As compared to nanoparticle films, nanotubes and nanowires transport much faster that provides direct pathways for electron.

iv) 3-dimensional nanostructures like oxide aggregates, branched nanotubes or nanowires, and nanotetrapods provide larger surface area. These help in achieving charge transport or collection and more effective light harvesting (17).

### 4.2 Nanoparticles Role in Quantum Dot

Higher stability toward oxygen and water is provided by quantum dot. Multiple exciton tuneable band gap generation with low cost, large extinction coefficient and single-photon absorption. By reducing QD's size, the effective band gap energy increases. As a result, light emission and absorption shift toward high energies. Photocurrent increases with QD size reduction which results conduction band shifting toward much negative potentials that in turn enhances the charge injection conditions. Furthermore, in the visible region better absorption is discovered as QD's size increases (18).

### 4.3 Role of Nanoparticles in Organic Solar Cell

There exists 2 layers in Organic solar cell (OSCs) apart from the electrodes that are a charge transport layer and a photoactive layer. Throughout the OSCs, photoactive layer with strong optical absorption induces excitons to improve PCE. For carrier transmission, it has strong charge mobility without recombination on both electrodes. As charge transfer materials, CNTs and strongly conducting graphes and transparent optically will serve as efficient load collection materials without blocking photon absorption from the photoactive substrate. CNTs and graphenes have more stability and conductivity than polymers conducting, CNTs and graphs are suitable for growing cell efficiency for these purposes (19).

## 5. RECENT ADVANCES IN THIN FILM SOLAR CELLS

### 5.1 Dye - Sensitized Solar Cell

Dye-sensitized solar cell (DSSC) is an efficient and easy to implement for future energy supply. DSSC provide a good power conversion efficiency (PCE) at

low material costs. This device is excellent choice for indoor applications due to its quality of better performance at lower light intensity.

**5.1.1 Dye - Sensitized Solar Cell (DSSC) Configuration and Charge Transportation:** There exist 2 glass plates in DSSC that are known as anode and cathode. Transparent conductive oxide is utilized for anode coating. It is generally utilized in tin oxide that are doped with fluorine or tin oxide. Herein, photosensitizers dyes are utilized. Several organic metal compounds are used for developing dye. Furthermore, DSSC's cathode is a glass plate that is covered with thin Pt film that acts as a catalyst. Triiodide and iodide solutions are used as electrolyte. For protecting cell from leaking, DSSC's electrodes are sealed by pressing them together. An oxide nanoparticle coated mesh is used along with light absorbing dye through which photons are converted as electrons. Furthermore, from solar cell's anode, electrons are initiated that moves to the device being powered through a wire and then electrons are looped back cathode. Electrons travels through the TiO<sub>2</sub> nanoparticles and the electrolyte for initiating the electric current (20).

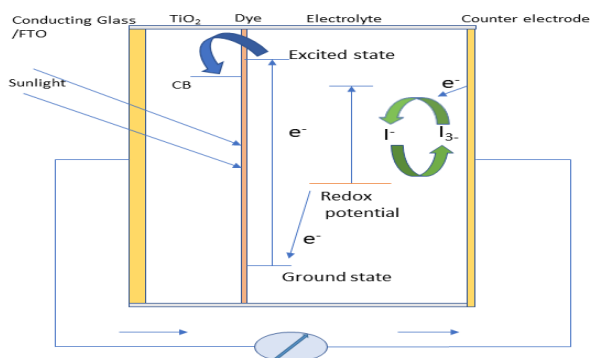


Fig. 8. Schematic illustration of the Dye sensitized solar cell (DSSC)

## 5.2 Quantum Dot Sensitized Solar Cell

Quantum dot solar cell (QDSC) uses quantum dots as the absorbing photovoltaic material. The tuneable band gap of quantum dot can be varied by changing their size and this property make quantum dot as an attractive material for multi junction solar cell. Different properties of quantum dot light harvesting materials like high absorption coefficient, multiple exciton generation possibility and tuneable absorption range make it suitable candidate for next generation of solar cells.

**5.2.1 Quantum Dot Sensitized Solar Cell (QDSCs) Configuration and Charge Transportation:** There are 3 main elements: a counter electrode, an electrolyte, and QD-sensitized photoanode. The Quantum dot absorbs solar energy when we radiate light and as a result electron are excited into the conducting band on the valence band of the QD's. Because of this enthusiasm electron-hole pairs are formed. Electrons are then pumped into the CB of a metal alloy from the leading strip of the QDs (21).

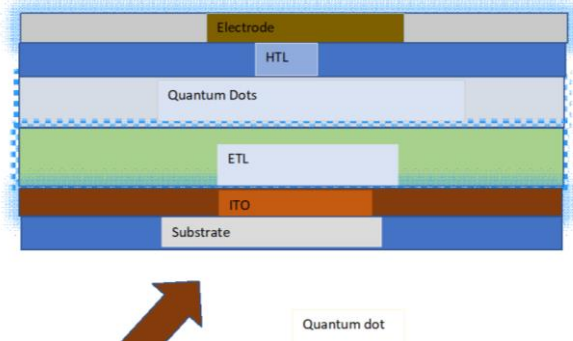


Fig. 9. Schematic illustration of the Quantum Dot Sensitized Solar Cell

## 5.3 Organic Solar Cell

Organic solar cells classified as third-generation solar cells. Here, organic polymer material used as the light absorbing layer. In an organic compound, electrical and optical properties are because of conjugated pi electrons. There exists excitons' production. In organic solar cell, there is production of free charges as well as electrodes are used for its collection. The charge transport's efficiency is calculated with the organic materials' impedance and electrical conductivity (22).

**5.3.1. Organic Solar Cell Configuration and Charge Transportation:** The light absorbed by the molecule used in formation of excitons. Excitons are basically the excited state of molecule. The exciton moves towards the donor/acceptor interface. There are few picoseconds in the lifetime of excitons. The exciton shifts inside the chain and causes deformation of the chain for reducing the extra volatile energy that is known as polaron. A jumping mechanism is called inter-molecular transfer of excitons. The average excitons mobility is restricted to 10nm, regarded as the exciton's diffusion length. After excitons diffusion, separation of the paired electron-hole into free charges occurs. Excitons dissociation occur on the interface of donor acceptor. There is a variation in the degree of LUMO in the compounds to facilitate exciton dissociation. The gap between

acceptor and donor energy rates must be greater in comparison to exciton binding energy for effective dissociation. The difference is usually approximately 0.2-0.3eV. Finally hole collected at the anode and electron at cathode (23).

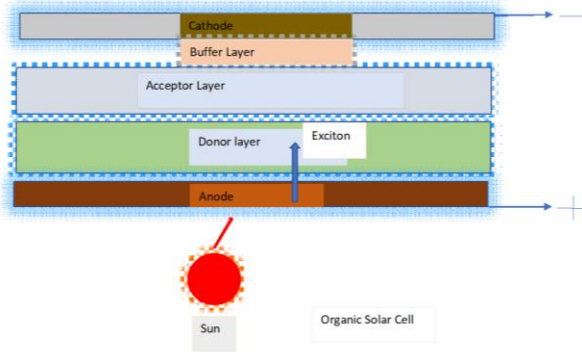


Fig. 10. Schematic illustration of the Organic Solar Cell

#### 5.4 Perovskite Solar Cell

Perovskite is an oxide mineral of calcium titanium which has the chemical  $\text{CaTiO}_3$  formula, a molecular type  $\text{ABX}_3$  structure. These materials are organic-inorganic metal halide compounds where Group A ( $\text{FA}^+$ , formamidinium,  $\text{MA}^+$ ,  $\text{CH}_3$ , or methylammonium) is situated on face-centred cubic lattice's centre and halogen anion X (I-, Br-, or Cl-, or a several halogens coexistence) as well as the metal cation B ( $\text{Sn}^{2+}$ ,  $\text{Pb}^{2+}$ , etc.) occupies the cube's face and corner respectively. A strong three-dimensional networks structure is linked together by the metal-halogen octahedra. Since the cube-striped layered structures in the octahedral and the unique optical, electromagnetic and thermal properties have been tested by Perovskite materials.

The material utilized in perovskite structure have the features

- i). Excellent photoelectric properties.
- ii). Higher optical absorption coefficient (upto  $10^4 \text{ cm}^{-1}$ ).
- iii). Lower exciton binding energy.
- iv). Large dielectric constant.

Because the light absorption sheet, perovskite can effectively absorb solar energy. This function results in a strong open-circuit voltage and short-circuit current intensity if this form of material is used in solar cell applications (24).

**5.4.1. Perovskite Solar Cell (PSSC) Configuration and Charge Transportation:** The highly efficient mesoporous structure for perovskite solar cell comprises of an electrode layer, a hole transport layer, a perovskite layer, a mesoporous oxide layer, a dense electron transport layer, and TCO cathode (mostly fluorine-doped tin oxide, FTO). For mesoporous framework, the material used is  $\text{TiO}_2$ . In perovskite solar cells, the used mesoporous materials has the property for increasing the photosensitive material's light-receiving area as well as enhancing the device's efficiency. Currently mesoporous structure has a PCE (power conversion efficiency) more than 20% (25). These layers play important roles describe below

- (i).  $\text{TiO}_2$  play substantial functional roles, like
  - a. blocking holes,
  - b. transporting electrons,
  - c. Reducing the electron-hole pairs' recombination in conductive substrate FTO. These functional properties improve the device's photoelectric conversion efficiency. The commonly used materials in place of  $\text{TiO}_2$  are metal oxides, like  $\text{ZrO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{ZnO}$ .
- (ii). The principal role of the transportation layer (ETL) of the electron is to establish an electron-selective interaction with the lights absorbent butovskite. Such arrangement increases photo-generated electrons' extraction efficiency and also impedes that the hole migrates to the counter-electrode thus reducing the recombination of charging carriers.
- (iii). Gather and transmission holes of the perovskite light-absorbing sheet are the primary feature of the holes transport layer (HTL). For the transmission of hole materials the largest occupied molecular orbit (HOMO) must be in the same valence unit. Spiro-OMeTAD is the most widely used substance for hole transport (26).

Photons absorbed in the perovskite substrate that generate excitons (electron-hole pairs) during exposure to sunlight. Such excitations may form electrons or holes in free carriers to produce a current. The free electrons, holes, and transport materials with electron



(ETM) and a void (HTM), are stored. Electrons are emitted and obtained from TiO<sub>2</sub> from perovskite material. At the same time, the hole is transmitted into the HTM layer and the metal electrode is collected. Finally, the FTO and the metal electrode are attached to the outer circuit and the photocurrent is produced. The low probability of recombining carriers of CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> and higher movement of carriers, the diffusion distance and the carrier's life time are very long and the perovskite solar cells work well (27).

Perovskite solar cell have following structure

- (i). p-i-n planar structure
- (ii). n-i-p planar structures
- (iii). p-i-n mesoporous structures
- (iv). n-i-p mesoporous structures
- (v). ETL free structure
- (vi). HTL free structure

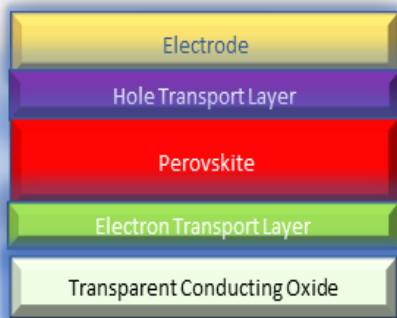


Fig. 11 Schematic illustration of the n-i-p planar structure



Fig. 12 Schematic illustration of the p-i-n structure

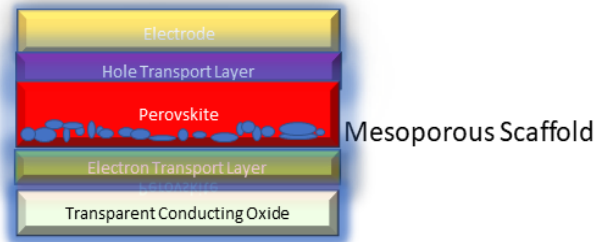


Fig. 13 Schematic illustration of the n-i-p mesoporous structure

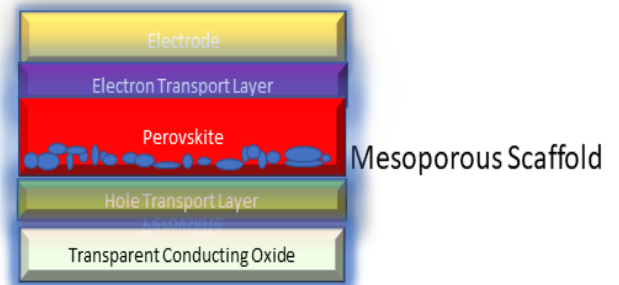


Fig. 14 Schematic illustration of the p-i-n mesoporous structure

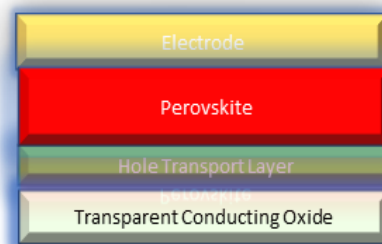


Fig. 15 Schematic illustration of the HTL free structure

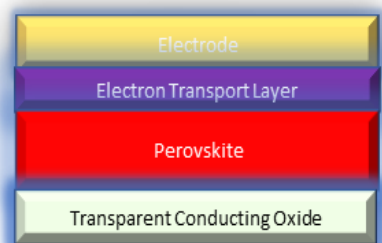


Fig. 16 Schematic illustration of the ETL free structure

5.4.2. Lead Free Perovskite: Lead's (Pb) toxic nature which utilized in perovskite material's active layer

become major issue for the safety of environment and health. Alternatively, lead free perovskite due to its low-cost, abundant and nontoxic nature are safe for health and environment issue. The organic-inorganic lead-free halide perovskite provides the same ABX<sub>3</sub> chemical composition. The cation of A<sup>+</sup> is found at the corners of one cubic, with the X<sup>TEN</sup> anion in the center of each side and the little B<sup>+</sup> (free plumb) cation in the center of the octahedral places produced by anions is perfect without plumbing organic-inorganic halide. For substitution of Pb(II) in half perovskites, like Ag, Bi, Sb, Ni, Ge and Sn, some of the low-toxicity cations have been suggested. The growing PCE was observed among the halide perovskites dependent on Sn(II). The Sn-based perovskites then become SnO<sub>2</sub>, which is an environmentally friendly element, after exposure to ambient air. Germanium, Antimony is also an alternative for replacing lead. Ge<sup>2+</sup> is chemically unstable. Antimony has good opto-electronic properties. The key issue with Sn-based perovskites' optoelectronic efficiency and durability is the poor chemical durability Sn<sup>2+</sup>, which can easily be oxidized to Sn<sup>4+</sup> under air conditions. Various methods to avoid oxidation of Sn have been developed. Nevertheless, it is always challenging to control its chemical stability (28).

**5.4.3. Synthesis Methods for Perovskite:** Perovskite oxide nanocrystals have uncontrolled and irregular morphologies and the poor electrical properties of the sintered ceramics obtain when synthesized via conventional solid-state reactions. Various wet chemical methods have been used to solve this problem such as sol-gel method, microwave-hydrothermal, sol-precipitation method, hydrothermal method, and solvothermal syntheses. These methods produced nanocrystals with narrow size distribution. chemical stoichiometry can be easily controlled by using these methods. One step and two step methods are widely used in fabrication of perovskite cell. One step method is widely used due to its low cost and easy to operate. This method requires complete precursor preparation with suitable stoichiometry. Inorganic halides and organic halide are used for preparing the perovskite precursor solution. Example of organic halides are MAI/FAI, methylammonium/formamidine iodide. PbX<sub>2</sub> (X=Cl, Br or I) is an example of inorganic halide. It does not require entire precursor preparation by the two steps perovskite deposition but MAI/FAI layers and PbX<sub>2</sub> (X= I, Br or Cl) coatings are separated (29).

**5.4.4. Optical and Electronic Properties:** The ABX<sub>3</sub> type compounds cubic's optical and electronic properties are analyzed using methods that use the

dynamic hybrid density which use the SOC effect. We obtain following result:

- (i) The ABX<sub>3</sub>'s band gap and lattice constant increases when A's size is increased;
- (ii) The ABX<sub>3</sub>'s band gap increases when B varies from Sn to Pb;
- (iii) There is decrease in band gap and increase in lattice constant when X ranges from Cl to Br to I;
- (iv) CH<sub>3</sub>NH<sub>3</sub>SnBr<sub>3</sub> is promising nontoxic substrate with a great band gap and strong optical absorption for the solar cell absorber.
- (v) The VBM (Valence band maximum) refers to the hybridized anti-bonding condition of Bs-X p orbitals and CBM (conductive band minima), All ABX<sub>3</sub> compounds of identical electronic properties, with a R band difference at direct band.

The determined Band Gap values indicate that the band gap is higher in (FA)<sub>2</sub>BiCuX<sub>6</sub> (X = I, Br, Cl) after substitution of halogen atoms. This covers the entire visible spectrum area. The Compound (FA)<sub>2</sub>BiCuI<sub>6</sub> has superior optoelectronic features such as a large absorption, promising dielectric characteristics and strong optic conductivity. The possible nominee will be a combination double to build next-generation non-toxic photovoltaic pb-free materials (30).

## 6. CHALLENGES AND FUTURE SCOPE

### 6.1 Quantum Dot Solar Cell Future

In the future, a great attention is deserved by the following aspects:

- (i) In future, for the counter electrode, carbon materials, entirely green QDSCs, might be a better selection because of low cost and high catalytic activity.
- (ii) QD sensitizer's new type requirement which possess features like environmentally friendly nature, low cost, wide absorption range, appropriate band edge position.
- (iii) TiO<sub>2</sub> electrode surface's large portion is discovered. Only nearly 34% area, on the TiO<sub>2</sub> electrode, is the QD's highest reported surface coverage ratio. For improving the light harvesting efficiency, QD-loading amount is required.

(iv) Because of the critical charge recombination in QDSCs, cell performance is limited.

(v) For real applications, the standard requirement of QDSC's stability is still not achieved. Although, for improving the QDSC's long-term stability various efforts are needed (31).

## 6.2 Organic Solar Cell Future

For future industries, high-stability and high-efficiency OSCs:

(i) Device degradation mechanisms' in-depth investigation with mechanical stress, heating, irradiation, water, and oxygen.

(ii) For setting up as well as promoting the stability tests' uniform standards for example, protocols.

(iii) For simultaneously increasing mechanical, thermal and air/photo stabilities, a polymer donor is designed with balanced flexibility and crystallinity.

(iv) For enhancing the OSC's PCE depending on the polymer with photo/air stable units and cleavable side chains.

(v) In spite of PCBM, non-fullerene acceptors can be used for improved mechanical, thermal and photo/ air stabilities.

(vi) For increasing the OSC's PCE deprived of solvent or thermal annealing and high BP solvent additives (32).

## 6.3 Challenges in Perovskites

(i). The natural instability of perovskite materials.

(ii). The phase transition within the solar cell operation temperature's range.

(iii). The instability with varying pressure and temperature.

(iv). The oxygen, UV light as well as moisture also causes permanent damages or may decay the layer of perovskite in sufficient duration of time.

(v). J-V hysteresis as well as lead's toxicity makes it tough for further improving the PSCs performance.

Stability of the ABX<sub>3</sub> perovskite materials is described by using tolerance factor which is given by :  $t = r_A + r_0 / \sqrt{2(r_B + r_0)}$

where,  $r_A$ = organic cation A's ionic radius

$r_B$ = inorganic cation B's ionic radius

$r_0$ = halide anion X's ionic radius

For ideal cubic perovskite structure, tolerance factor( $t$ )  $t = 1$  and for cubic structure  $t$  lies between 0.89 to 1 or  $0.89 < t < 1$ .

When  $0.89 < t < 1$ , it helps in acquiring the Cubic structure

Lower resistance implies lower symmetry as well as perovskite will switch to orthorhombic or tetragonal form that will have detrimental effects on perovskite optoelectronics. MAPbI<sub>3</sub>, a resistance marginally higher than 0.9, tends to be the most robust perovskite substance.

## 6.4 Future of Perovskites Solar Cell

A variety of problems do need to be addressed by cost control, performance and reliability development, and industrialisation. Below are other things

Next: the:

(i) Currently, focus is being placed on the improvement of large-scale film syntheses or material properties; but inorganic perovskite solar cells are still missing physical mechanism. A more thorough understanding and detailed study of interfacial charge recombination mechanism and material stability should be conducted for the search of new structures.

(ii) Whether solar cells are able to absorb light between 300nm and 1200nm. Such kind of narrow light reaction leads to a serious loss of solar energy. In order to achieve PCE efficiency, it is important to increase the inorganic PSCs' ability of light absorption. Inorganic perovskite, due to its large bandwidth, is better material for tandem solar cells. With inorganic PSC solar cells, tandem solar cell could in future be the main research area.

(iii) Inorganic CsPbBr<sub>3</sub> perovskite is considered to be greatly stable under heat attacks, water as well as/or UV glare. Nevertheless, the light and steam mediated phase degradation also influences many inorganic PSCs. The fabrication of high PCE PSCs continues to be a future task.

(iv) Lead is a common and potentially harmful substance that is all based on extremely effective solar

perovskite cells. The essential future approach would be to build plumbing perovskite light absorbing layers. Several researchers have been working on the plumbing perovskite solar cell, but the performance of photoelectric conversion remains less (33).

## 7. CONCLUSION

Nanotechnology is improving our everyday lives by improving the performance and efficiency of objects. It provides a clean renewable energy for a sustainable future. Harvesting solar energy has the potential of delivering cleaner and affordable energy among various renewable energy resources. This chapter mainly focus on synthesis of nanoparticles and its utilisation in various type of solar cell. Synthesis of nanoparticles can be done by using various deposition techniques which are discussed in this chapter. Different type of solar cell with their future are discussed which tells about the importance of solar cell for renewable energy in future.

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