

Research Paper on Advanced Material used in Solar Panel - Perovskite, A organic, Inorganic and Halide Compound

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Abstract

Solar energy becomes an essential requirement in present days. It is a very important energy resource in the aspect of environmental safety, simplicity and availability. Solar energy is widely using this time all over the world, and India is a country which is leading in the use of this [1]. The main drawback of solar energy is the high initial cost, low efficiency (PCE) and lack of disposal methods [2]. Researches in this field regularly overcome these drawbacks. These drawbacks suggest he is to bring the use of such materials which gives a high PCE at low cost. While selecting the suitable material for PC, its hazardous effect on the environment should also keep in mind.

Keywords: Put your keywords here; a comma separates keywords.

INTRODUCTION

A French Scientist Alexandre Edmond Becquerel was the first who discovered the photovoltaic effect, in 1839 [3]. He built the world's first Photovoltaic cell in his father's laboratory. After that, in this sequence, Russel Ohl invented the first modern solar cell made of silicon in 1946 [4], [5]. Most of the solar cells are made of silicon. PV cells are in the form of thin silicon wafers which convert sunlight energy into electric power. When these individuals solar cell are combined to form of modules, it is called solar panel. A single-junction silicon solar cell can produce a maximum of 0.5 to 0.6 volt. Solar cells are photodetectors like Infrared detectors, which are detecting light and electromagnetic radiation, near the variable range. Modern photovoltaic technology is based on the principle of electron-hole creation. In this, each cell composed of two different layers (p-type & n-type materials) of semiconductor material.

In this arrangement, when a photon of sufficient energy imping on p-type & n-type junction an, electron affected by gaining the energy from striking photon and moves from one layer to another layer. Due to this, a hole and electron are created, and thus electrical power is generated [6]. Based on the use of variable types of material in solar cells the solar cells are categorized into various classes like single crystal, multi-crystalline amorphous silicon [7, 8, 9, 10] Cadmium Telluride [7, 8] copper-indium-

gallium-selenide [7, 8, 11] copper-indium-gallium-sulphide [12, 6] and most importantly Perovskite[13].

Development of Solar Cell Material

A solar cell or PV cell is an electrical device that converts sunlight energy into electric current. According to Plank theory of energy moves in the form of energy packets called photon when these photons strike a metal conductor then now holes & electrons created which gives rise to flow of a current. The Electrical characteristics of a photoelectric cell such as current-voltage or Resistance vary when exposed to light. Individual solar cells devices can be combined to form modules, otherwise known as the solar panel, which can produce an open circuit voltage of 0.5 to 0.6 volt.

The area of material used for a solar cell is very vast. So many researches are going on in searching for efficient material for a solar cell which can provide maximum PCE at low cost. Some of them are discussed here-

1. Single/Mono Crystalline Silicon Solar Cell

This is the first generation of solar cell called a wafer-based solar cell. These Silicon solar cells are made by a process called Czochralski Process [6, 14, 15]. Si crystals are cut from the big sized cylindrical ingots, so their corner looks like clipped, like an octagon. These cells are more efficient and more expensive than other cells. Solar panels using Mono-Si cells display a distinctive pattern of small white diamonds, and there PCE lies between 17%-18% [11].

2. Poly Crystalline Silicon Solar Cells

Polysilicon cells are the most used solar cells due to its lesser cost. But these are also less efficient 12%-14% [16]. These solar cells are composed of several different crystals, coupled to one another in a single cell. These are manufacture by a cooling a graphite mould filled with molten silicon.

3. Thin Film Solar Cell – Second Generation Solar Cell

A thin-film solar cell is called a second-generation solar cell and are more economical as compared to the first-generation solar cell. These



solar cells have a very thin light-absorbing layer generally of the order of 1-micrometre thickness while first-generation silicon wafer cell has 250micrometre thick light-absorbing layer [17]. These technologies reduce the amount of active material in a cell. In this active material acts as a sandwich between two panes of glass. Examples of this film technology Amorphous Silicon, Cadmium Telluride (CdTe), copper indium gallium Di Selenide (CIGS) etc. [6]-[12].

4. Nanoscale Materials Based Solar Cell

Nano crystal-based solar cells are generally called as quantum dots. Quantum dot is just a name of size ranging within a few nanometers, e.g. Porous Silicon or Porous TiO_2 (Titanium dioxide) [18]. Nanocrystals are used as an option for effective and cheap solar cells. It is assumed that the Nanocrystals shape and sized will allow for the customization of bandgap through absorption of light across the whole spectrum.

5. Polymer Solar Cell

The first polymer/organic solar cell was invented by the research group of Tang et al. at Kodak Research lab [19]. These cells have the benefit of flexibility due to polymer substance. These cells are composed of a serially connected thin function layer (typically 100nm) coated on a polymer foil or ribbon. It makes a combination of the donor (polymer) and an acceptor (Fullerene). The material used for this purpose is polyphenylene vinylene, carbon fullerenes derivatives etc. [20].

6. Dye-Sensitized Solar Cells (DSSC) or light Absorbing Dye

Michel Gratzel introduced the first Dye Sensitized solar cell in the Swiss Federal Institute of Technology [12, 21]. These cells are made of low-cost material and do not need to elaborate on manufacturing equipment. Recently researchers have been focused on improving solar efficiency by molecular manipulation, use of nanotechnology for harvesting light energy [22]-[25]. DSSC can be coated on flexible sheets, but its conversion efficiency and the absorption coefficient is low [26]. These cells generally employ dye molecules between the different electrodes. The DSSC device consists of four components: semiconductor electrode (n-type TiO_2 and p-type NiO) a dye sensitizer, redox mediator and a counter electrode (Carbon or Pt) [20]. Typically a Ruthenium Metal-organic dye (Ru-centred) is used as a Monolayer of light-absorbing material.

7. Perovskite Solar Cells

This is the latest technology on which so many researches are going on. Perovskite is a class of compound defined by the formula ABX_3 where A and B are cations of different size and X represent a

halogen such as I^- , Br^- , Cl^- . An active layer or Perovskite structured material is used. Mainly, this is a solution-processed hybrid organic-inorganic tin (Sn) or Lead (Pb) halide based material. Here group A consists of methyl Ammonium (CH_3NH_3^+) or Formamidinium $\text{CH}(\text{NH}_2)_2^+$ while group B consists of Lead (Pb^{++}), Tin (Sn^{++}). The metal halogen octahedral are joined together to form a stable three-dimensional network structure. The researches show more interest in the research of these solar cells increased from 5% to 20% in 2014 [30, 31]. These solar cells are considering as extremely cheap solar cell. Although till now, the use of Perovskite solar cells have not commercialized while so many researches are going on to achieve it.

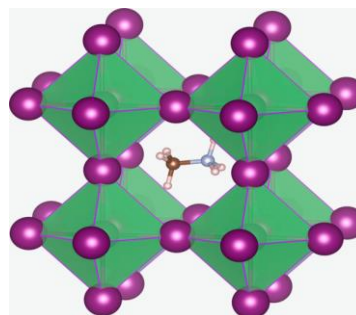


Fig: Structure of Perovskite Solar Cell [74]

These solar cells possess several advantages over conventional silicon-based solar cell need expensive multiple processing steps and require high temperature greater than 1000°C and vacuum facilities [27, 28]. These solar cells have an efficiency maximum of up to 31% [29]. These Perovskite-based solar cells may be best used in next-generation electric automobiles batteries, according to an investigation recently performed by Volkswagen [28, 29]. However, their stability is a big issue among the researches because its materials degrade over time and hence overall efficiency drops.

Structure of Perovskite Solar Cells

The basic molecular structure of a Perovskite material is ABX_3 . Here A and B are cations of different size. Here group A represents Methyl Ammonium (CH_3NH_3^+) or Formamidinium $\text{CH}(\text{NH}_2)_2^+$ and group B represents a metal cation like Pb^{++} or Sn^{++} etc. and a halogen anion is represented by X, e.g. Chlorine, Bromine or Iodine or coexistence of several Halogen. The Perovskite material is derived from calcium titanate (CaTiO_3), which has a similar molecular structure of type ABX_3 . Perovskite materials have cubic-lattice nested octahedral layered structures due to which these materials have unique optical, thermal and electromagnetic properties. Perovskite material is organic-inorganic material halide compound in which group A is located in the vertex of face-centred cubic

lattice and metal cation B, and halogen anion occupies the core and apex of core and apex of octahedral. So these are joined together to form a stable three-dimensional network structure [32].

There are mainly four features possessed by a Perovskite solar cell. Firstly, the materials possess good photoelectric properties, lower exciton binding energy and high optical absorption coefficients.

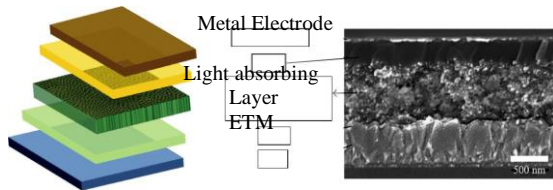


Fig: Schematic diagram and SEM section image of mesoscopic architecture PSCs

These solar cells also absorb solar energy efficiently by the light-absorbing layer. These materials also possessed a high dielectric constant & can efficiently transmit and collect electron and holes [32, 33]. Electron and holes can be transmitted simultaneously, and transmission distance is up to 100nm or more and even more than 1micrometer.

Due to all these features, these solar cells give high open-circuit voltage (V_{oc}) and a short circuit current density (J_{sc}) [34, 35].

Working Principle of a Perovskite Solar Cell

When these solar cells are exposed to light, they absorb a photon and produce electron-hole pairs called excitons. Due to difference in exciton binding energy of the Perovskite materials, these excitons can form free carriers to generate a current. Then these free electrons and holes are collected by an EIM (electron transport materials) and an HTM (holes transport material). Electrons are transferred from the Perovskite material to TiO_2 , which is used from EIM layers and finally collected by FTO. At the same time, the holes are transferred to the HTM layer and collected by the metal electrode. Yet, the FTO and metal electrode are connected, and the photocurrent is generated in the outer circuit [34, 35]. In recent years, various structures of Perovskite solar cells have been developed, including the mesoporous structure and planner heterostructure.

Development in Perovskite Solar Cell

Among all the components of Perovskite solar cells, the Perovskite materials play a core role in light absorption and photoelectric conversion. Perovskite compositions with single ions occupying each of the A, B and X sites are denoted as simple Perovskite. To increase the photoelectric conversion efficiency optimization of materials and structure should be done.

LiF
Au
PCBM ₆₀

$CH_3NH_3PbI_3$
Poy TPD
PEDOT: PSS
ITP
GLASS

Fig: schematic diagram of Perovskite Solar Cell Layers [56].

By Varying X Halide Anions

It can be noted that the electronic structure of Perovskite material is mostly related to p orbit of Halogen (x) and Lead (Pb). So the bandgap of Perovskite ($MA PbX_3$) can be controlled by adjusting the p orbit of mixed halide anions [36, 37, 38]. Noh et al. first demonstrated the PV effect of mixed $MAPbI_3-xBr_x$. They achieved an efficiency of the order of 12.3% [39]. He found that lower bromine content, almost less than 10% yielded the highest initial efficiency. The reason was a narrow bandgap. But if a higher Br content is used (greater than 20%) achieved good stability is a function of transformation from the tetragonal phase to a pseudocubic phase. The close accumulation of Perovskite structure to a certain extent prevented the degradation of $CH_3NH_3^+$ [39]. By the deposition of dense Perovskite films and through solvent engineering methods Jeon et al. achieved a PCE of 18.4% in Perovskite solar cell using $(FAPbI_3)_{1-x}(MAPbBr_3)_x$ as an aight absorbing layer

Most extensively studied binary mixed Perovskite is $MAPbI_{3-x}Cl_x$ which is formed by doping Cl atoms with partially substituted I atoms. In 2013, Stranks et al. indicated that the diffusion length of electron and holes in $MAPbI_{3-x}Cl_x$ was greater than 1micrometer and that Cl doping improved the stability and conductivity of Perovskite materials[40, 41].

By varying (mixed) A-site Cations

It is generally believed that in the cubic perovskite structure, the energy band structure of it can be adjusted within a certain range by changing the size of the A-site ions. A larger or smaller cation causes the lattice to expand or contract, thus changing the B-X bond length, which has been shown to influence the band gap[42, 44]. By varying the ratio of MA^+ and FA^+ , Pellet et al. reported the first mixed A-cation and described the structure of $(MA)_x(FA)_{1-x}PbI_3$ based solar cells. The highest PCE was achieved by a composition of $(MA)_{0.6}(FA)_{0.4}PbI_3$ upto 14.52% [43]. Lee et al. prepared $FAPbI_3/MAPbI_3$ films with stacked structures by ion-exchange extended the absorption range of the long-wave spectrum and reported a current density of 20.22 mA/cm^2 and the best PCE of 16.01%. An optimized structure of $(MA)_{0.6}(FA)_{0.4}PbI_3$ resulted in the highest PCE of 18.3% [45].

It can be easily concluded that organic material has less stability then inorganic material, so future designs were based on replacing the organic cations with inorganic monovalent cations in

Perovskite structure. Niu et al. reported a higher efficiency of 18.1% in their optimized $\text{Cs}_x(\text{MA})_{1-x}\text{PbI}_3$ cell device with $x=0.09$ [46]. The thermal stability of unencapsulated device was significantly improved compared to MAPbI_3 [47]. Rb^+ cations also can enhance both efficiency and stability of Rb-mixed Perovskite solar cells. Park et al. studied the $(\text{FA/Rb})\text{PbI}_3$ system using the same Rb quantity and achieved PCE of 16.15% and 16.2% respectively [48, 49]. The main achievement in this was 85% RH of Rb-Mixed Perovskite was highlighted. The result also suggests the stability of all inorganic Perovskites can be further improved by incorporating some specific cations into the unit cell such as Ag^+ and Bi^{3+} .

By Varying (Mixed) B-site Cations

Toxic behaviour of Pb is a major drawback in its use at large scale. So researchers give more attention to Lead-free Perovskite material. Sn and Pb belong to the same family in the periodic table. So Tin (Sn) may be the main alternative of Lead (Pb). Generally the bandgap of Sn^{2+} based Perovskite materials is less than that of Pb^{2+} based Perovskite materials. So it is more beneficial to prepare Perovskite materials with mixed Sn and Pb in the B-site. So that absorption can reach the near-infrared region.

Ogomi et al. studied the optical properties of $\text{MASn}_{1-x}\text{Pb}_x\text{I}_3$ with different ratios of Pb to Sn. They found that the bandgap could be adjusted within the range 1.17-1.55eV and that the optical absorption wavelength could be extended to 1060nm [50]. Sn-based Perovskite solar cell has been reported to demonstrate PCE of around 5.6% in the conventional plane structure. Zou et al. reported the synthesis of binary Pb-Sn Perovskite with a structure of $\text{MAPb}_{1-x}\text{Sn}_x\text{I}_{1-y}\text{Cl}_y$ with a PCE of 10.1% in an inverted planar hetero-junction device. Further, Liu et al. achieved a PCE of 13.9% with a Perovskite structure of $\text{MAPb}_{0.75}\text{Sn}_{0.25}\text{I}_3$ in an inverted planar hetero junction device [51, 52]. Marshall et al. work on increasing the stability of Perovskite solar cell by addition of SnCl_2 in the light-absorbing layer. This also increases the energy conversion efficiency of a solar cell.

Electron Transport Layer

The main function of Electron transport layer is to form an electron-selective contact with Perovskite light-absorbing layer to improve the extraction capacity of photogenerated e^- and also to effectively prevent the hole from migrating to the counter electrode. Titanium Dioxide (TiO_2), ZnO and n-type semiconductor material are effective electron transport material due to its wide bandgap. For a material to be Electron transport Material it should have higher carrier mobility, should be transparent to visible light, preparation condition should be mild, and it should be available at low temperature. Also, its band structure should match the Perovskite material. Research shows that selection of commonly

used Electron Transport Material is not the main factor affecting Power conversion efficiency of solar cell [53, 54, 55, 56].

Hole Transport Layer

In Hole Transport Material the highest occupied molecular orbit (HOMO) must match the valence band of Perovskite materials for hole transport. The main function of HTL (Hole Transport Layer) is to collect and transport holes from the perovskite light-absorbing layer to promote the separation of the excitons in the Perovskite material through cooperating with Electron transport layer. HTM can be divided into two categories-organic HTM and Inorganic HTM according to their chemical composition. Spiro-OMETAD is an organic HTM, which gives good penetration in nanoscale perovskite and is a good combination with valence band energy of Perovskite. Their hole mobility is less than other organic HTM. Some doping can also be done to increase the hole mobility of an HTM. Doping materials are p-type composites (Cobalt compound), Sulfonimide Lithium, LITFSI etc. [57]. From all of organic HTM, Polymer HTM has good hole mobility and also they have better film-forming ability, e.g. PTAA, P3HT, PEDOT: PSS, PCDTBT and PCPDTBT etc. PTAA (poly[bis(4-phenyl)(2,4,6-trimethylphenyl)amine]) is commonly used as HTM due to its good hole mobility. A perovskite MAPbI_3 solar cell using PTAA as HTM gives highest PCE of 16.2%. P3HT polymer HTM is good for the stability of Perovskite solar material [58].

Inorganic p-type semiconductor material shows the potential to replace organic HTM due to their advantages like high hole mobility, wide bandgap and simple solvent treatment process, e.g. CuI is a powerful competitor to Spiro-OMETAD because it has better conductivity so that it improves the filling factor of the device [59]. Seo et al. prepared a Perovskite solar cell based on MAPbI_3 and achieved a PCE of 16.4% with an undoped NiO ultrathin film [60].

Preparation Method of Perovskite Light Absorbing Layer

The synthesis methods of the light-absorbing layer of perovskite solar cells can be divided into three types:

1. Solution method,
2. Vapour-Deposition method, and
3. Vapour-Assisted solution method

In the solution method more internal defects will be produced in synthetic crystals and the holes transport layer is in direct contact with the electron transport layer, thus reducing the device's filling factor and the open-circuit voltage. This method is simple and economical. The perovskite films prepared by the Vapour-deposition method show a high surface density and fewer defects, which improve the filling factor and the open-circuit voltage.

But, in this method, manufacturing requires a high-vacuum environment and thus involves high energy consumption.

The vapour-assisted solution method includes the benefits of both methods, i.e. the solution method and the evaporation method. The perovskite materials with fewer internal defects can be synthesized, at a lower vacuum.

1. Solution Method

The solution synthesis methods of perovskite materials can be divided into one- and two-step methods according to the number of deposition steps. In the one-step synthesis of the perovskite light-absorbing layer, PbX_2 and MAX are dissolved in solvents at a certain stoichiometric ratio to form a precursor solution. This solution is now directly spin-coated on a TiO_2 substrate and dried at a suitable temperature and atmosphere to obtain the light-absorbing perovskite layer. The crystal quality and properties of the perovskite layer are loosely related to the solvent used, annealing temperature, and annealing time [56, 61]. The one-step deposition method is simple, but it is not easy to control the morphology and size of the synthetic crystals.

In a two-step, sequential deposition method which was first proposed by Liang et al. [62], a saturated methanol solution of PbI_2 is used as the precursor solution for the spin-coating on the TiO_2 substrate. And then, the PbI_2 -coated substrate is immersed in a 2-propanol solution containing MAI for a suitable time and then rinsed with 2-propanol. After drying at a suitable temperature, the PbI_2 reacts with MAI, and the perovskite layer is synthesized. The dipping time and MAI solution concentration are crucial to the morphology and optoelectronic properties of the final $MAPbI_3$ films. Burschka et al. Prepared perovskite solar cells with a high PCE of 15% according to a slightly modified two-step method by spin-coating MAI solution on the PbI_2 film rather than dipping [63]. The two-step method is beneficial to the fabrication of perovskite films under the relatively high humidity, as compared to the one-step solution method because the relative humidity of less than 60% is hard to affect the overall performance of solar cell [64].

2. Vapour-Deposition Method

The vapour-Deposition synthesis method of the perovskite absorbing layer is generally carried out under high-vacuum conditions. PbX_2 and MAX are deposited simultaneously or alternately on the pre-coated TiO_2 substrate by thermal evaporation from dual sources of PbX_2 and MAX. $MAPbX_3$ is formed at a suitable temperature and atmosphere, and after that, it gets crystallized into a perovskite film. Snaith et al. first reported the co-evaporation deposited $MAPbI_3$ film and applied it in the planar heterojunction perovskite solar cells, achieving PCE of 15.7% and J_{sc} of 21.5 mA/cm^{-2} [65, 66 67]. In this

method, to evaporate the solid PbI_2 into high vapour temperature is required. This method produces more toxic gases, so not safe for the environment. The drawbacks of the synthesis of the perovskite layer could be avoided if a new metal halide with low evaporation temperature and low toxicity can be developed and selected to replace PbI_2 .

Similar to the two-step solution process, a modified vapour-deposition method, named "sequential vapour deposition," was proposed, in which PbX_2 was first deposited by thermal evaporation followed by vapour deposition of MAX. This sequential deposition was developed because of the difficulty in monitoring the MAI deposition rate in the co-deposition process.

The photovoltaic performance of the devices prepared by the sequential deposition was found to depend significantly on the substrate temperature. Researches show that the $MAPbI_3$ perovskite thin films devices prepared by the sequential vapour deposition method exhibited a PCE of 15.4% [68]. For'acs et al. reported a perovskite tandem solar cell fabricated by sequential vapour deposition and delivered a maximum PCE of 18%, thus highlighting the potential of sequentially deposited multilayer structures to improve the efficiency of single-junction perovskite devices [69].

3. Vapour-Assisted Solution Method

To avoid the drawbacks of the solution method and the vapour-deposition method, this method was developed. This method is a relatively economical method of synthesis of high-quality light-absorbing perovskite layers. The process of the vapour-assisted solution method can be outlined as below. PbX_2 is deposited on FTO glass covered with TiO_2 by the solution method, and then $MAPbX_3$ grains grow by in situ reaction in MAX vapour at $120\text{--}165^\circ\text{C}$ in a nitrogen atmosphere for 2–4h. Chen et al. first reported perovskite films with micro-scale grain sizes, low surface roughness, and complete surface coverage by using the vapour-assisted solution method [70]. They applied the films in the planar heterojunction perovskite solar cells and measured an average PCE of 12.1% with high reproducibility. However, in this method, the PbX_2 films at the bottom cannot react completely with the MAX vapour, thus increasing the internal Resistance and decreasing the output power of the perovskite cells.

Among the preparation mentioned above methods, the development of preparation methods aims to obtain compact perovskite films with high purity, few defects, and high coverage. The essential purpose of the research into these preparation methods is to improve the electrical contact between different layers, to reduce the defect density and the carrier loss during transmission, and to achieve a high power conversion efficiency.

Solar Cell Performance Parameters

Type of Solar Cell Used	Open Circuit Voltage (V)	Current Density (mA/cm ²)	Filling Factor	Percentage Efficiency (%)
Solution Processed Solar Cell	0.83	17.4	0.57	8.6 %
Vapour-Deposited Solar Cell	1.07	21.3	0.66	15.3 %
Vapour-Assisted solar Cell	1.06	19.2	0.64	12.7 %

Result

The perovskite absorber was deposited by a dual-source evaporation system (Kurt J. Lesker Mini Spectros) with ceramic crucibles (organic light-emitting diode sources) in a nitrogen-filled glove box. The vapour-deposited perovskite devices were fabricated on FTO-coated glass. A compact layer of TiO₂ was deposited on the FTO-coated glass by spin-coating (solution-processing) it with a mildly acidic solution of titanium isopropoxide in ethanol-17. After that, the perovskite absorber is deposited on the TiO₂-coated FTO substrate. Methyl Ammonium Iodide (CH₃NH₃I) and Lead chloride (PbCl₂) were the organic and inorganic precursor salts, evaporated simultaneously from separate sources at 1025mbar with a deposited molar ratio of 4:1, based on the reading of the sensors above the crucibles. After evaporation, a dark reddish-brown colour is observed. To crystallize the perovskite layer completely, Annealing is done of the perovskite absorbers before spin-coating the hole-transporter layer. After that, Spiro-OMeTAD, from a Chloro-Benzene solution to form the photoactive layer (including lithium bis(trifluoromethyl syfonyl)imide salt and tert-butyl pyridine as additives),[71]. Through thermal evaporation, these devices are capped with silver metal electrodes at 1026 bar. Full details of material and device fabrication and characterization techniques are available in Methods. All other characterizations and measurements were carried out as previously described [72].

Summary

In this paper, we study the advances in the recent developments, fundamentals and basic structures of the perovskite solar cells. The versatility in the fabrication techniques of the perovskite light-absorbing layer, which include the solution-deposition method, vapour-deposition method, and the vapour-assisted solution method, is attractive and

such methods are also discussed. In the development of Perovskite solar cells, some critical factors may affect the development of it. The stability of the organic lead halide perovskite is greatly affected by external environmental factors (such as humidity, temperature, and ultraviolet radiation), which lead to the low stability of the devices and the great difficulties in encapsulating cells in the later stage. Therefore, the development of a high-stability device composition, including the light-absorbing layer, electron/hole transport layer, and electrode materials, as well as the development of a simple and effective device-packaging method, will be of great significance to promote the practicability of such devices [73]. The hole transporting material Spiro-OMeTAD used in perovskite solar cells is expensive (10 times the market price of gold) and its synthesis process is complex. Hence to promote commercial applications of perovskite solar cells, new hole transport material (HTM) need to design and synthesize. It is difficult to deposit a large area of continuous perovskite film with the traditional methods described above and so other methods should be improved to prepare high-quality and large-area perovskite solar cells. Lead (Pb) element employed in Perovskite solar cells is highly toxic, which will hinder the industrial promotion and development of perovskite solar cells. Therefore, it is necessary to find a low-toxicity or nontoxic ingredient to replace Lead (Pb) in the future. There is also a lack of understanding of the microscopic physics mechanism of perovskite solar cells. Therefore, it is necessary to establish a complete theoretical model to explain the reasons for the increase in the conversion efficiency. Theoretical studies will not only help to improve the performance of perovskite solar cells further but also provide ideas to develop simpler and more efficient new materials and structures. In a word, all the above issues need to be addressed before making full application of the perovskite solar cells technology.

Acknowledgement

This paper is prepared with the help of my respected faculty Dr Mukesh Kumar and Mr Izlaal Ahmad Rizvi in IEC Group of Institutions, Greater Noida.

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