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Origin and Fundamentals of Perovskite Solar Cells



Abstract: - Since decades renewable and non-renewable sources of energy are used to fill the demands of different forms of energy. In twentieth century, world has change immensely in terms of infrastructure and health sector. And hence awareness towards nature has also increased. Energy produced from Renewable resources are proven to be effective and efficient to fill the energy demands in future. Energy produced from solar cells is preferred over other resources as it is cheaper, easily available, and eco-friendly. Initially solar cells were developed in 1950's from Si and have efficiency from 16-22%. Metals with halogen evolved as a most promising material in the field of photovoltaics in 2013. Methyl ammonium lead halide perovskite was employed as a visible light sensitizer to create perovskite solar cells (PSCs). The maximum power conversion efficiency is 23.7% and was accomplished for PSCs based on methyl ammonium lead halide in 2018. PSCs is preferred more for practical usage over other materials because of its higher conversion rate and efficiency. Now, in this conclave researcher has discussed about structure and compilation of PSCs, its properties and advancement of fabrication on PSCs.

With the development of extremely effective solid-state hybrid solar cells based on organometal trihalide perovskite absorbers, the field of developing photovoltaics has had an unanticipated breakthrough and quick evolution over the past 12 months. The steps that lead to this discovery are examined in this perspective, along with the prospects for this quickly developing idea. The next few years of solar development will probably bring this technology to the best efficiency possible at the lowest possible cost and energy embodied. Assuming the stability of the perovskite-based technology can be demonstrated, researchers will see the rise of a competitor for solar electricity that is eventually less expensive.

High performance solar cells have been using organometal lead halide perovskites as its light harvester for a long time. Methylammonium lead halide perovskites ($\text{CH}_3\text{NH}_3\text{PbX}_3$, $\text{X} = \frac{1}{4}\text{Cl}, \text{Br}, \text{I}$) must be processed in an inert atmosphere since they are typically sensitive to moisture in the surrounding air. Here, it is shown how moisture can cause a transition of perovskite crystals on a $\text{TiO}_2/\text{ZrO}_2/\text{Carbon}$ triple-layer scaffold to create printable mesoscopic solar cells. Ammonium chloride (NH_4Cl) is added as a supplement to help the perovskite crystallization, wherein the creation and change of intermediate. High-quality perovskite $\text{CH}_3\text{NH}_3\text{PbI}_3$ is made possible by $\text{CH}_3\text{NH}_3\text{X}$ ($\text{NH}_4\text{PbX}_3(\text{H}_2\text{O})_2$ ($\text{X} = \frac{1}{4}\text{I}$ or Cl)). Crystals exhibiting a preferred direction of development. Thus, the intrinsic perovskite devices based on $\text{CH}_3\text{NH}_3\text{PbI}_3$ attain a lifetime of more than 130 days and an efficiency of 15.6% in surrounding circumstances.

Keywords: methyl ammonium lead halide, perovskites light absorbers, photovoltaics, perovskite solar cells.

1. Introduction:

Scientists and researchers concur that solar energy has the potential to meet rising energy demands among all energy sources [1]. Sunlight is one of the primary sources of solar energy that the earth receives [2]. This sun-derived light can be to meet our energy needs, it is converted to electrical energy [3]. The solar panels Sunlight can be directly converted into electricity using a device (solar cells) [4]. During the recent years the development of numerous types of photovoltaic devices, including dye-sensitized solar cells (DSSCs), PSCs, polymer solar cells, quantum-dot sensitized solar cells, and are examples of organic solar cells made of perovskite [5–9].

Due to the easy manufacturing technique and low-cost these solar cells have fascinated the entire research community [10]. The perovskites emerged as most appreciating photovoltaic cells because of its efficiency and cost-effectiveness [11–16].

The photovoltaic cells made of perovskites has a very thin absorber film of perovskite. The molecular formula of PSCs is ABO_3 . Calcium titanate CaTiO_3 was also termed as perovskite term. There are so many other materials emerged with the chemical formula of ABX_3 (where $\text{X} = \text{I}, \text{Br}, \text{or Cl}$ and $\text{A} = \text{Cs}^+, \text{CH}_3\text{NH}_3^+$; $\text{B} = \text{Pb}^{2+}$ or Sn^{2+}). Excellent absorption, charge carrier, and band gap properties characterize this class of PSCs materials. The visible light sensitizer MAPbX_3 was used by the authors to create the dye-sensitized solar cells [17].

Power conversion efficiency of $\sim 3.8\%$ [17] has come out to be very appreciating in case of dye sensitized solar cells with MAPbX_3 but then it just went off because of presence of

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light electrolyte. So, it was decided more emphasis would be placed on that solid state electrolyte/hole transport substance. In this approach, countless solutions to the liquid electrolyte problem were found. To find the PSCs, Lee et al. [18] introduced a solid-state electrolyte into this arrangement. The power conversion efficiency of the newly developed PSCs cell is good at 10.9%. There have been a lot of novel inventories took place for advancement of PSCs photovoltaic cells [19–30]. It has been found that the best performance cell efficiency was achieved at 23.3% [31]. In this chapter, researcher has discussed the structure of PSCs.

Green et al. [3] analysed in his theory about the noteworthy accomplishments made in the increased efficiency of perovskite till date. Green et al. had also defined the special qualities of these perovskites that led to their quick emergence and talked about the difficulties in developing and commercializing perovskite solar cells. The idea has covered its continuous development from the year 2012 to 2015. It has been analysed that these solar collectors are going to be the biggest contributors to new electricity generation capacity around the world from 2014 to 2030. Technologies have been offered either noticeably improved energy conversion efficiency or noticeably lower processing costs. On every level, the latest generation of hybrid organic-inorganic perovskites with halide provides enticing possibilities. The ability to take advantage of more than 20 years of development of related dye-sensitized and organic photovoltaic cells that produce electricity, its ease of production, powerful solar being absorbed with low non-radiative carrier rate of recombination for such simply prepared materials are the key characteristics of these perovskites. Due to the several advantages and diversity of perovskites, they are going to integrate with other cells to form a high-performance tandem cell. In this regard, Si and CIGS modules seem very promising.

The fact that CdTe cells have already attained a respectable market share proves that Pb's toxicity is not yet a significant barrier to widespread professional use. Some CIGS and silicon modules also include Cd or Pb at a general level like what is probably seen in perovskite modules. The risk is that as regulations become more stringent and prevalent, technology that depends on harmful materials may be pushed to the margins. So, it has been observed that eliminating the Pb and replace it with Sn is one of the best solutions.

Alternately, study of the current perovskites may enable more accurate identification of the characteristics that have led to such quick advancement, encouraging identification and study of non-toxic material systems with comparable capabilities.

One drawback of these perovskites is that they lead in causing toxicity concerns during the manufacturing, consumption, and disposal of the devices. Additionally, they degrade when exposed to moisture and UV light even sometimes rather quickly. During wet heat testing, unencapsulated CIGS cells often deteriorate but this can be minimized to acceptable levels by using the right encapsulation. According to the latest research, 'Breathable' designs are not practical that looked at the viability of encasing CIGS cells within flexible modules. To keep the level of moisture absorption low, the layers that efficiently block the entry of water are needed in addition to internal encapsulated layers with high moisture solubility.

Present-day market CIGS modules feature double glass layers and edge sealing compounds which combined effectively to stop moisture from entering. The other approaches could be the involvement of materials that are moisture resistant like Al_2O_3 in the structure of the device that can help to get restricted with the designs for perovskite solar cells.

The future of the perovskite solar cells is going to be vast as they will be going to use in multiple fields and will be used in the existing as well as the traditional approaches to form a new product.

Methylammonium lead halide perovskites ($\text{CH}_3\text{NH}_3\text{PbX}_3$, $\text{X} = \frac{1}{4} \text{Cl, Br, I}$) have garnered significant interest in the energy industry for research. Because of their unique optical and electrical characteristics, for example, a high charge carrier mobility and absorption coefficient substantial diffusion length and little defect density [32-34]. The strength of perovskite solar cells has grown from 3.81% in 2009 [35] and conversion efficiency verified to 22.1% in 2016.

It is the photovoltaic technology that is developing the fastest. date [36-39]. In addition to their great efficiency, PSCs outperform conventional silicon-based solar cells, As a result of its inexpensive raw materials and

straightforward manufacturing procedure. Still, the deterioration problem of ordinary Perovskite $\text{CH}_3\text{NH}_3\text{PbI}_3$ in relation to moisture poses the broader uses and mass manufacturing of this innovative technologies [40-42].

To create an ambient stable device and to better understand the degradation of $\text{CH}_3\text{NH}_3\text{PbI}_3$ is linked to moisture, and a great deal of recent experimental and theoretical work has been done.

According to Kamat et al., hydrated perovskite phases will generate $\text{CH}_3\text{NH}_3\text{PbI}_3 \cdot \text{H}_2\text{O}$ and $(\text{CH}_3\text{NH}_3)_4\text{PbI}_6 \cdot 2\text{H}_2\text{O}$. During $\text{CH}_3\text{NH}_3\text{PbI}_3$'s initial breakdown process, the monohydrate phase is completely reversible [43]. Through exposure to a dry atmosphere, the hydrated perovskite i.e. The dihydrate phase's irreversible breakdown and will result in the total breakdown of PbI_3 (CH_3NH_3) [44]. Different and many strategies have been created to increase the stability of PSCs against moisture, including device encapsulation, interface modification, and optimized perovskite composition [45-48]. In contrast to conventional three-dimensional perovskites, Two-dimensional perovskites with layers have shown excellent enhanced steadiness in the face of humidity [49].

The device's performance is still inferior to that of traditional perovskite-based devices [50]. To achieve stability in addition to high performance, Huang and colleagues has kept $\text{CH}_3\text{NH}_3\text{PbI}_3$ as the cross linkable, light-absorbing silane molecules that are bound using fullerene's hydrophobic functional groups to create the electron transport layer based on fullerene and the entire apparatus extremely resistant to water [51].

Menna, Snaith, and coworkers Colleagues took the place of the most popular hole transport layer, N-di-p-methoxy-phenylamine, or -tetracids, spirobifluorene (spiro-OMeTAD) with single-walled carbon nanotubes [52]. It has been organically functionalized, significantly improving the apparatus. resistance to water. Bella et al.'s multifunctional fluorinated photopolymer coating process enhanced the device's performance. Significantly increased efficiency to about 19% and longer device life to more than six months.

Perovskite film characteristics, such as shape, crystallinity, and defect density of the perovskite grains, are important in achieving high-performance PSCs. Differential deposition techniques such sequential two-step antisolvent treatment technique [53], vapour-assisted process [54], and other techniques have been created to get homogeneous and consistent perovskite thin sheets for planar or mesoscopic heterojunction PSCs. But to slow down the moisture-assisted deterioration of perovskite $\text{CH}_3\text{NH}_3\text{PbI}_3$ in the process of forming thin films. These methods often call for an inert environment or high vacuum conditions to control the humidity level in the surrounding air. This typically coexists with severe problems with energy consumption and as a result cannot coexist with industrial output. The One-step solution processing with additive assistance is thought to satisfy the conditions for easy film formation technique in addition to enhanced device stability [53-55].

A crucial outcome will come from maximizing these techniques under ambient circumstances and connecting them to device performance. Knowledge of the kinetics of perovskite crystallization in atmosphere air and present an easy-to-follow method for creating effective PSCs with increased resistance to moisture. Successfully transfer from application modules in the open air to artwork in the glove box will mark a significant turning point in the advancement of such inexpensive solar technologies. According to a triple-layer PSC architecture, the devices manufactured under ambient settings have a PCE of 15.6%, and the air lasting more than 130 days while keeping performance ~ 96.7% of the starting amount.

2. Construction of PSCs:

Different layers of semiconducting materials are required to produce PSCs, including transparent conductive oxide fluorine doped with tin oxide (FTO), electron transport layer (often made up of semiconducting metal oxides), light absorber layer (perovskite), hole transport material (HTM) layer, and metal contact (Au) layer. PSC construction is a sequential process.

Step 1: First, the FTO glass substrate is etched using HCl and zinc powder. After the substrate has been etched, it is cleaned with acetone, DI water, and 2-propanol.

Step 2: After washing, a coating of thin, firmly packed TiO_2 is applied to the FTO substrate for 30–40 minutes at or below 500°C . The electron transport layer is applied on the electrode using a spin coater, which is then annealed at 500°C for 30–40 minutes.

Step 3: Applying the same method for 20–60 minutes at 80–120 °C. Lastly, using thermal evaporation approach metal contact layer is deposited.

The construction of PSCs is represented in fig. 1[56].

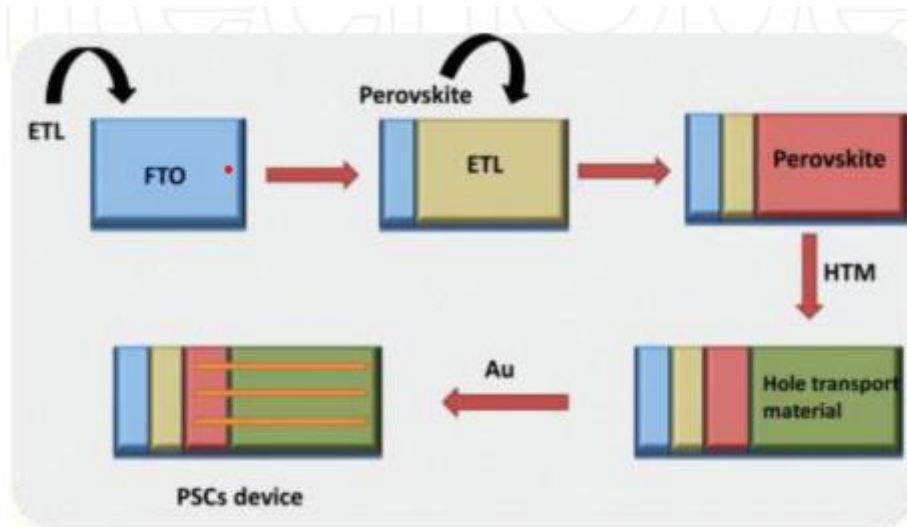


Fig 1 [56]

Through, it is possible to determine the effectiveness of the created perovskite photovoltaic cell. Diverse methods, such as photocurrent-voltage (I-V), external quantum efficiency (EQE), incident-photo-to-current-conversion efficiency (IPCE), etc., and photoluminescence spectroscopy.

There are few variables, including fill factor, PCE, photocurrent density, and open circuit voltage, affect how well any photovoltaic cell device works.

In perovskite materials, researcher can determine the lifespan of the produced electrons. by Photoluminescence spectroscopy which is associated with recombination process. In Perovskite photovoltaic devices it is observed that better evidence is provided by long electron lifetimes and low recombination reaction rates which shows better power conversion efficiency.

Photovoltaic cell made of perovskite absorbs the sunlight and electron-hole pairs are generated inside the absorbing layer. This absorbing layer is very thin and light in nature. Through light absorbing layer electron is passed to conductive phase of electrode. Generally, layer for electron transport constitutes of oxide of a transition metal which has elements of TiO₂ or SnO₂. Function of electron transport layer is to transport the conducting electrode (FTO) with the produced electron and hole transportation takes place through hole transport material respectively. In rarer case the transferred electron recombines and effect the

performance of perovskite photovoltaic cell. So, multi layers are used to lessen the amount of recombination of electrons. In perovskite photovoltaic cell, device itself is used as a light absorber.

2.1 Origin of PSCs:

Kojima et al. [57] first discovered a photovoltaic cell in 2009, and since then, the PCE has increased by 3.1%. To enhance the PCE of the PSCs, many various chances were taken advantage of. Currently, the Zinc Oxide Nano Walls (ZnO NWs) have been created by Tang et al. by processing at low temperature. ZnO NWs has prepared the electron collection layer which leads to development of Perovskite cells [58]. The properties of prepared ZnO NWs can be known through SEM and TEM technique. (SEM is scanning electron microscopy and TEM is transmission electron microscopy).

The result of these techniques is used for confirmation of formation of new product i.e., ZnO NWs. In next steps using ZnO NWs, perovskite photovoltaic cells were formed which act as electron collection layer. It is noted that

MAPbI₃ act as a light absorber. The constructed perovskite photovoltaic cell shows differential PCE with ZnO NWs and ZnO thin films. Highest PCE of 13.6% is exhibited with ZnO NWs. It results that ZnO NWs accumulates more charge than ZnO thin films. It is also because ZnO thin films exhibits PCE of 11.3% which is less than ZnO NWs. NWs is found to be more efficient for generating electrons.

Perovskite fabricated with ZnO NWs and ZnO various 1000 mV open circuit voltage and 980 mV respectively. Hence PSCs compared to PSCs made using ZnO thin films, those created with ZnO NWs exhibit superior IPCE.

In one of their efforts, Mahmud et al. [59] created low-temperature treated ZnO thin film. Utilizing UV-vis (ultraviolet-visible) absorption spectroscopy optical properties of ZnO thin film were prepared. The ZnO tauc confirms the band gap of 3.53 eV. It also shows the Optical advancement in Nanophotonics - Fundamentals and Applications. On employing X- ray diffraction i.e., XRD method also confirmed the formation of ZnO on ITO glass substrate.

The XRD pattern is shown in fig 1 [59].

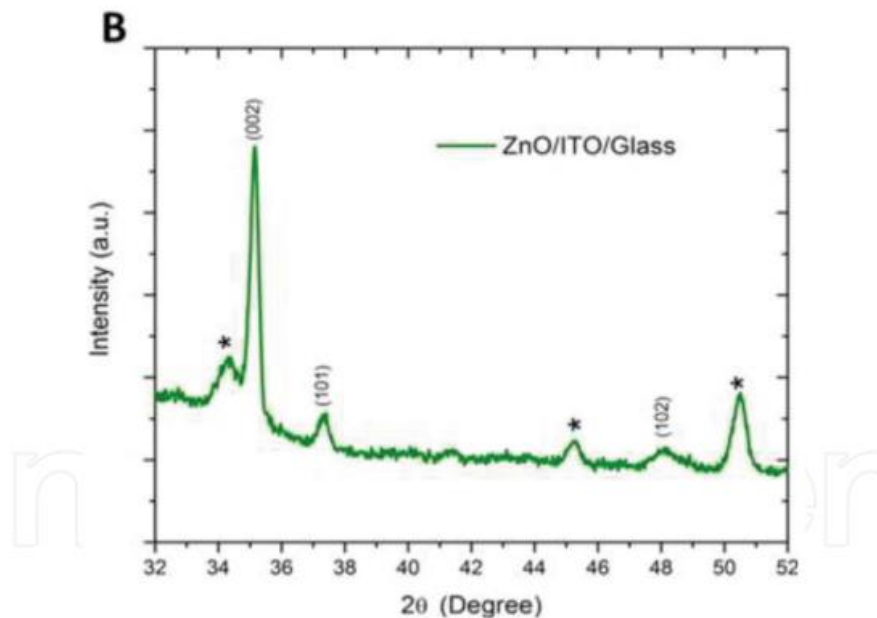


Fig 1 [59]

The crystalline behaviour having strong diffraction peaks is shown in XRD pattern of ZnO. For the manufacturing of PSCs ZnO thin films are induced as as electro transport layer. Use of the MAPbI₃ as a light absorber layer as morphological features of the MAPbI₃ films on ZnO was investigated by authors. Further the presence of linear and symmetrical surface morphology of the MAPbI₃ perovskite was confirmed by SEM [60]. In Fig 2 [60] Fabricated PSCs and its structure is shown.

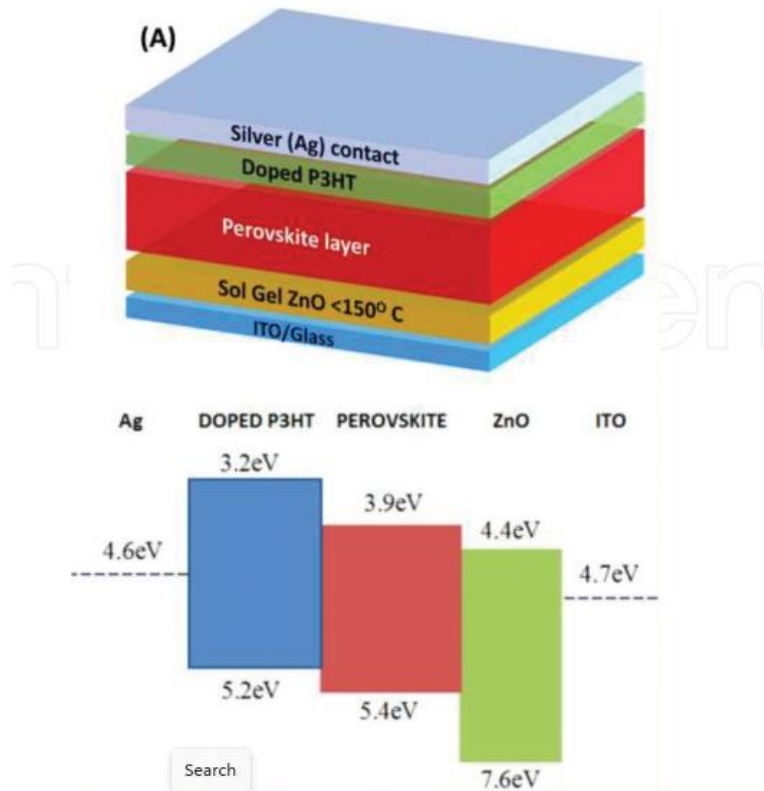


Fig 2 [60]

J-V curve is used to visualize the IPCE performance of fabricated perovskite device. It is observed through the curve that the highest PCE of 8.7% with open circuit voltage of 932mV is obtained when the PSCs is fabricated with ZnO thin films.

In 2017 Li et al. [61] saw the simple conditions-based synthesis of ZnO/Zn₂SnO₄. A compact layer of synthesized ZnO/Zn₂SnO₄ was used to produce PSCs based on MAPbI₃. The MAPbI₃ perovskite layer's XRD pattern was recorded by Li et al [61] and is represented in Fig 3. XRD and X-ray photoelectron spectroscopy (XPS) was used to check the formation of ZnO/Zn₂SnO₄ and recorded XRD pattern is shown in Fig 3. Through these diffraction patterns, diffraction planes are depicted for SnO₂, Zn₂SnO₄, and ZnO and hence verified the structure and existence of ZnO/Zn₂SnO₄ [61].

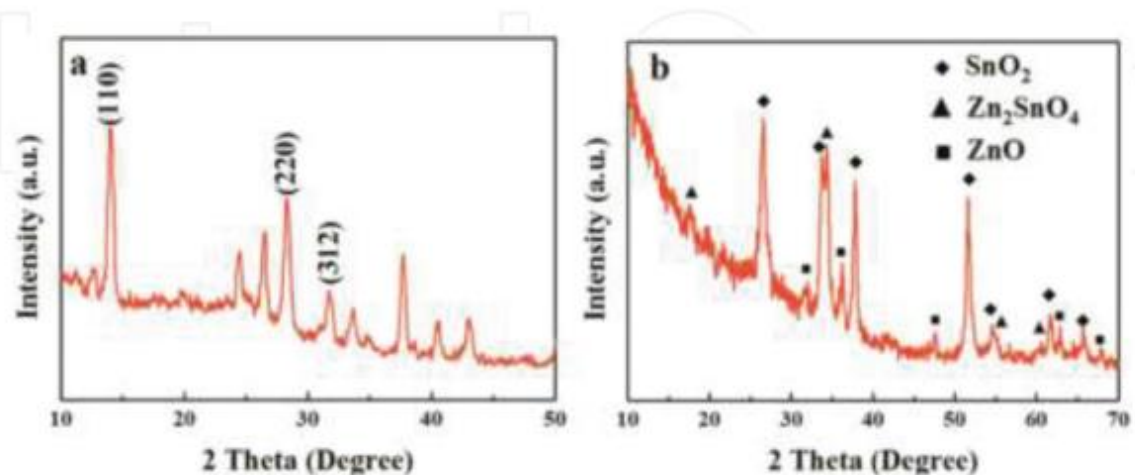


Fig 3 [61]

Li et al. developed the perovskite devices by infusing a tightly bound thin layer of ZnO/Zn₂SnO₄ and with TiO₂ varying breadth [62]. The J-V technique was used to determine the IPCE of developed perovskite devices. The J-V curve of materials made of perovskites with different thicknesses (40 nm, 60 nm, 80 nm, 100 nm, and 120 nm) is shown in Figure 4. The device fabricated with TiO₂ exhibit highest performance when thickness is 100nm.

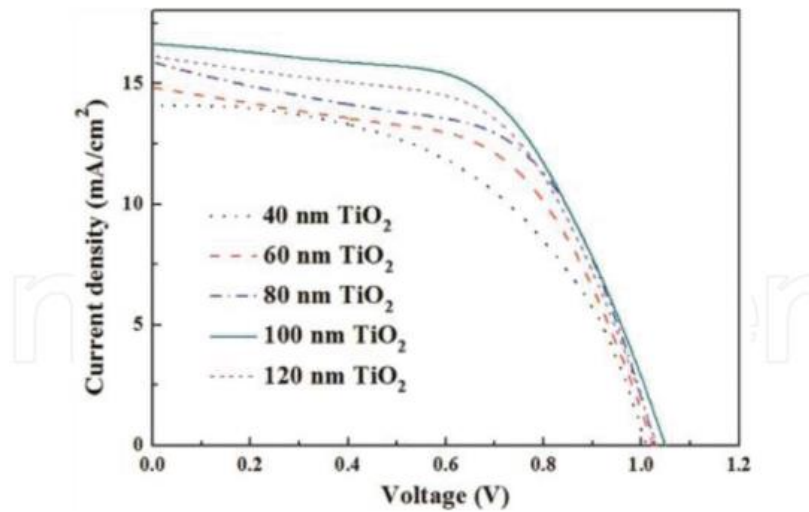


Fig 4 [62]

The performance of the photovoltaic cell is shown using the J-V curve in Fig 5. The IPCE shown using the fabricated Perovskite developed with ZnO/Zn₂SnO₄ with varying thickness of 15, 35, 55, 75, and 95 nanometres was determined.

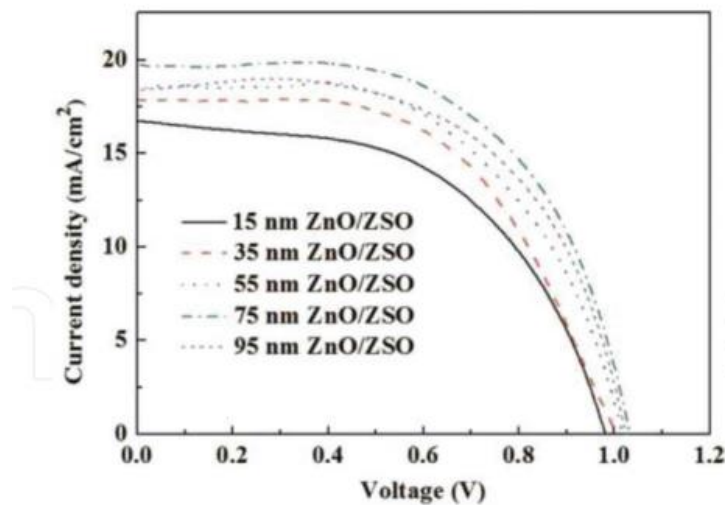


Fig 5 [63]

Li et al. also observed that poor performance is due to poor photovoltaic parameters, and it is observed when perovskite material manufactured using ZnO /Zn₂SnO₄ of 15 nanometres thickness [63]. It infers that Perovskite developed with ZnO/Zn₂SnO₄ having thickness of 75 nm is more efficient than TiO₂.

Chang et al. fabricated Ce with CH₃NH₃PbI₃ using perovskite light. CsI is used by authors to know the morphological characteristics and crystallization properties of Ce when fabricated with CH₃NH₃PbI₃ perovskite light absorber layer [64-66]. Ce is also given more importance because researcher can obtain large crystal CH₃NH₃PbI₃ size perovskite. Larger size of the grains larger is absorbing layers and ranges from 270 nm–650 nm in case of CH₃NH₃PbI₃. XRD analysis helped in confirmation of light absorbing layer of perovskite. Researcher used the Tauc relation to estimate the perovskite's optical band gap light layer that absorbs. The band

gap of the Cs doped $\text{CH}_3\text{NH}_3\text{PbI}_3$ absorption of light in perovskite was 1.59 eV, and it increased slightly with higher CsI concentrations. This confirmed that Cs was incorporated into the layer of perovskite light absorbers.

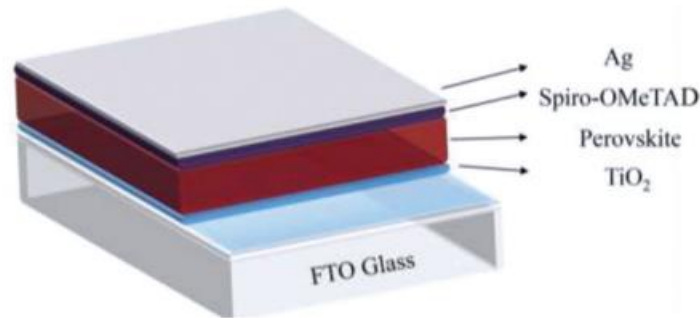


Fig 6 [66]

Chang et al. also took the $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite light-absorbing layers in SEM images, both with and without CsI treatment [67]. Small grains were present in the layer of $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite that served as the light absorber. The $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite light absorber layer was added with CsI, however, as demonstrated by the SEM pictures, and the grain size increased. When the $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite absorber layer was exposed to 6 mg/mL CsI, the most consistent surface morphology was seen [67].

The $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite light absorber layers were also used in the fabrication of PSCs devices. The schematic design for the PSCs device is shown in Figure 6. The device with the $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite absorber layer and the greatest PCE of 14.4% had an open circuit voltage of 1.05 V. The PSCs that did not get CsI therapy had a lower PCE of 10.5%. Different light-absorbing materials are used by various types of solar cells. Table 1 contrasts the PSCs' photovoltaic performance with that of other solar cells that have been published.

Absorber layer	J_{sc} (mA/cm ²)	V_{oc} (mV)	PCE (%)	Type of solar cells	References
MAPbI_3	19.2	720	10.2	PSCs	[36]
perovskite	22.7	240	2.02	PSCs	[37]
MASnI_3	16.8	880	6.4	PSCs	[38]
FASnI_3	17.53	600	6.7	PSCs	[39]
FASnI_3	24.1	520	9	PSCs	[40]
MASnI_3	11.1	970	7.6	PSCs	[41]
$\text{FASn}_{0.5}\text{Pb}_{0.5}\text{I}_3$	21.9	700	10.2	PSCs	[42]
$\text{MASn}_{0.25}\text{Pb}_{0.75}\text{I}_3$	15.8	730	7.37	PSCs	[43]
Al^{3+} doped $\text{CH}_3\text{NH}_3\text{PbI}_3$	22.4	1001	19.1	PSCs	[44]
Dye	13.2	570	4.63	DSSCs	[45]
Dye	15.46	821	8.20	DSSCs	[46]
Polymer light absorber	20.65	946	14.45	Polymer	[47]
Polymer light absorber	19.1	990	11.5	Polymer	[48]
Perovskite quantum dot	15.1	1220	13.8	Quantum dot PSCs	[49]
Quantum dot light absorber	26.70	780	13.84	Quantum dot solar cells	[50]
Organic light absorbing material	21.8	940	14.8	Organic solar cells	[51]

Table 1 [67]

3. Future Prospective:

From beginning fabricated perovskites cells have emerged as a wider scope when fabricated with other materials of different thickness. Scope and advantages have grasped so much attention because of fabrication compatibility, high performance, and affordability. One of the main reasons is that the lead halide perovskite light absorbers that are organic inorganic have optoelectronic properties.

A power conversion efficiency of greater than 24% was the highest achieved in case of photovoltaics cells. There are few reasons which hinders the practical applications of PSCs for example, light absorbers' inadequate aerobic stability and moisture sensitivity. So, it is very essential to remove these hinderance caused due to poor stability and moisture sensitivity.

In last so many years many technologies and strategies have been made to bring out the stabilization and commercialization of PSCs.

Following points can be kept in mind to improve the stability and performance of PSCs:

1. New strategies and structures of PSCs should be developed to bring more efficiency.
2. Using different technologies such of creating new charge extraction and electron transport layers performance parameters can be improved.
3. Certain actions such as cationic groups that are hydrophobic should be induced to improve the perovskite light absorbers' sensitivity to moisture and aerobic stability.

4. Conclusions:

To meet the energy requirements is the topmost agenda to be considered seriously. Solar energy is found in abundance and hence solar cells are the best option to solve this problem. In last decade, much research took place in advancement of perovskite solar cells. It is observed that PSCs has wonderful IPCE and can be used in fabrication procedures also. MAPbX₃ is used as a light absorbing layer to bring out the maximum efficiency of PSCs. PSCs performance is also dependent upon electron transportation. NREL certified highest IPCE of more than 24% for MAPbX₃. This IPCE is the exact parameter require for the industrialization purpose of Si based solar cells. Hence, its quoted that energy needs can be attained through PSCs in upcoming times. Fabrication, development, and advancement of PSCs with various thickness and materials, electron movement layer and layers for charge collection are discussed and reviewed in this chapter.

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