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PEROVSKITE-EMERGING SOLAR CELL

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Abstract: The photovoltaic solar cells are attracting great deal of interest from across the globe due to their potential of producing electrical energy by harvesting photon energy, available on the earth, which is abundant and available free of cost. However, the cost of electricity production and the efficiency with which it is produced are important attributes. Subsequently, several solar cell generations have been emerged in order to chase the low cost-high efficiency race. Conversion of abundant photon energy into electrical energy with high efficiency at low cost is possible with emerging photovoltaic solar cell i.e Perovskite. Perovskite solar cell, a new type of promising photovoltaic solar cell, exhibited a fast improvement in efficiency from 3.8 in 2009 to 24.2 in 2019. The emergence of PSCs has revolutionized photovoltaic research and development because of their high efficiencies, inherent flexibility, the diversity of materials/synthetic methods that can be employed to manufacture them, and the various possible device architectures. Further optimization of material compositions and device architectures will help further improve efficiency and device stability. But their stability is the major bottleneck for their possible commercialization.

Index Terms - Solar cell, Perovskite, Efficiency of Perovskite.

I. INTRODUCTION

Adequate energy supply is essential need of the modern society. The Global energy consumption has been increasing rapidly [1]. Over the period of time, mankind is able to satisfy this demand with conventional energy sources i.e. coal, Petroleum products etc. with huge negative environmental impact on the planet. Furthermore, these energy resources are believed to be extinct in near future. So, in order not to further degrade the atmosphere and to find an alternative to these non-renewable resources, mankind is forced to move towards the renewable energy sources. The utilization of clean, renewable energy sources has become a prerequisite for the development of human society. Among a variety of new energy technologies, solar power is undoubtedly one of the most promising technologies. It is one of the prominent technologies to render usable the solar energy. In recent years. Solar power is forecasted to become the world's largest source of electricity by 2050, with solar photovoltaics and concentrated solar power contributing 16% and 11%, respectively [2]. Solar cells harvest sunlight and convert sunlight into electrical energy by the photovoltaic effect.

Solar cells are generally classified into four generations depending on time and categories of materials which are used for their fabrication. The most common solar cells available in the market are the first-generation solar cells which comprise single and multicrystalline silicon. Second-generation solar cells were introduced as a response to high material usage and cost of silicon solar cell. To reduce the material usage the maximum film thickness for this generation was brought down to a few nanometers to tens of micrometers. Meanwhile many researchers have attempted light management concepts using dye-sensitized solar cells (DSSCs), perovskite, organic solar cells, photo chemical cells, Quantum Dots, nanostructuring, and nanopatterning. Fourth-generations solar cells fall in the class of conjectural generation consisting of composites [3]. Fig.1 shows the schematic representation of different generations of solar cells.

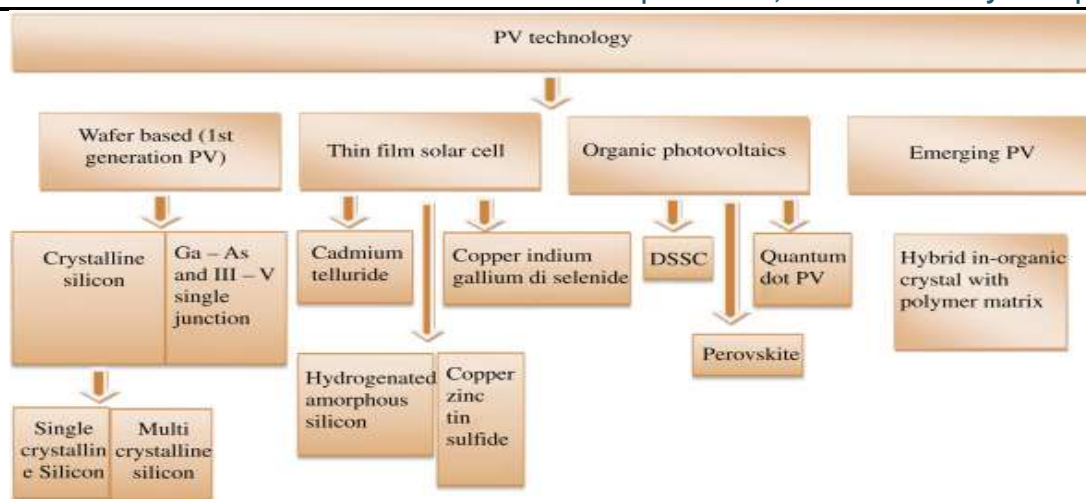


Fig.1
generations

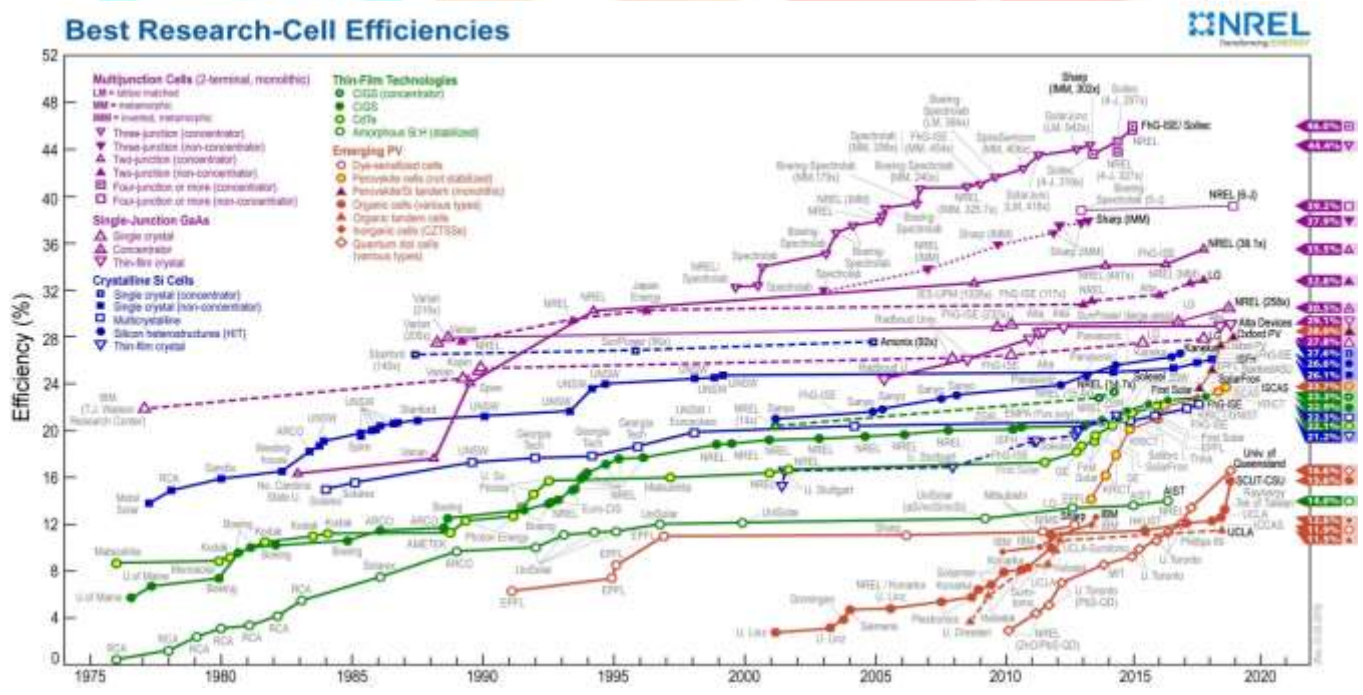
Different
of solar cells.

II PEROVSKITE SOLAR CELLS

2.1 INTRODUCTION TO PEROVSKITE MATERIAL

Very recent in the field of photovoltaic yet so interesting, the perovskite solar cells have caught the attentions of all. The rapid improvement of perovskite solar cells has made them the rising star of the photovoltaics world. The first and foremost reason being the sudden rise in efficiency that these devices have shown till the date (Fig 2). The efficiency of these devices rose from 3.8% to 24.2% in a span 10 years. These dynamic rises in efficiency have forced researchers around the world to explore more about these materials and make the most of that.

Fig.2 NREL Efficiency Chart for Photovoltaic Technologies



Historically, the term perovskite has been used to describe the materials with same type of crystal structure as calcium

titanium oxide (CaTiO_3), which was discovered in 1839 by Lev Alexeievitch Perovski. [4] The chemical formula of the perovskite compounds is ABX_3 , where A is a large cation coordinated to 12 X anions and filled in the holes among the octahedral, B is a metal bonded to 6 X anions and X is the anion bonds to A and B. The ideal cubic-symmetry perovskite structure has the B cation in 6 fold coordination, surrounded by the BX_6 octahedron anions, and BX_6 octahedron are corner-connected to form a three dimensional framework. Perovskite materials have attracted wide attention because of the cubic lattice-nested octahedral layered structures and the unique optical, thermal, and electromagnetic properties. Perovskite materials used in solar cells are a kind of organic-inorganic metal halide compound with the perovskite structure, in which Group A (methylammonium, CH_3 , MA^+ , or formamidinium, FA^+) is located in the vertex of the face-centred cubic lattice, and the metal cation B (Pb^{2+} , Sn^{2+} , etc.) and halogen anion X (Cl^- , Br^- , or I^- , or a coexistence of several halogens) occupy the core and apex of the octahedra, respectively. The metal-halogen octahedra are joined together to form a stable three-dimensional network structure. The crystal structure is shown in Figure 3.

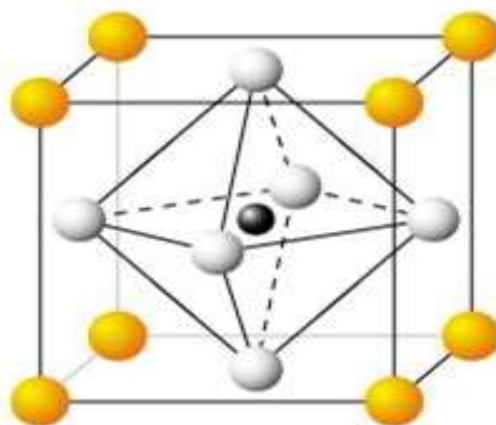


Fig.3 Typical perovskite cubic lattice structure

The materials with such a structure have the following four features. Firstly, the materials possess excellent photoelectric properties, lower exciton binding energy, and high optical absorption coefficients (up to 10^4 cm^{-1}) [5]. Secondly, perovskite as the light-absorbing layer can absorb solar energy efficiently [6]. Thirdly, the materials possess a large dielectric constant and electrons and holes can be effectively transmitted and collected. Lastly, electrons and holes can be transmitted simultaneously and the transmission distance is up to 100 nm or more and even more than $1 \mu\text{m}$ [7].

These features lead to a high open-circuit voltage and a short-circuit current density if the materials are employed in solar cell devices. During exposure to sunlight, the perovskite layer firstly absorbs photons to produce excitons. Due to the difference in the exciton binding energy of the perovskite materials, these excitons can form free carriers to generate a current or can recombine into excitons. Due to the low carrier recombination probabilities of $\text{CH}_3\text{NH}_3\text{PbI}_3$ (MAPbI₃) and other perovskite materials and the higher carrier mobility, the diffusion distance and lifetime of the carrier are long. For example, the carrier diffusion distance is at least 100 nm for MAPbI₃ and longer than $1 \mu\text{m}$ for Cl_x [6]. The longer diffusion distance and lifetime of carriers are the source of the superior performance of perovskite solar cells. Then, these free electrons and holes are collected by an electron transport material (ETM) and a hole transport material (HTM). Electrons are transferred from the perovskite material to TiO_2 , which is used for the ETM layers and finally collected by FTO. At the same time, the holes are transferred to the HTM layer and collected by the metal electrode. Finally, the FTO and metal electrode are connected and the photocurrent is generated in the outer circuit.

2.2 PEROVSKITE SOLAR CELL ARCHITECTURE

The device configuration is one of the most crucial factors for evaluating the overall performance of perovskite solar cells. Perovskite solar cell can be classified as regular (n-i-p) and inverted (p-i-n) structures depending on which transport (electron/hole) material is present on the exterior portion of the cell/encountered by incident light first. These two structures can be further divided into two categories: mesoscopic and planar structures. The mesoscopic structure incorporates a mesoporous layer whereas the planar structure consists of all planar layers. Perovskite solar cells without electron and hole-transporting layers have also been tested. In summary, six types of perovskite solar cell architectures have been studied by various researchers thus far: the mesoscopic n-i-p configuration, the planar n-i-p configuration, the planar p-i-n configuration, the mesoscopic p-i-n configuration, the ETL-free configuration, and the HTL-free configuration.

2.2.1 REGULAR N-I-P STRUCTURE

The conventional n-i-p mesoscopic structure was the first arrangement of perovskite photovoltaics to be tested, in which the light-harvesting dye was replaced with lead halide perovskite semiconductors in a traditional DSSC-type architecture [8]. The interest in perovskite solar cells increased more when so-called mesoscopic device structures (Fig. 4a) were formed by substituting the liquid electrolyte with a solid-state hole-conducting material [9]. The assembly begins with a transparent glass cathode followed by the electron transportation material (ETM). The structure is then layered with a mesoporous metal oxide containing the perovskite, followed by the hole transport material (HTM), and capped with a metallic anode (Fig. 4a). This initial advancement in PSCs created an important field of interest for photovoltaic researchers and consequently led to the development of other PSC device configurations (Fig. 4b–d). The planar architecture is an evolution of the mesoscopic structure, where the perovskite light-harvesting layer is sandwiched between the ETM and HTM. The absence of a mesoporous metal oxide layer leads to an overall simpler structure. It is possible to achieve a high efficiency without the mesoporous layer by carefully controlling the interfaces between the different layers that make up the PSC (the perovskite light absorber layer, the electron-transporting layer, the hole-transporting layer, the electrodes as well as the perovskite layer itself). With the same materials and approach, a planar n-i-p PSC shows increased V_{OC} (open-circuit voltage) and J_{SC} (short-circuit current density) relative to a mesoscopic PSC device; however, the planar configuration also had more severe J-V hysteresis which calls into question the accuracy of the reported efficiencies.

2.2.2 INVERTED P-I-N STRUCTURE

The p-i-n PSC structure is derived from the organic solar cell. In the case of the p-i-n planar perovskite architecture, the HTM layer is deposited first followed by the ETM layer. It was discovered that perovskites are capable of transporting the holes themselves. With this advancement, the inverted p-i-n configuration has expanded the options to explore more for selective layer from organic to inorganic materials and the use of oxide HTM allow for constructing mesoscopic p-i-n device architecture. Planar p-i-n PSC offers low-temperature processing, negligible hysteresis behavior with high efficiency. The device configuration of the inverted p-i-n planar and mesoscopic PSC is shown in Fig. 4c, d.

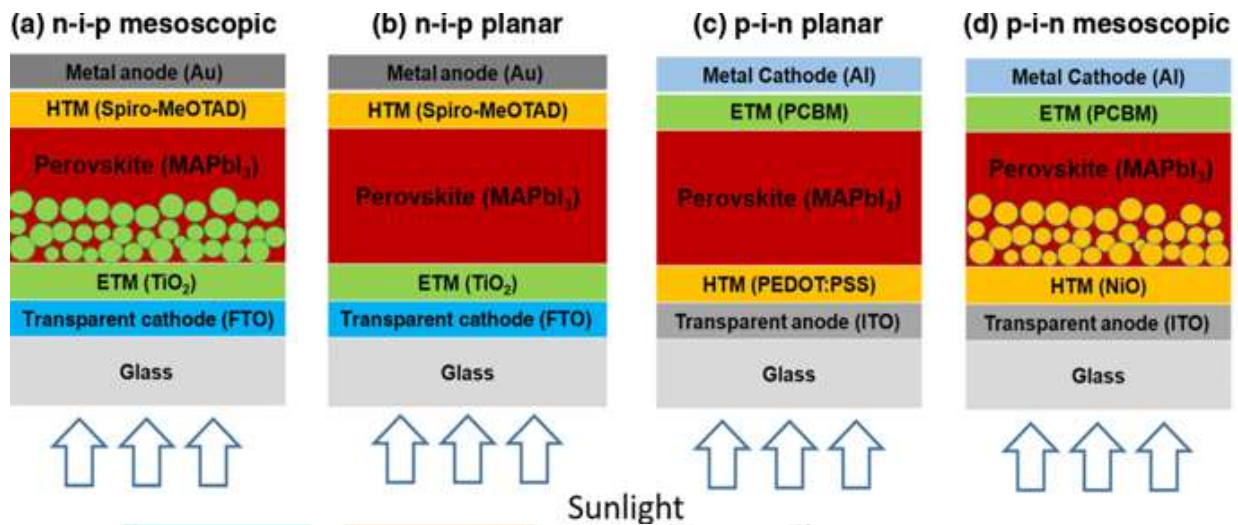


Fig.4 Schematic showing the layered structure four typical of perovskite solar cells (a) n-i-p mesoscopic, (b) n-i-p planar, (c) p-i-n planar, and (d) p-i-n mesoscopic

2.3 ADVANTAGES OF PEROVSKITE SOLAR CELL

- 1) Perovskite material offers direct optical band gap of around 1.5 eV.
- 2) Perovskite material offers long diffusion length and long minority carrier lifetimes.
- 3) It has broad absorption range from visible to near infrared spectrum and high absorption coefficient.
- 4) Perovskite cells deliver efficiencies of more than 22 percent.
- 5) Perovskite material such as methylammonium lead halides are far inexpensive and simple to manufacture.
- 6) It has high dielectric constant, fast charge separation process, long transport distance of electrons and holes and long carrier separation lifetime.
- 7) This low cost material help on converting windows of buildings, top of cars and walls to achieve solar power generation.
- 8) Perovskite uses less material in order to absorb same amount of light compare to silicon. Hence it is cheaper than silicon.

2.4 DISADVANTAGES OF PEROVSKITE SOLAR CELL

- 1) Degradation issue of methyl ammonium lead iodide Perovskite need to be studied.
- 2) Main issue in perovskite solar cells are film quality and thickness.
- 3) The perovskite material will break down quickly due to exposure of heat, moisture, snow etc.
- 4) The material is toxic in nature.

III. THE FUTURE OF PEROVSKITES

Future research into perovskites is likely to focus on the reduction of recombination through strategies such as passivation and reduction of defects, as well as boosting efficiency through inclusion of 2D perovskites and better-optimised interface materials. Charge-extraction layers are likely to move away from organic materials to inorganic, to improve both efficiency and stability. Improving stability and reduction in the environmental impact of lead are likely to both continue to be significant areas of interest. Whilst the commercialisation of standalone perovskite solar cells still faces obstacles in terms of fabrication and stability, their use in tandem c-Si/perovskite cells has progressed rapidly (with efficiencies above 25% achieved) and it is likely that perovskites will first see the PV market as part of this structure. Beyond solar, there remains significant potential for use of perovskites in other applications, such as light-emitting diodes and resistive memories.

IV. CONCLUSION

In conclusion, along with the astounding progress in the efficiency of perovskite solar cells.

The shift from traditional mesoscopic structures to planar structures, the transition from liquid sensitizers to all solid-state structures, and the simplicity and straightforward nature of new low-temperature fabrication methods will all undoubtedly aid in improving the PCE/stability of PSCs and accelerate progress towards their eventual commercialization. To allow the perovskite solar cells to be commercialized, instability of device is one of the main barriers that have to be first overcome in the laboratory. Although the stability of perovskite has been improved from several minutes to thousands of hours, its improvement is not good enough for practical applications; we should extend the lifetime of perovskite solar cell to more than ten years for commercialization. In order to enhance the stability of the perovskites, a number of factors must be taken into account for their systematic engineering, including structure design, charge transport materials, electrode material preparation, and encapsulation methods. we recommend developing some new materials and designs with high stability in severe conditions.

V. ACKNOWLEDGMENTS

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