PEROVSKITE SOLAR CELLS: A BRIEF REVIEW ON STRUCTURAL EVOLUTION AND FABRICATION TECHNIQUES

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ABSTRACT

Solar energy is regarded as one of the most promising renewable energy sources for future green technology. Solar energy can be directly converted into electricity by electrical devices called solar cells through photovoltaic effect. Intensive research works have been done in the photovoltaic field since the first solar cell was fabricated in 1954, leading to the formation of various kinds of solar cells. Among those, Perovskite solar cells (PSCs) have received great attention from researchers in recent years due to their outstanding performance. Since the first Perovskite solar cell was introduced, research in this area has intensively increased resulting in a rapid increment in power conversion efficiency of devices from 3.8% in 2009 to 25.2% in 2020. PSCs have become competitive candidates in the photovoltaic market to replace traditional Silicon solar cells. This article provides a brief review on structural progress of PSCs and the development in fabrication methods. The remaining challenges for long-term stability of PSCs are also addressed.

Keywords: *Solar energy; Perovskite solar cells; Perovskite solar cell structure; fabrication methods; stability.*

1. INTRODUCTION

During the past decades, global energy demand has been continuously increased with the development of the economy and the growth of world population. Since fossil fuels become more and more depleted, the search for alternative sources of energy is required as one of the top global issues [1-4]. Several renewable energy sources have been used effectively in replacement for fossil fuels, such as wind energy, solar energy, hydropower, geothermal, biofuel, and biomass. Among them, solar energy is regarded as the fastest growing source of power technology in recent times due to its remarkable features of being clean, ecological and sustainable [3-6]. The huge abundance of solar power has the potential to meet the total energy demand of the world [7, 8].

Solar energy can be directly converted into electricity through a device called photovoltaic cell (also called solar cell). The photovoltaic effect was discovered in 1839 by Becquerel[9]. In 1954, the first photovoltaic device based on silicon p-n junction was fabricated by Chapin *et al.,* with an overall efficiency of 6% [10]. Since the first practical solar cell was introduced, research in the photovoltaic field has intensively increased. Many achievements in photovoltaic technology have been attained, and various photovoltaic cells have been developed. Among those, Perovskite solar cells (PSCs) have emerged as an outstanding candidate for practical application in the field of photovoltaic devices due to their high power conversion efficiency (PCE), comparatively low cost and facile fabrication processes. Figure 1 shows the number of publications on PSCs and the highest reported PCE of each year [3].

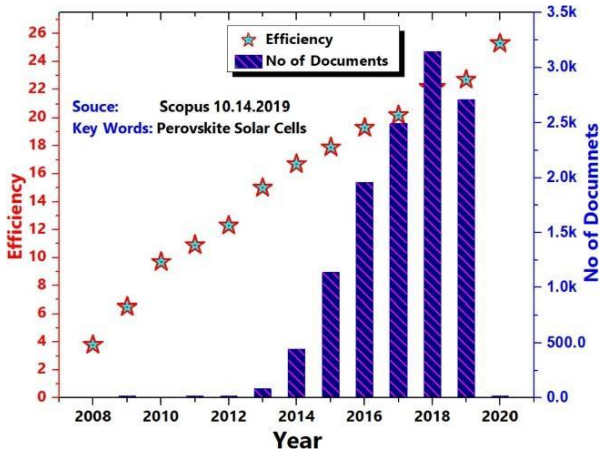

Figure 1. *An overview of the number of publications and PCE in PSCs.*

2. PEROVSKITE MATERIAL AND PSCs

Perovskite refers to any material with the same crystal structure as calcium titanium oxide ($CaTiO_3$). The name perovskite was derived from a Russian mineralogist Lev A. Perovski. Perovskite materials can be represented by the general formula ABX_3, where A and B cations coordinate with 12 and 6 X anions, forming cuboctahedral and octahedral geometry, respectively [11]. The crystal structure of perovskites is depicted in Fig. 1-1.

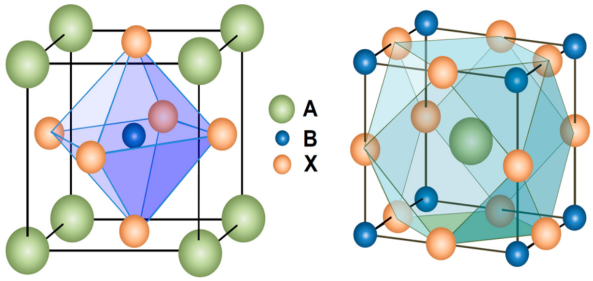

Figure 2. *ABX_3 perovskite structure showing BX_6 octahedral and AX_{12} cuboctahedral geometry.*

Perovskite materials can be divided into two main categories: inorganic oxide perovskites and halide perovskites. In the case of perovskite solar cells, the devices are constructed using organometal halide perovskites, where A is an organic cation ($CH_3NH_3^+$ (MA^+), $CH(NH_2)_2^+$ (FA^+), B is a metal cation (Pb^{2+}, Sn^{2+}), X is a halogen anion (Cl^-, Br^- or I^-). The most common perovskite material for photovoltaic application is methylammonium lead trihalide ($CH_3NH_3PbX_3$).

Organometal halide perovskites have unique properties such as high extinction coefficient, suitable band gap, broad-spectrum absorption range and sufficient carrier mobility. Furthermore, the large abundance of the materials, along with the low cost of processing and the high efficiency of the devices makes PSCs the most promising photovoltaic cells to enter the market in the near future [11-13].

The first PSCs were developed by Miyasaka group in 2009. In these devices, $(CH_3NH_3)PbBr_3$ and $(CH_3NH_3)PbI_3$ were used as sensitizers instead of N719 dye in DSC, the resulting cells give PCEs of 2.2% and 3.8%, respectively [14]. In 2011, Im *et al.* employed a similar structure using 2-3 nm sized perovskite $(CH_3NH_3)PbI_3$ nanocrystal sensitized on TiO_2 and obtained 6.5% in PCE[15]. The main problem of the cells is that they were unstable in the liquid electrolyte and lasted only a few minutes. The first all-solid-state PSC was reported by Kim *et al.* in 2012. In the device, the liquid electrolyte was replaced by a hole transport material (HTM) and a PCE of 9.7% with a remarkable stability was obtained [16]. After this breakthrough, PSCs have attained tremendous developments with a certified PCE up to 25.2% [17] . This article reviews structural evolution of PSCs as well as development in fabrication methods.

3. STRUCTURAL EVOLUTION OF PSCS

Figure 3 illustrates four different architectures of PSCs: sensitization structure, meso-superstructure, mesoscopic structure, and planar structure [18]. The two latter architectures are the most commonly studied.

In the sensitization structure, perovskite is coated onto the TiO_2 surface in a nano-dot form (this structure is similar to DSC but used perovskite instead of dye) [16]; in meso-superstructure, a thin perovskite layer is formed on the Al_2O_3 surface. One

challenge in the fabrication of both these structures involves the full infiltration of HTM in the pores of the mesoporous layer, and the devices usually suffer from the low poor filling, leading to low performance.

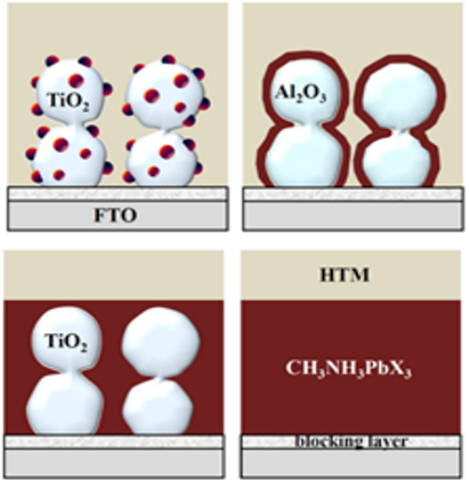

Figure 3. *Structural progress in PSCs.*

Subsequently, the mesoscopic structure (also called pillared structure) of PSCs has been developed, in which the pores of the mesoporous oxide film are penetrated with perovskite, and the HTM is coated on top of a thin capping perovskite layer. Generally, the compact TiO_2 layer is used to prevent the direct contact of the HTM or perovskite with the TCO, the TiO_2 mesoporous acts as the electron transport, perovskite is the light harvester and a layer of HTM is applied to transport holes to the metal contact [19]. The fabrication processes for this type of structure are relatively simple, but it is difficult to avoid the defects and control the morphology of the films.

After that, the planar structure (n-i-p structure), which consists of an electron transport layer, a planar perovskite structure, and a hole transport layer, was constructed. In this architecture, the mesoporous layer is omitted because perovskite has ambipolar properties and is able to transport electrons and holes. Recently, the inverted structure (p-i-n structure) PSCs, where the order of electron and hole transport layer are reversed, have been reported [20-22]. The planar structures have the advantage of high uniform films and better contact between each layer, but a high vacuum technique is required, which causes the increase in fabrication cost.

4. FABRICATION METHODS

Several techniques have been developed to fabricate PSCs, including one-step deposition, two-step sequential deposition, vapor deposition, and vapor-assisted solution process[18].

4.1 One-step deposition

One-step deposition technique is the simplest method to fabricate the active perovskite layer. In this method, both inorganic (*e.g.,* PbX_2, X=Cl, Br, I) and organic (*e.g.,* MAI) materials are included and dissolved in the same solution using polar organic solvents (*e.g., γ*-butyrolactone, *N,N*-dimethylformamide, dimethylsulfoxide) or a mixture of them. The precursor solution is then spin-coated or drop-casted on prepared substrate. A subsequent thermal annealing is required to complete the reaction between organic and inorganic materials [16].

4.2 Two-step sequential deposition

Two-step sequential deposition method was first introduced by the Grätzel group [23]. In this method, a PbX_2 precursor solution is spin-coated on the substrate, and then the deposited film is dipped into MAI solution. By using the sequential deposition technique, the pore-filling of perovskite in the mesoporous TiO_2 considerably increases and the defects of the device lessen due to the *in-situ* growth process [23, 24].

4.3 Vapor deposition

Vapor deposition technique is used to fabricate planar PSCs, first introduced by the Snaith group. This method involves the deposition of two separate sources of organic and inorganic materials. The perovskite film is formed directly on the substrate with high purity and less structural defects [19].

4.4 Vapor-assisted solution process

Vapor-assisted solution technique was proposed by Chen *et al.* as a novel approach

to fabricate planar PSCs [25]. Firstly, the inorganic precursor (*e.g.,* PbX_2) is deposited onto the substrate by a solution process, and then the prepared film is treated with an organic vapor source (*e.g.,* MAI). A high-quality perovskite film can be obtained with remarkable grain size up to microscale.

5. REMAINING CHALLENGE

PSCs have emerged as promising candidates in the field of photovoltaic devices due to their high-power conversion efficiency, comparatively low cost and facile fabrication processes. Despite many advantages, a critical issue that still remains to date is the poor stability of the devices when exposed to the environment. To be more specific, a normal Perovskite solar cell has lifetime ranges from a few weeks to months, which is much shorter than a Silicon counterpart [26]. The main reason being that Perovskite material is easily decomposed under external factors such as moisture, light, oxygen and temperature [27-29] . In addition to that, the degradation caused by the electron transport layer, hole transport layer and electrodes has been reported [30-32]. Extensive efforts need to be conducted to construct PSCs using more stable materials to achieve longer lifetime for practical application in the future.

6. SUMMARY AND OUTLOOK

In this article, an overview of the perovskite materials, PSCs architectures and the most common fabrication processes was introduced. The remaining challenge of PSCs related to long-term stability of devices was also discussed. Further research on interfacial engineering and encapsulation techniques should be focused on the commercialization of PSCs in the future.

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