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Paper Authors

Shyamal Datta, Subhasis Roy



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A mini review of recent strategies towards stable nano-structure perovskite solar cell fabrication

Shyamal Datta, Subhasis Roy*

Department of Chemical Engineering, University of Calcutta, 92 A. P. C. Road, Kolkata 700009, India

*Corresponding author's email: srchemengg@caluniv.ac.in

Abstract— Organic-inorganic perovskite solar cells (PSC) are drawing interest towards photovoltaic device fabrications due to low raw materials cost, easy room temperature fabrications, and exhibiting excellent tunable optoelectronic properties. Power conversion efficiency increased dramatically in the last few years despite challenges like instability in moisture and high ambient temperature conditions. However, techniques employed like encapsulation used to reduce perovskite degradation rate, long-term stability still an issue for commercial scale-up. Most of the perovskite materials, more precisely halide perovskites, are affected by the ambient humid conditions. In this present study, we explore the recent development of different strategies to fabricate moisture-resistant stable perovskite solar cell fabrication. This review discusses the structural influence on the stability of PSC.

Keywords: Perovskite, Stability, Degradation, solar cells

1. INTRODUCTION

The enhancement and development of renewable energy have attained much more attention due to a continuous increase in energy demand. Comparing with any other renewable energy sources, solar energy is abundantly available and comparatively cheap than traditional energy sources. Nanotechnology is a vast research area and has a wider application, including solar cells where nanomaterials are widely used for rapid development in photovoltaics [1].

Among the third generation solar cells, perovskite solar cells' efficiency improves from ~3% to ~22%, in a brief period (less than ten years). Dye-sensitized solar cells and organic solar cells are among the third generation solar cells but do not achieve the performance like perovskite devices [2].

The first photochemical reaction was found by the French physicist Becquerel in 1839. Production of current by the application of

radiation of sunlight was discovered by British scientist Adams [3]. In 1883, the first semiconductor solar cell was successfully prepared by Fritt's using a very thin layer of gold with germanium coating, though the efficiency was abysmal (~1%). In the year 1954, Pearson led Bell labs to develop crystalline solar cells with a 4.5% efficiency started a new chapter in photovoltaics [4].

Due to polycrystalline structure and grain boundaries (GB), two scientist groups discovered that it might improve the PCE of perovskite solar cells [5,6]. Yang's group reported recombination of the carrier near the grain boundaries can be minimized by forming PbI_2 near grain boundaries, and grain passivation can also improve the PCE. But an excessive accumulation of Pb may be caused degradation of perovskite materials as controlling the amount of Pb is very difficult. Seko's group reported that the presence of PbI_2 in perovskite material reduces the hysteresis effect, ionic migration [7]. Although perovskite solar cells have attained high efficiency within a short period, it still faces some obstacles such as ionic migration [8-10], hysteresis [11-12], heavy metal lead [13-16], light soaking [17], etc.

Perovskite materials degrade faster in humid ambient due to Pb salt and ammonium precursors [18-20]. Some minor factors, i.e., phase transition [21-23], thermal decomposition [24,25], and bias induced ion migration [26], leads to degrading the perovskite materials. As a result, the stability of the PSC is a vital issue compared to other PV technology. Many reviews have been published based on the degradation mechanism of PSC and strategies to improve the PCE. But moisture-stable nanostructured PSC is quite a new approach. In this review, we are going to demonstrate the structural influence on the stability of PSC. The major problems associated with PSC's stability and development of moisture tolerance in perovskite materials by adjustment of crystal structure, interface modification by using low dimensional perovskite, i.e., 0D, 2D, and quasi-2D and facile hydrophobic passivation method.

2. Effect on the stability of the perovskite solar cell by structure alteration

2.1 Mesoporous structure

High porosity and large precise surface area (up to $10^3 \text{ m}^2/\text{s}$) are the main advantages of mesoporous materials. It is present in perovskite in the form of metal oxide to increase the efficiency of the device. As shown in fig.4, the perovskite device

architecture consists of an electron transport layer, light-absorbing material like perovskite, hole transport layer, and metal electrodes. TiO_2 is very commonly used as the mesoporous material as it permits the nanocrystal to penetrate through the pores of TiO_2 to form an absorbing layer. Besides, TiO_2 also helps to transport electrons, preventing the recombination of electron-hole pairs, thus improving the device's efficiency. The holes are generated in the perovskite absorbing layer, hole transport materials block the electrons and collected the generated holes, and transfers charges via metal electrodes. Spiro-OMeTAD is the most commonly used hole transport material in PSCs.

The advantages of using this kind of structure are (i) less recombination tendency between electron and holes and (ii) sufficient diffusion length to collect electrons and holes virtually [35]. Qiu et al. reported that all-solid-state 1D perovskite solar cell gives PCE near about 4.87% and open-circuit voltage of 0.82V. He has also observed that the PCE has increased linearly and then decreased with increasing the diffusion length [36]. MAPbI_3 solar cell with mesoporous TiO_2 nanostructure scaffolding reported a FF of 0.62 and PCE

9.7% by Kim et al. The efficiency of PSCs can be improved significantly by the two-step solution deposition method [37,38]. Al_2O_3 can replace the role of TiO_2 , but it has some drawbacks, (i) Al_2O_3 acts only as a supportive layer in PSC (ii) the electrons are not absorbed by the conduction band of Al_2O_3 but directly transmitted to FTO conductive layer. They were thus decreasing the efficiency of the perovskite solar cells. Lee et al. observed V_{oc} of 980mV, FF of 0.63, and PCE of 10.9% when they used Al_2O_3 as a supporting material to manufacture MAPbI_3 PSCs. After modification of the process, conversion efficiency increased to 12.3% [39].

2.2. Simple Planar Heterojunction Structured Solar Cells

It can be observed, the mesoporous metal oxide structure is removed, which makes a significant difference from mesoporous structure solar cells. The device fabrication attracts more interest due to the easy low-temperature fabrication procedure with high power conversion efficiency PCE. As the metal oxide portion is being removed and perovskite material is sandwiched between electron transport material (ETM) and hole transport material (HTM), there forms an interface between ETM and perovskite;

thus, the efficient separation of an electron can be possible. Similarly, another one interfacial layer is formed between perovskite material and HTM, and hole separation can also occur effectively. According to Snaith's group, they made a heterojunction structured perovskite solar cell by FTO/ TiO₂/MAPbI₂Cl/spiro-OMeTAD/Ag and obtained an efficiency of 1.8%. As the efficiency value does not give a satisfactory result, these same groups designed a series of solar cells. They achieved an open circuit voltage of 1.03 volt under the optimized situation, an efficiency of 15.7%, and a fill factor of 0.749 [36].

Wang et al. reported that they achieved an efficiency of 15 % for CH₃NH₃PbI₃ and 18 % for MA_{0.7}FA_{0.3}PbI_{3-x}Cl_x and a fill factor of 0.80 when used very high-quality lead halide crystal as a precursor solution. They achieved an excellent performance of PSC by optimizing the precursor solution. The advantage of using these precursor solutions are, (i) the rapid growth of perovskite crystal, thereby improves the perovskite light absorbance's characteristics, a significant reduction in crystal defect, and also reduces the tendency of charge recombination. (ii) increase the tendency of charge collection and transportation [40].

Zhou et al. used yttrium-doped TiO₂ in his experiment as an electron transport material and observed that the electron's mobility increased rapidly. Actually, by tuning the humidity, the defect density of PSC film is reduced significantly, and lead chloride and methylammonium iodide form the perovskite film. The outcome possesses excellent PCE improvement with a notable 19.3% and a high open-circuit voltage [41].

2.3. Inverted structure perovskite solar cells

Inverted structure perovskite device looks similar to organic solar cells' structure at the beginning [42]. Phenyl-C61-butyric acid methyl ester (PCBM) is widely used as an electron transport layer and poly-styrene sulfonic acid (PEDOT: PSS) or NiO plays an essential role as a p-type hole transport layer. Yang Bai et al. reported an inverted structure PSC having a nanocrystal layer of NiO (relatively rough) as a hole transport layer and normal PCBM as electron transport material [43]. It was observed that to form a stable perovskite layer, the rough nature of NiO is suitable. There is one more advantage of using a rough layer that makes a favorable condition for hole extraction. Now focusing on electron transport material, it is required to form a uniform PCBM layer where film defects are negligible. As a result, undesirable electron-hole

recombination between the perovskite layer and the metal electrode is minimized.

The solution is to modify the technique of manufacturing PCBM. In general, PCBM layer is made by a spin-coating process, and to optimize the spin-coating method, speed and precursor solution must be changed. But the formation of an excellent quality thin film of PCBM over the rough surface is quite challenging due to the less viscous property of the PCBM solution. Yang Bai et al. also reported that the small addition of polystyrene (PS) 1.5 wt% into the PCBM solution improves the property of the thin film. It also reduces the tendency of recombination between electron-hole in the electron transport layer. This feature contributes to the enhancement of PCE from 9.56% to 10.68% [44].

3. Conclusions and outlook

The degradation of perovskite materials under humid ambient conditions is going through continuous research and attracts more attention as poor understanding of chemical stability needs to be explored more. Improving water retention ability by encapsulation or proper interfacial engineering must be employed to address PSC's stability. Several factors, including

modification of HTM/ETM layer, layer architecture, compositional, and crystal structure engineering, modulate PSC materials' chemical stability. Encapsulation or coating is the cheapest, versatile, and easy to do, unlike interfacial modifications that impact the solar cells' life span due to the interfacial doping. The researchers are now more focused on developing new perovskite structured nanomaterials that have inherent water stability without showing other undesirable side effects or compromising the cell's efficiency.

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