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Review Article

Charge-transport-layer-free Perovskite Solar Cells Exceed 16% Efficiency

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Abstract

Charge-transport-layer-free (CTL-free) perovskite solar cells have attracted much interest due to their simple device architecture and facile fabrication methods. However, the low efficiency hampers their practical applications. Most recently, a perovskite hetero-bilayer structure was introduced as absorbing layer and embedded between electrodes to form solar cells with efficiency surpassing 16%, which sets the record for all CTL-free perovskite solar cells. Here, we highlighted several main points in this work, as well as propose perspective for future CTL-free solar cell investigations.

Keywords: Charge-transport-layer-free (CTL-free); Perovskite Solar Cells (PSC); Hole Transport Layer (HTL)

Introduction

Perovskite solar cells (PSC) have been widely thought as promising candidates for next generation of photovoltaics due to their rapid development of power conversion efficiency (PCE) [1,2]. However, conventional PSCs typically consists of five main layers [3], viz., electron transport layer (ETL) and hole transport layer (HTL) for charge carrier transportation, transparent conductive oxide and metal as electrode to collect and extract charges, as well as perovskite absorbing layer for photon absorption. However, the preparation of charge transport materials/layers (CTL) is generally complex and require high energy consumption, which might raise the overall cell cost and deteriorate device stabilities [4]. The intrinsic bipolar-transporting and ionic features of perovskite materials make the employment of CTLs unnecessary [5]. Nevertheless, the PCE of CTL-free PSCs are far behind their normal counterparts due to the worse charge separation and extraction performance. Most recently, Yang., *et al*. proposed and fabricated successfully a "perovskite hetero-bilayer" solar cell, with the champion cell demonstrates a PCE of over 16.57% under reverse bias conditions, which sets the record for the highest efficiency of CTL-free PSCs [6].

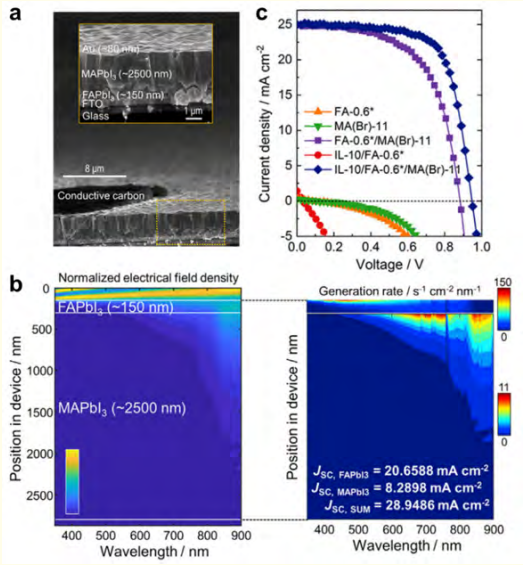

Figure 1: (a) Cross-sectional SEM images of the optimized CTL-free PSC. Inset shows the zoomed image. (b) Normalized electric field intensity distribution (left) and corresponding exciton generation rate distribution (right), determined from the transfer matrix model. (c) J-V curves of the PSCs based on different configurations. Adopted with permission from [6].

To obtain efficient CTL-free devices, the bottom substrate was first modified via an ionic liquid (IL), 1-butyl-3-methylimidazolium tetraflfluoroborate, to tune the substrate energy level and improve its light transmission. Double layers of perovskite materials, $FAPbI_3$ and $MAPbI_3$, were spin coated subsequently. A dynamic spin coating method was further developed to prepare perovskite films with no thickness upper limits, which allow the authors to finely optimize the film opto-electronic properties. A metal electrode (e.g., gold) layer was then deposited on top of perovskite layer via thermal evaporation. The above cell fabrication process could significantly reduce the production time and cost. The cross-sectional structure of CTL-free PSC is illustrated in figure 1a. Note that the ultrathin $FAPbI_3$ layer (~150 nm) contributed to most photon absorption and generate 20.66 mA/cm^2 of photocurrent density, as unraveled by the transfer matrix model (Figure 1b), while the much thick $MAPbI_3$ (~2500 nm) only generate photocurrent of 8.29 mA/cm^2, in accordance with conventional PSC results. Nevertheless, the deposition of $MAPbI_3$ is necessary to achieve efficient solar cell devices. PSCs of single $FAPbI_3$ and $MAPbI_3$ were also fabricated, which reveals extremely low forward-onset voltage and PCE of less than 0.01% (Figure 1c), indicating poor charge carrier separation and extraction. On the other hand, strong built-in electric field was measured in perovskite hetero-bilayer films, which is assumed to be located at the interface of two perovskite layers (Figure 1b). Moreover, ultraviolet photoelectron spectroscopy (UPS) was employed to reveal the PSC energy level alignment (Figure 2a).

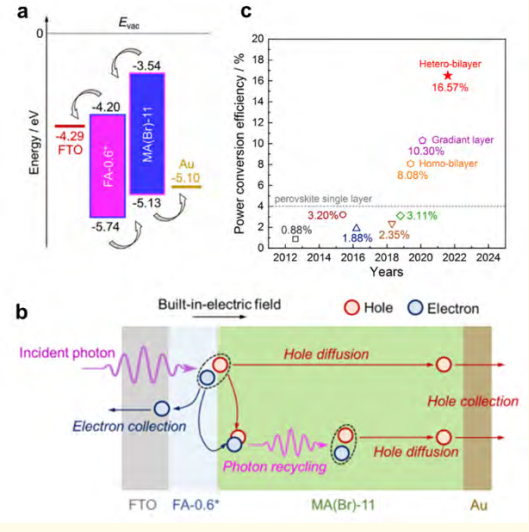

Figure 2: (a) Energy level alignment of the CTL-free PSC, derived from UPS results. (b) Working mechanism of CTL-free PSC. (c) Efficiency chart of CTL-free PSC. Adopted with permission from [6].

Based on the above results, the working mechanism of CTL-free PSCs were proposed and schematically demonstrated in figure 2b. Upon light absorption, the photogenerated electron-hole pairs will get separated and swept into opposite directions due to the presence of strong electric fields at the heterojunction region. Comparing to electron collection process, holes need to diffuse much longer distance along the thick $MAPbI_3$ layer. Thanks to the long diffusion length of perovskite materials and photon recycling effects [7,8], much holes may reach the positive metal electrode to get extracted. The resultant CTL-free perovskite hetero-bilayer solar cells obtain the best PCE of 16.57%, which is the first work demonstrating CTL-free PSCs with efficiency over 15% (Figure 2c).

Conclusions

Despite the tremendous progress achieved in CTL-free PSCs, there still remains several major issues. First, their efficiencies are still far behind conventional PSCs (~25.7%). Additionally, the stability/lifetime of PSCs fabricated in this work was not evaluated, which must be investigated further before they can enter into markets [9]. We anticipate more reports on the research of CTL-free PSCs coming in the near future.

Acknowledgements

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Conflict of Interest

There is no conflict of interest to declare.

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