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# Low Temperature Solution Processable n-i-p Perovskite Solar Cell

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**Abstract**

**Recently, the perovskite solar cells draw lots of attentions because of low cost, solution-processable and promising high efficiency. The power conversion efficiency (PCE) is rapidly reached to a certified value of 20.1%. However, the conventional electron transport layer (ETL) of the device needs to be sintered over 500°C which is high energy-consumption process and cannot use on flexible substrate. Therefore, many research groups endeavor to develop low-temperature solution processable electron transport material in perovskite solar cells. In this review, we present systematic and critical discussions on the evolution of perovskite solar cells from meso-superstructure solar cells (MSSCs) to low-temperature solution processed planar heterojunction (PHJ) perovskite solar cells. This review will provide a guideline for the fabrication of high PCE perovskite solar cell using solution process at temperature of 150°C or under, which has potential to achieve large scale fabrication by roll-to-roll technique for commercial products in near future.**

**Keywords: perovskite solar cell, electron transport, hole transport, meso-superstructure, planar heterojunction, low-temperature, solution**

## 1. Introduction

In human history, energy always plays an important role in the development of industries and societies. However, the limited reserve of fossil fuel and the risk of radiation leakage of nuclear power urge scientists to find sustainably alternative energy. Solar power is a promising alternative energy because it is inexhaustible and pollution-free. Recently, the organometallic trihalide perovskite solar cell has drawn a lot of attentions by the advantages of tunable absorption range, high light absorption coefficient, extremely high PCE of certified 20.1% and low-temperature solution processability (<150°C). The organometallic trihalide perovskite materials have the chemical formula of $ABX_3$ (A=organic cation; B=metal cation; X=halide, Cl, Br or I). The optical and electrical properties can be controlled by changing the composition of A, B or X. For example, by substituting part of I by Cl, the mixed halide $CH_3NH_3PbI_{3-x}Cl_x$ perovskite has longer charge carriers diffusion length (over 1 μm) than the triiodide $CH_3NH_3PbI_3$ (about 100nm)[1]. In addition, by replacing the organic cation methylammonium $(CH_3NH_3)^+$ of $CH_3NH_3PbI_3$ with a larger formamidinium $(CH(NH_2)_2)^+$, the band gap can be tuned from 1.57 eV to 1.48 eV, which shows the structural-dependent property of the organometallic trihalide perovskite materials[2].

The PCE of perovskite solar cell dramatically surged up from 3.81% to 20.1% in recent six years. In 2009, T. Miyasaka *et al*. first utilized the $CH_3NH_3PbI_3$ and $CH_3NH_3PbBr_3$ as the sensitizers in the dye sensitized solar cells (DSSCs) technology[3]. The device is composed with a $TiO_2$ mesoporous structure on a compact $TiO_2$ layer. The $TiO_2$ adsorbs the perovskite material and extracts out electrons at the same time. However, the device only achieved the PCE of 3.81%. In 2011, N.-G. Park *et al*. demonstrated a perovskite quantum dot-sensitized solar cell[4] achieving the PCE of 6.20%, which outperformed the standard N719 dye-sensitized solar cell with much higher current density. However, the liquid electrolyte used here could easily dissolve the perovskite material and decrease the lifetime and stability of the devices. To solve this problem, N.-G. Park *et al*. in 2012 developed an all sold-state perovskite-sensitized solar cell by replacing the liquid electrolyte with a small molecule 2,2',7,7'-Tetrakis-(N,N-di-4-methoxyphenylamino)-9,9'-spirobifluorene (spiro-OMeTAD) as a hole transport material[5]. The PCE of the devices reached to 9.7% with a long term stability over 500 hours.

As stated above, the n-type of $TiO_2$ mesoporous layer in "perovskite sensitized solar cell" can extract and transport electrons from perovskite material. However, H. J. Snaith *et al*. in 2012 replaced the $TiO_2$ mesoporous structure with $Al_2O_3$ mesoporous structure to fabricate a new device architecture with a PCE of 10.9% and $V_{oc}$ of 1.1V[6]. Unlike $TiO_2$, the high energy band gap of $Al_2O_3$ (about 7 to 9 eV) restricts the transport of photon-induced electrons through $Al_2O_3$ mesoporous structure. The electrons can transport through the perovskite material itself to the compact $TiO_2$ layer and the $Al_2O_3$ is only served as a scaffold to adsorb the perovskite material. This type of solar cell with insulating mesoporous scaffold which isn't involved in the electron transporting is called "meso-superstructure solar cells (MSSCs)". The MSSCs verifies that the n-type mesoporous material is not necessary in the perovskite based solar cell. Further remove the $TiO_2$ or $Al_2O_3$ mesoporous layer and leave only the compact $TiO_2$ layer to serve as ETL that creates the "planar heterojunction (PHJ) perovskite solar cells".

This kind of solar cells significantly simplified the complicated process of fabricating the mesoporous layer without sacrificing the PCE.

Although the PCE of perovskite based solar cell has already surpassed the other thin film solar cells, the high-temperature sintering of high quality metal oxide ETL can damage the flexible substrate. To date, many research groups are still working on the development of new low-temperature processable materials or new device architectures toward the roll-to-roll process which provides an easy and fast method to scale up the fabrication of the devices. For example, in 2014, H. J. Snaith *et al*. developed a new method by using $TiO_2$ nanoparticles ($TiO_2$-NPs) to fabricate the compact $TiO_2$ layer with only 150$^oC$ process temperature. The MSSCs fabricated with this method showed a high PCE of 15.9%[7]. In addition, Y. Yang *et al*. utilized doping yttrium into $TiO_2$ nanoparticles to improve the conductivity of compact $TiO_2$ layer. Using other strategies such as using modifying the surface energy state of ITO by polyethylenimine (PEIE) and fabricating the perovskite layer under controlled humidity, the device achieved a PCE of 19.3%[8], which was the highest record represented in the literature.

In this review, we focus on the recent developments of low-temperature solution processed ETLs in MSSCs and n-i-p PHJ perovskite solar cells which have processing temperature at or under 150$^oC$. Different electron transport materials will be reviewed in detail. Finally, we conclude the review and provide some recommendations for the future development of low-temperature solution processed perovskite solar cells.

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