

Interface Manipulation in Solution Processed Hybrid Perovskite Solar Cells

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Abstract: Hybrid organo-metal halide perovskite solar cells (PSCs) is one of the most promising candidates for next generation photovoltaic device primarily due to their high efficiency, printability and low cost. Interface Engineering know-hows in advancing the organic polymer solar cell (OPV) technology have also been successfully applied in hybrid perovskite solar cell research. This presentation will be on (a) Perovskite/HTL interface tuning in PSCs; and (b) Efforts on novel solution processed tin oxide nanostructures as electron transport layer for PSCs. © 2019 The Author(s)

Hybrid organo-metal halide perovskite solar cells (PSCs) and organic polymer solar cells (OPVs) are both promising candidates for next generation photovoltaic device primarily due to their high efficiency, printability and low cost. PSCs have exhibited externally verified power conversion efficiencies (PCE) exceeding 23% outclass from 3.8% in 2009. Interface Engineering has played significant role in advancing the organic polymer solar cell technology, including inverted solar cell structure, tandem polymer solar cells etc.^[1] Many of the know-hows have also been successfully applied in hybrid perovskite solar cell research. This paper is a summary of a few recent works on (a) Perovskite/HTL interface tuning in PSCs; and (b) Efforts on novel solution processed tin oxide nanostructures as electron transport layer for PSCs.

1. Perovskite/HTL interface manipulation

The astonishing progress in PSCs is strongly related to the device engineering that manipulates the perovskite morphology and optimize interfacial nature function. The film morphologies of the perovskite film - including grain boundaries (GBs), size of the grains & the distribution, film coverage, and crystal property, play crucial roles on the PSC device performance. Electronic trap states in PSCs are typically determined by the GBs, and are tunable based on the material compositions and processing conditions. These traps can enhance non-radiative recombination and reduce seriously charge carrier lifetime and photoluminescence (PL) yield. To obtain the high quality perovskite films, many approaches have been practiced. We have explored the application of hydrophobic organic semiconductors in PSCs to simultaneously enhancing the device efficiency and stability.

We incorporated (a) non-fullerene acceptor IT-M (Fig. 1a), and (b) p-type π -conjugated donor polymer PBDB-T (Fig. 1b) into the anti-solvent process of perovskite film formation.^{[2],[3]} The hydrophobic organic semiconductors effectively passivate the trap states of the mixed perovskite ($\text{Cs}_{0.05}(\text{MA}_{0.17}\text{FA}_{0.83})_{0.95}\text{Pb}(\text{I}_{0.83}\text{Br}_{0.17})_3$ - Fig. 1c) film, improves charge-transport, lead to high-efficiency and significantly improved device stability. The incorporation of the two organic semiconductor species were conducted during the anti-solvent

film formation process of perovskite film. Chlorobenzenen was used as anti-solvent for perovskite formation.

The organic semiconductor molecules are believed to partially incorporated into the gran boundary of perovskite crystals, as illustrated in Fig. 1d. Fig. 1e shows the J-V curves of the PSC devices with different amount of IT-M in antisolvent. The control device shows a PCE of 18.69%. 0.2 mg/ml IT-M concentration in antisolvent leads to 20.5% PCE with a high fill factor of 81% - one of the highest reported in planar n-i-p PSCs. Fig. 1F shows that we can achieve similar effect of perovskite surface passivation using conjugated p-type polymer (PBDB-T). The reference perovskite device without PBDB-T passivation gives PCE of 17.28%, with

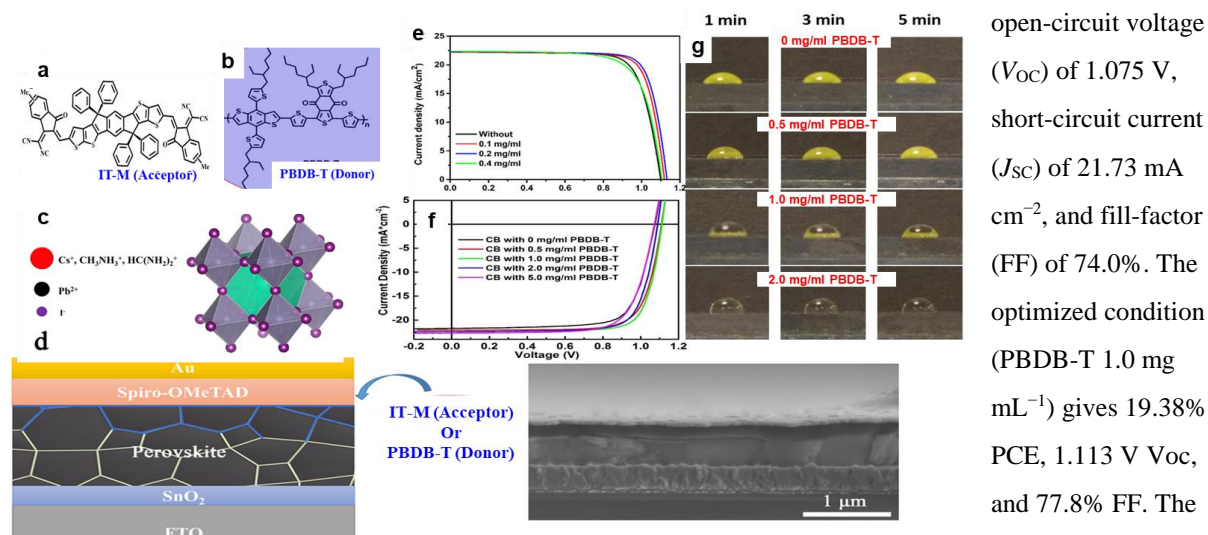


Figure 1. Passivation of perovskite film by (a) IT-M acceptor molecule, (b) PBDB-T donor polymer in (c) mixed cation perovskite, through anti-solvent approach (d); PSC J-V curves with different IT-M concentration (e), and PBDB-T concentration (f). The cross-section photos of a water drop on perovskite films passivated by different PBDB-T concentration (0, 0.5, 1.0, and 2.0 mg/mL).

open-circuit voltage (V_{OC}) of 1.075 V, short-circuit current (J_{SC}) of 21.73 mA cm^{-2} , and fill-factor (FF) of 74.0%. The optimized condition (PBDB-T 1.0 mg mL^{-1}) gives 19.38% PCE, 1.113 V V_{OC} , and 77.8% FF. The polymer passivated perovskite film become much better hydrophobic. As seen in Fig. 1g, 1.0 mg/mL PBDB-T

can already effectively prevent perovskite film from being dissolved in water, and 2.0 mg/mL is even better.

2. Novel solution processed tin oxide SnO_2 nanostructures as electron transport layer for PSCs

We synthesized small size (3 – 5 nm) SnO_2 quantum dots^[4], and investigated its application in PSC. It's found that reducing the size of QD significantly reduced hysteresis, and annealing temperature in n-i-p planar PSC. Very promising results were achieved - 20.8% PCE in rigid, 17% PCE in flexible PSC, and 19.8% in 1 cm^2 PSC. We also achieved chemically pure SnO_2 nanoparticles via facile solid-state ball-milling synthesis^[5], which will be reported in the presentation.

In summary, we have demonstrated passivation of perovskite film surface with organic molecules – both acceptor and donor molecules – is an effective approach in boosting efficiency and stability. In addition, QD and ball-milling are two novel approach for effective ETL for PSCs.

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