

## New Electron Extraction Layer for Perovskite Solar Cells

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### Abstract

A low-cost, easy to synthesise, solution processable, environmental friendly dye N,N'-dipentyl-3,4,9,10-perylenedicarboximide (NNDPPDI) was employed as an alternative electron extraction layer (EEL) for the commonly used fullerene EEL, PCBM in inverted planar perovskite solar cells (IPSCs). The IPSCs with NNDPPDI demonstrated a PCE of 10.4%, when mixed halide (iodide and bromide) lead perovskite was employed as the active layer. Though this efficiency is comparatively lower than the devices with PCBM as EEL, the cost effectiveness, environmental friendliness, easy processability and derivatization make NNDPPDI to be considered as an alternative for PCBM.

### 1. Introduction

Demand for green energy is increasing day by day with the adverse effects of conventional energy sources on the environment. Solar energy is available abundantly and if it can be utilized efficiently, all of world's energy needs can be met with solar energy alone. Photovoltaics (PV) is an interesting area developing at a fast pace, the latest milestone of which is perovskite solar cells. Perovskite solar cells have achieved high efficiencies [1] comparable to commercial Si solar cells [2] but lacks reproducibility, stability and use of toxic materials limits their commercialization. Perovskite solar cells can be classified into mesoscopic and planar, where planar type is favorable due to their easy processability. In inverted planar structure, the structure is p-i-n with PEDOT:PSS as the commonly used hole extraction layer and PCBM as the commonly used electron extraction layer (EEL) [3]. Since PCBM is a fullerene derivative, it has high cost, complex synthesis steps, non-eco-friendly nature and limited possibilities of derivatization [4]. Only a few studies have been done for finding alternate EELs. Here, we studied the possibility of employing a low-cost dye called N,N'-dipentyl-3,4,9,10-perylenedicarboximide (NNDPPDI) as an environmental friendly EEL with easy processability as an alternative to PCBM in IPSCs.

### 2. Experimental

The device fabrication was similar to that of Boopathi et al. [5] with slight modifications in active layer and NNDPPDI was used instead of PCBM. Perovskite layer was

deposited by a two-step spin coating similar to the procedure

mentioned in [5]. The second layer consisted of MAI and small amounts of MABr in order to fabricate  $\text{MAPbI}_{3-x}\text{Br}_x$  perovskite. We used three different MAI:MABr ratios – 1.5:1.5, 2.0:1.0, 2.5:0.5. The EEL was fabricated from a 1 wt% solution of NNDPPDI in Chlorobenzene spun at 4000 rpm for 30s followed by annealing at 100 °C for 30 min. Sequential thermal evaporation of  $\text{C}_{60}$  (30 nm), BCP (10 nm) and Al (100 nm) was done to complete the device (Figure 1a).

### 3. Results and Discussion

The energy level match is an important factor in perovskite solar cells. The LUMO of NNDPPDI was higher than that of PCBM and so the energy level of the perovskite had to be tailored so as to match with that of our EEL. Use of  $\text{MAPbI}_3$  as active layer resulted in negligible device performance due to energy level mismatch. So, we employed the mixed halide approach to incorporate  $\text{Br}^-$  to shift the LUMO of perovskite by increasing bandgap so as to match with NNDPPDI (Figure 1b). Absorption onset was blue-shifted with increasing the MABr concentration and a corresponding increase in bandgap was also observed. XRD studies (Figure 2a) revealed that the crystal structure changes from cubic to tetragonal with the addition of MABr. We calculated charge carrier mobility of NNDPPDI from dark J-V characteristics of electron-only devices made with EELs. The J-V parameters were fitted with SCLC equation, to calculate the mobility (Figure 2b) and it was revealed that our material NNDPPDI showed reasonable electron mobility to be employed as an EEL.

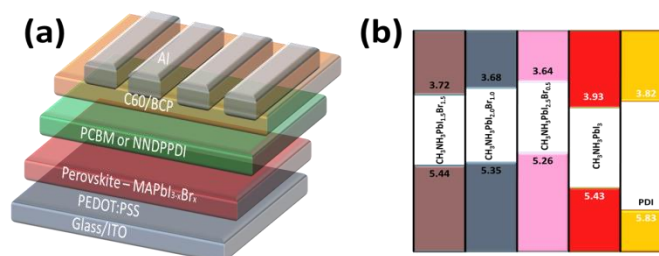


Fig. 1 a) Device architecture, b) Energy level diagram (The numbers in subscripts represent the weight percent ratios of I and Br, not the atomic concentrations).

The devices with NNDPPDI showed a  $V_{oc}$  of 0.93 V,  $J_{sc}$  of 18.12 mA cm<sup>-2</sup>, (FF) of 61.49%, and a PCE of 10.35% respectively, in the reverse scan (Figure 3a).

We further investigated the recombination mechanisms by studying the J-V behavior of our devices under different sun illumination. The logarithmic plot of light intensity versus

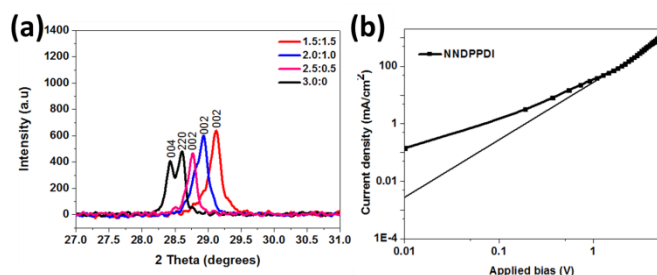


Fig 2 a) XRD of different ratios of MAI:MABr, b) Logarithmic plot of  $V$  vs  $J_{sc}$  of electron-only devices fitted with SCLC equation.

$J_{sc}$  of the devices with NNDPPDI as EEL showed slope closer to 1 (Figure 3b). NNDPPDI based devices showed a slope value of 0.98. A space-charge limited solar cell exhibits a value close to 0.75 [6].

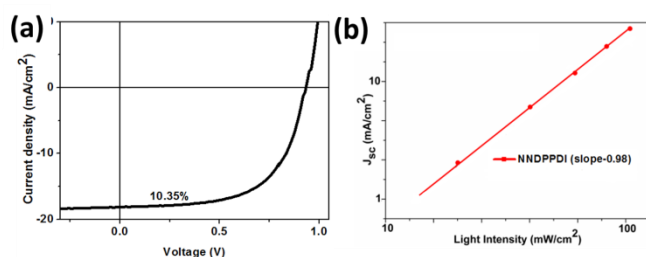


Fig 3 a) J-V characteristics of IPPSCs with PCBM and NNDPPDI as EELs, b) Logarithmic plot of light intensity vs  $J_{sc}$

A value closer to 1 shows that the bimolecular recombination is completely absent. In our case, NNDPPDI based devices showed a value closer to 1 which implies balanced charge carrier mobility, no substantial space-charge buildup, a predominance of monomolecular recombination (due to defects/traps) and an absence of bimolecular recombination leading to efficient charge extraction.

#### 4. Conclusions

A cheap, commercially available, easy to make, solution processable organic material has been successfully employed as an alternative to fullerene derivative PCBM in inverted perovskite solar cells. This study is believed to open new possibilities to explore similar materials for replacing fullerene in perovskite solar cells.

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