Performance Enhancement of Planar Heterojunction Perovskite Solar Cells by \( n \)-Doping of Electron Transporting Layer

Shin Sung Kim, Seunghwan Bae and Won Ho Jo*  
Advanced Materials for Organic Photovoltaic Lab.  
Department of Materials Science & Engineering, Seoul National University

Introduction

Why Perovskite Solar Cells?

- Large absorption coefficient

Effect of \( n \)-Doping to Fullerene Derivatives

- Easy and low-cost process
- High charge carrier mobility
- Easily tunable optoelectronic properties
- Extremely large exciton diffusion length

Objectives

- To increase the electric conductivity of PCBM by \( n \)-doping
- To enhance the photovoltaic performance of planar heterojunction perovskite solar cells by \( n \)-doping to the electron transporting layer (ETL)
- To examine the effect of doping according to the PCBM layer thickness

Results

Synthesis of Dopant and Characterization of Doping

- Synthesis of DMBI
- \( ^1 \)H NMR
- Absorption spectra

Photovoltaic Performance of Device with \( n \)-Doped PCBM

- UPS spectra

Device fabrication

- Active layer was formed by spin-coating the perovskite precursor solution (MAI + PbI\(_2\)) in DMSO.
- DMBI and PCBM were dissolved in chloroform for different ratio, and mixed solution was spin-coated to form the \( n \)-doped ETL.

Objectives

- To increase the electric conductivity of PCBM by \( n \)-doping
- To enhance the photovoltaic performance of planar heterojunction perovskite solar cells by \( n \)-doping to the electron transporting layer (ETL)
- To examine the effect of doping according to the PCBM layer thickness

Conclusions

- Addition of DMBI raises the Fermi level of PCBM toward the LUMO energy level, indicative of \( n \)-doping.
- The solar cell device with \( n \)-doped PCBM as electron transporting layer has shown a high PCE of 13.8% with 10% enhanced \( J_{SC} \) of 22.0 mA/cm\(^2\).
- \( n \)-Doping enhances the electric conductivity of PCBM, then facilitate the increase of PCBM layer thickness.
Performance enhancement of planar heterojunction perovskite solar cells by \textit{n}-doping of electron transporting layer

Shin Sung Kim, Seunghwan Bae, Won Ho Jo$^\dagger$

\textit{Department of Materials Science and Engineering, Seoul National University}

Recently, organic-inorganic hybrid perovskite has attracted great attention as a next generation material for solar cell because of its superior intrinsic properties such as extremely long exciton diffusion length, high absorption coefficient, and excellent carrier transport. Most of state-of-the-art perovskite solar cells utilize TiO$_2$ and 2,2’,7,7’-tetrakis(N,N-bis(p-methoxy-phenyl)amino)-9,9’-spirobifluorene as electron and hole transporting materials, respectively. However, since the formation of mesoporous TiO$_2$ layer requires high temperature sintering process, all solution-processible bilayer structure has been investigated as an alternative device structure by several groups. This planar heterojunction structure utilizes commonly PCBM and PEDOT:PSS as electron and hole transporting materials, respectively. In this architecture, sufficiently thick PCBM layer is required to prevent direct contact between perovskite film and metal electrode. However, relatively low electron mobility and low electric conductivity of PCBM may provide a limit to achieve high power conversion efficiency (PCE) of the device with thick PCBM layer. In this study, an \textit{n}-type dopant, 1,3-dimethyl-2-phenyl-2,3-dihydro-1H-benzoimidazole (DMBI), was added into PCBM layer to enhance the electric conductivity of PCBM. Addition of a small amount of DMBI raises the Fermi level of PCBM toward the LUMO energy level, indicative of \textit{n}-doping and an increase of free electrons. As a result, the solar cell device with \textit{n}-doped PCBM as electron transporting layer shows a remarkable enhancement of short-circuit current density ($J_{SC}$) and the PCE. While the device without the dopant exhibits S-shaped curve with a fill factor (FF) of 0.55, the device with 1% doped PCBM shows higher FF of 0.72. Consequently, the doped device have shown a high PCE of 13.8% with 10% enhanced $J_{SC}$ of 22.0 mA/cm$^2$. Particularly, the effect of doping was more prominent when the thickness of PCBM layer was increased.