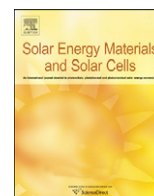




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Influence of n-type chemical doping layer on the performance of organic photovoltaic solar cells

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ABSTRACT

We report the performance improvement of organic solar cell by addition of an n-type chemical doping layer in organic bulk heterojunction device. The power conversion efficiency (PCE) of P3HT and PCBM-71 based polymer solar cells increases by adding a mixture of TCNQ (7,7,8,8-tetracyanoquinodimethane) and LCV (Leucocrystal violet) between active layer and cathode electrode. The PCE of the cell increases by 14% compared to the control cell with Al-only cathode electrode. The device with an organic n-doped layer shows the J_{SC} of 8.88 mA/cm², V_{OC} of 0.51 V, FF of 60.1%, and thus the PCE of 2.72% under AM1.5 illumination of 100 mW/cm².

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1. Introduction

Polymer solar cell is an attractive alternative to silicon based solar cells due to its scalability, low cost, large area, and roll-to-roll printing technology. Roll-to-roll processing is required for low-cost manufacturing of polymer solar cells to compete with other thin film solar cells using amorphous silicon, CdTe, and CIGS. High speed printing at low temperatures can be possible using roll-to-roll coating. The remarkable advancements in cell structure and solution based-materials have been achieved recently [1–7]. And also, in organic photovoltaic devices, the cell parameters such as short-circuit current density (J_{sc}), open-circuit voltage (V_{oc}), and fill factor (FF) are affected by morphology and thickness of active layer, and also by work function of electrodes [8,9]. To enhance the performance of polymer solar cells, cathode modifier such as LiF or Au/LiF is thermally evaporated on the top of active layer before Al deposition [10].

The performance of organic photovoltaic has been limited by short exciton diffusion length, high exciton binding energy, poor exciton dissociation, losses to geminate recombination, and inefficient carrier extraction. On the other hand, chemical doping has been shown to control the position of the Fermi level, and thus to increase the conductivity. Therefore, an addition of chemically doped organic layer can have significant impact on the performance of OPVs [11].

The alkali metals such as Li or Cs are currently used for electron injection to the cathode in OPV. However, these alkali metals should have the high doping ratio for high conductivity, and thus completely change the matrix properties. Furthermore, metal ions can diffuse into the device during growth and operation. Therefore, it is not possible to have well-defined doping profiles. An organic donor that can be used for typical electron transport materials by solution process is not yet available [12].

To obtain high-performance devices, it is critical to realize efficient and balanced injections of holes and electrons to anode and cathode, respectively. The large barrier at the active layer/cathode interface makes electron injection difficult and thus results in a lower conversion efficiency. The common approach for lowering the barrier height is to employ low work function metals such as Ca and Ba as cathode [13–15]. However, these metals are highly reactive and tend to generate quenching sites at the areas near active layer/cathode interface, which are detrimental to the efficiency and stability of devices. And polymeric polyelectrolytes, surfactants, or metal organic compounds that are either spin-coated or blended into the polymer emissive layer can also improve electron injection from active layer to the cathode and hence result in significant performance enhancement [16–19].

In this work, we studied the influence on the cell performance of organic solar cell by addition of n-doped layer, TCNQ (7,7,8,8-tetracyanoquinodimethane) doped with LCV (Leucocrystal violet), between active layer and cathode. We introduced the n-doped layer by solution process and found that n-type doping was confirmed through the analysis of UV/Vis and FTIR spectroscopy. The conversion efficiency of the cell with n-doped layer improves by 14% compared to control device with only Al cathode.

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2. Experimental

We have fabricated the solar cells using P3HT as an electron donor and PCBM-71 as an electron acceptor with and without an n-doped layer. Fig. 1 shows the device and chemical structures of the materials used in this study. We used regioregular P3HT as a p-type semiconducting polymer (Aldrich) and PCBM-71 as an n-type semiconductor (American Dye Source, Inc.). To form n-doped layer, TCNQ (7,7,8,8-tetracyanoquinodimethane) as a host and LCV (Leucocystal violet) as a dopant were used. To have solution process, TCNQ and LCV were prepared with concentration of 0.1 wt% each in acetonitrile and ethanol solvents, respectively.

Polymer solar cells were fabricated according to the following procedure. The patterned indium tin oxide (ITO) on glass was first cleaned with acetone, methanol, and IPA ultrasonically and, subsequently rinsed with DI water and then treated with UV-ozone to improve wettability for coating. The active areas were isolated from each other by a photo-resist, and then PEDOT:PSS (Heraeus,

CLEVIOS™ Al 4083) was spin-coated onto ~ 50 nm ITO from an aqueous solution. The substrate was then cured for 20 min at 120°C on a hot plate in a glove box to remove the solvent. Active layer comprising of P3HT and PCBM-71 with the ratio of 1:0.6 blending solution in dichlorobenzene was coated and annealed at 130°C for 30 min on a hot plate. And then, n-doped layer was spin-coated on the active layer and its thickness was kept to 10 nm by controlling the spin speed. Finally, on top of the cell, ~ 0.5 nm LiF and ~ 100 nm Al were deposited by thermal evaporation in vacuum of $\sim 10^{-7}$ Torr and the cells were encapsulated using UV curable resin in a N_2 filled glove box. The area of the devices fabricated was 0.04 cm^2 .

Performance parameters of the solar cells were obtained from the current density–voltage characteristics under solar simulator (AM1.5). The J – V characteristics were obtained using a semiconductor characterization system (Keithley 2400LV) at room temperature in air. External quantum efficiency (EQE) was measured by using a 300 W Xenon light source with an Oriel Cornerstone 130 monochromator.

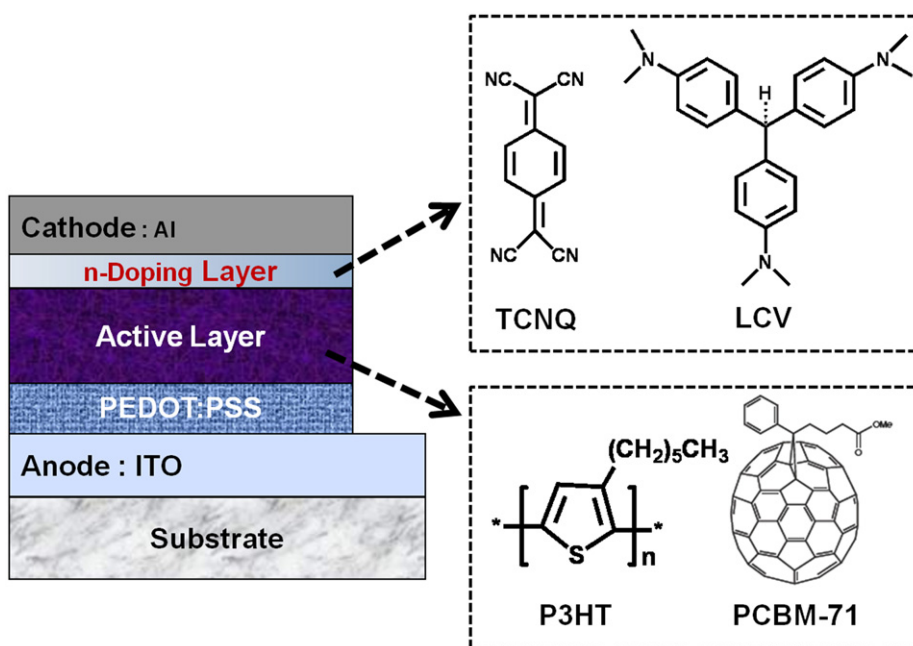


Fig. 1. Schematic cross-section of the bulk heterojunction photovoltaic device including n-doped layer between active layer and cathode, and chemical structures of the organic semiconductors used in this work.

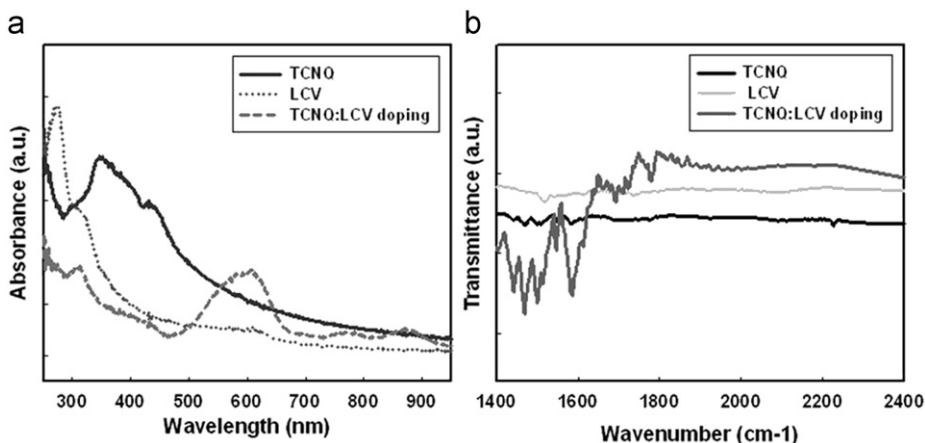


Fig. 2. (a) UV absorptions and (b) FTIR spectra for the TCNQ, LCV, and TCNQ:LCV layers.

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