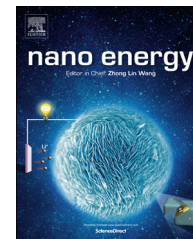


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RAPID COMMUNICATION

Efficient ternary bulk heterojunction solar cells with PCDTBT as hole-cascade material

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KEYWORDS

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Abstract

Q2 Ternary bulk hetero-junction (BHJ) architecture for organic solar cells has been developed to enhance the power conversion efficiency (PCE) by expanding the light absorption range and smoothing the energy level at the BHJ interface. In this work, we report on a ternary polymer blend solar cell with two donor materials, polythieno[3,4-b]-thiophene/benzodithiophene (PTB7), poly[N-9"-hepta-decanyl-2,7-carbazole-alt-5,5-(4',7'-di-2-thienyl-2',1',3'-benzothiadiazole) (PCDTBT), and using C₇₁-butyric acid methyl ester (PC₇₁BM) as acceptor material. The resultant device shows an optimized PCE of 7.81% (control sample, 7.06%), with an open circuit voltage (V_{oc}) of 0.76 V, a short circuit current (J_{sc}) of 15.4 mA/cm² and a fill factor (FF) of 66.7%. The improved device performance is mainly attributed to the enhanced charge separation, improved hole mobility, and better film morphology. And we find that the third component PCDTBT can reduce charge recombination in the ternary blend system as well. The results bring new insight into the future development of high efficiency ternary organic solar cells.

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Introduction

Photovoltaics based on clean and abundant energy from solar have attracted considerable attention. Especially, organic solar cells have been served as a promising photovoltaic technology owing to its low-cost, simple preparation, and high efficiency [1,2]. Great efforts have been devoted to improving the power conversion efficiency (PCE) of polymer solar cells (PSCs), such

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as developing new p-type donors with narrow bandgap, lowering the highest occupied molecular orbital (HOMO) with improved electronic properties [3-5], employing effective electron or hole transporting buffer layers [6-8], optimizing donor-acceptor (D-A) morphology and so on [9-12]. Recently, the PCE of single bulk solution processable hetero-junction (BHJ) solar cells has been reported over 10% [4].

However, there generally are two major factors that limit the further improvement of the binary structure solar cells: (1) the limited light absorption window of the donor polymer and (2) the other is the low charge carrier mobility that hinders the maximum obtainable photocurrent.

To overcome these problems, recently, ternary PSCs that consist of two donor materials and one fullerene acceptor (D1:D2:A) [13-17] or one donor material with two fullerene acceptors (D:A1:A2) [18,19] were demonstrated. For double donor cases, several materials such as dye sensitizers [20], small molecules [21], polymers [15,22,23] and quantum dots [24] have been used to incorporate in the D1:D2:A ternary system as the third component to enhance the J_{sc} by extending or increasing the absorption of the solar spectrum. For double acceptor devices, indene- C_{60} bisadduct (ICBA) was widely utilized to improve V_{oc} due to the relatively higher LUMO energy levels compared with $PC_{71}BM$ [18,19]. These results support that the ternary systems can potentially overcome the obstacle of the traditional binary PSCs and meanwhile keep the facile fabrication process compared with the more complex tandem devices.

In this work, we demonstrate an efficient ternary solar cell with PCDTBT as intermediate donor material, and the PCE can be achieved as high as 7.81%. We show that the improvement of the J_{sc} is due to the increasing charge separation, and the enhanced FF is ascribed to the smooth energy level at the D1/D2/A junction interface that favors the charge transfer. The cause of the slightly increased V_{oc} was also investigated by means of Kelvin probe force microscopy (KPFM) and charge modulated electroabsorption spectroscopy (CMEAS). Our finding suggests

ternary system could be a facile and efficient approach to improve the performance of the PSCs.

Experimental

Solar cell fabrication process

PTB7, PCDTBT and $PC_{71}BM$ were purchased from 1-Material Chemsitech, Inc., and Lumitec respectively, and used as received. The devices with configuration of ITO (180 nm)/PEDOT:PSS(40 nm)/PTB7/PCDTBT: $PC_{71}BM$ (~100 nm)/LiF (1 nm)/Al (100 nm) were fabricated. Firstly, a pre-patterned ITO (conductivity: 10-15 Ω /square) glass was cleaned by detergent, deionized water, acetone and isopropanol in sequence, followed by oxygen plasma treatment for 90 s. A thin hole injection layer of PEDOT:PSS was spun-cast onto pre-cleaned ITO glass with a thickness of ca. 40 nm, and then annealed at 145 $^{\circ}C$ for 10 min in air. PTB7 was mixed with varying PCDTBT content and then blended with $PC_{71}BM$ at a total D/A mass ratio of 1:1.5. Afterwards the mixture was dissolved in a mixed solution composed of 1,2 o-dichlorobenzene (o-DCB), chloroform (CF) (1:1 vol) and 2% diiodooctane (DIO) with a total concentration of 25 mg/ml. The mixed solution was then spun-cast atop the pre-coated PEDOT:PSS layer to form the active layer, giving rise to a thickness of ~100 nm. Following that, 20 min soft annealing and a further annealing at 120 $^{\circ}C$ for 10 min were conducted. Finally, a thin LiF interfacial layer (~1 nm) and a 100 nm thick Al electrode were deposited sequentially by thermal evaporation.

Instrumental

The evaporator was BOC Edwards Auto 306 and the active layer area of the device was defined by a shadow mask of 2 mm \times 6 mm. Electrical measurements were performed by a semiconductor characterization system (Keithley 236) at

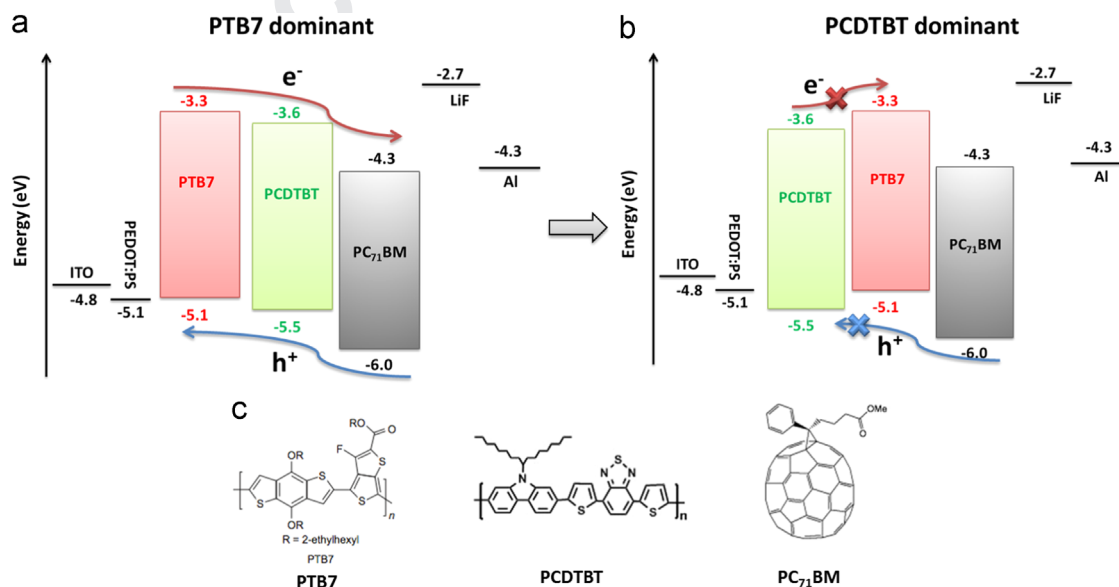


Fig. 1 Energy diagram of the ternary-BHJ solar cell, (a) PTB7 dominant, (b) PCDTBT dominant; (c) chemical structure of PTB7, PCDTBT, $PC_{71}BM$ used in the study. For PTB7 dominant case, hole and electron were separated effectively at the junction interface. On the other hand, for PCDTBT dominant case, both hole and electron were blocked at the PCDTBT/PTB7 interface.

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