



Efficient organic solar cells with polyfluorene derivatives as a cathode interfacial layer

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ARTICLE INFO

Article history:

Received 17 December 2008

Received in revised form 11 February 2009

Accepted 12 February 2009

Available online 20 February 2009

PACS:

71.20.Rv

72.80.Le

73.50.Pz

73.61.Ph

79.60.Jv

Keywords:

Organic solar cells

Bulk-heterojunction

Water-soluble conjugated polymers

Cathode modification

ABSTRACT

Use of a polyfluorene derivative (WPF-oxy-F) as the cathode interfacial layer was investigated for low-cost and high-efficiency organic solar cells (OSCs) based on poly(3-hexylthiophene) (P3HT) and 1-(3-methoxycarbonyl)-propyl-1-phenyl-(6,6)C₆₁ (PCBM). Insertion of the WPF-oxy-F interfacial layer between the P3HT/PCBM active layer and the metal cathode increased overall power conversion efficiency from 2.95% to 3.77% primarily due to the improved open circuit voltage and enhanced fill factor, resulting from a reduction of the metal work-function through the introduction of WPF-oxy-F.

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1. Introduction

Conjugated polymer-based organic solar cells (OSCs) have received significant attention because they are a cost-efficient and flexible power source. As a result, OSCs have undergone considerable development and the organic syntheses and fabrication methods used in their production have been significantly improved [1–11]. Among the available polymer solar cell systems, poly(3-hexylthiophene) (P3HT) and 1-(3-methoxycarbonyl)-propyl-1-phenyl-(6,6)C₆₁ (PCBM) blends have efficiencies of up to 4–5%; however, further improvement in efficiency is required for practical applications [9–11].

Typically, P3HT and PCBM based bulk-heterojunction (BHJ) solar cells have a sandwich-like structure consisting of an indium tin oxide (ITO) anode, a photoactive layer, and an Al metal cathode. Here, to achieve high-performance OSCs, the interface between the electrode and active layer must be an Ohmic contact to minimize the contact resistance and to maximize the open circuit voltage (V_{oc}) [12,13]. A preferred and simple method to enhance the contact between the electrode and the active layer is modification of the electrode by insertion of a buffer layer. For example, the insertion of poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) between the ITO anode and active layer is commonly used in OSCs to enhance hole collection and increase V_{oc} [14]. In the case of cathode modification, it was suggested that a thin LiF layer improves cell efficiency through the formation of an interfacial dipole that reduces the

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work-function of Al for better electron collection [15]. However, LiF is not an ideal interfacial layer in polymer-based cells for the following reasons: the LiF layer must be very thin (<1.2 nm) [15], which is difficult to achieve; and, vapor deposition of LiF in a vacuum is not well-suited for use in high-throughput roll-to-roll manufacturing, which is the most significant advantage of polymer-based cells [16].

Recently, the use of metal oxides, such as TiO_x and ZnO, as an efficient buffer layer led to significantly enhanced cell efficiency [17–19], and OSCs with SAM-modified ZnO showed dramatic improvements in efficiency, mostly due to enhancements in V_{oc} and fill factor (FF) resulting from the formation of a favorable interfacial dipole [12,13]. In particular, Zhang et al. demonstrated that a solution-processed poly(ethylene oxide) (PEO) layer can form internal dipoles at the active layer/Al interface, resulting in enhanced the power conversion efficiency (PCE) and V_{oc} [16]. This organic-based interfacial layer that can be created using a simple solution-based process may be desirable for the realization of low-cost and high-efficiency OSCs. However, until very recently, only a few approaches for an organic-based interfacial layer in OSCs have been reported and, to date, insertion of an organic-based cathode interfacial layer into P3HT/PCBM-based OSCs has not been achieved.

The aim of the present study was to realize a low-cost and high-efficiency organic solar cell by insertion of an organic-based cathode interfacial layer into the cell using a simple solution-based process. We investigated the use of a water-soluble polyfluorene derivative (WPF-oxy-F) as the cathode interfacial layer in polymer solar cells, which was synthesized using a palladium-catalyzed Suzuki coupling reaction [20]. Herein, we demonstrate that simply by spin-coating the WPF-oxy-F, the overall power conversion efficiency of solar cells was increased, mainly resulting from the enhanced V_{oc} and FF.

2. Experimental

The structure of the solar cell and the chemical structure of the WPF-oxy-F are presented schematically in Fig. 1. To fabricate the OSCs, glass substrates coated with ITO (Samsung Corning Co., Ltd.) having a sheet resistance

of $\sim 10 \Omega/\text{sq}$ were cleaned and PEDOT:PSS (Baytron P VPAI 4083) was spin-coated onto ITO followed by drying at 120 °C for 10 min, with a thickness of ~ 20 nm. A solution of 30 mg of P3HT (Rieke Metals) and 15 mg of PCBM (Nano-C) in 2 ml of chlorobenzene was then spin-coated on top of the PEDOT:PSS layer, forming the active layer with a thickness of ~ 80 nm. The WPF-oxy-F, dissolved in methanol at a concentration of 1 mg/ml, was spin-coated onto the active layer. Finally, aluminum (100 nm) was thermally evaporated on the WPF-oxy-F layer in a vacuum at 10^{-6} Torr. For comparison, solar cells without the WPF-oxy-F layer were also fabricated using experimental procedures identical to those used to make the cells with the WPF-oxy-F layer. Photocurrent–voltage (I – V) measurements were performed using a Keithley 4200 instrument under 100 mW/cm² illumination from a 1 kW Oriel solar simulator with an AM 1.5 G filter in a N₂-filled glove box. A calibrated silicon reference solar cell certified by the National Renewable Energy Laboratory (NREL) was used to confirm the measurement conditions.

3. Results and discussion

First, we investigated the effect of the WPF-oxy-F layer and its thickness on the performance of OSCs without thermal annealing of the active layers. A reference cell containing only Al and cells with a WPF-oxy-F layer spin-coated at either 6000, 4000, or 2000 rpm were fabricated. The thicknesses of WPF-oxy-F layers spin-coated at various speeds were as follows: ~ 3 nm at 6000 rpm, ~ 4 nm at 4000 rpm, and ~ 6 nm at 2000 rpm. The photocurrent density–voltage (J – V) characteristics of the cells with a WPF-oxy-F layer are shown in Fig. 2, and detailed information on V_{oc} , short-circuit current density (J_{sc}), FF, and PCE, calculated from the J – V curves in Fig. 2a, is presented in Table 1. As shown in Fig. 2b, V_{oc} values in all cells with a WPF-oxy-F layer were increased by 110 mV. V_{oc} was relatively constant at ~ 0.68 V, independent of the thickness of the WPF-oxy-F layer, while FF and J_{sc} were slightly reduced as the thickness of the WPF-oxy-F layer increased. Thus, the cell with the WPF-oxy-F layer that was spin-coated at 6000 rpm had the highest efficiency. Furthermore, compared with the efficiency of the reference cell, the efficiency of each cell with a WPF-oxy-F layer was dramatically enhanced.

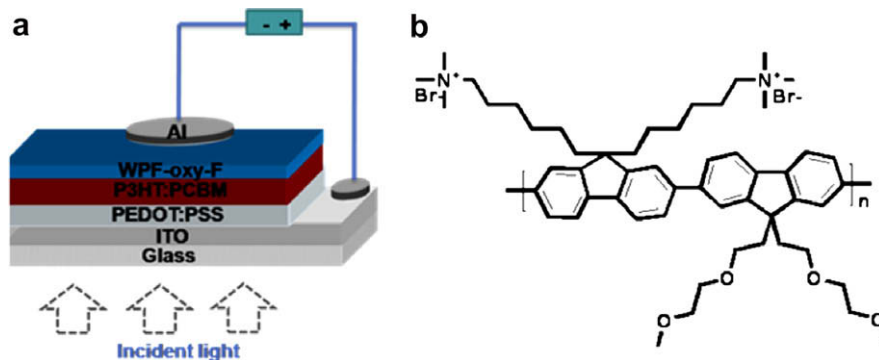


Fig. 1. (a) Structure of the organic solar cell with a WPF-oxy-F layer. (b) The chemical structure of the WPF-oxy-F polyfluorene derivative.

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