Simple Structured Polyetheramines, as Electron Transporting Modified Layers for Efficient Organic Photovoltaics

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Abstract

In this study, we have successfully found that interfacial layers (IFLs) based on Jeffamines (industrial polyetheramine derivatives) can improve the performance of organic photovoltaics (OPVs). We used two different Jeffamines—D2000 and ED2003—having either a monoamine or diamine structure and various ratios of ethylene oxide (EO) and propylene oxide (PO) for their suitability as IF materials for OPV applications. The presence of the Jeffamine improved the electron transport and altered the work function of ZnO, thereby causing the ZnO layers to function more efficiently as electron-selective electrodes. The power conversion efficiencies (PCEs) of inverted devices having the layered configuration glass/indium tin oxide (ITO)/ZnO (with or without the Jeffamine)/PTB7:PC71BM/MoO3/Ag increased from 8.1 ± 0.11 to 8.6 ± 0.37% when containing the Jeffamine-D2000 under illumination with AM 1.5G solar light (1000 W m⁻²), the result of a significantly increased fill factor (FF). The greatest OPV performance was that of the device incorporating Jeffamine-D2000—a PCE of 9.1% and a remarkable FF of 74.2%.

1. Introduction

Great efforts have been exerted in the development of roll-to-roll, cost-effective, low energy consumption OPVs as promising alternatives to traditional PVs for certain applications. Advances in device engineering and materials development have led to the power conversion efficiencies (PCEs) of bulk-heterojunction (BHJ) OPVs reaching 12%. Interfacial (IF) layers play a unique and important role in the enhanced performance of OPVs. Many IF materials have been tested successfully, including polyelectrolytes, self-assembled layers, organic, inorganic hybrid materials and non-conjugated organic materials [e.g., polyethylenimines (PEIs) and their ethoxylated derivatives (PEIEs)]. Several mechanisms have been proposed to explain how the IFs improve the performance of OPVs; for example, improving charge extraction to minimize series resistance, by suppressing carrier recombination, altering the work function (built-in dipole) to facilitate efficient energy level pinning for high-performance carriers extraction, improving charge transport, and changing the BHJ morphology of the active layers for efficient charge transfer and transportation (well-defined nanoscale phase segregation or a gradient distribution of the donor/acceptor morphology for enhanced carrier transport).

Table 1. J–V properties of the OPV devices.

<table>
<thead>
<tr>
<th>Devices</th>
<th>Jsc (mA cm⁻²)</th>
<th>Voc (V)</th>
<th>FF</th>
<th>PCE (%)</th>
<th>Best</th>
<th>Rs (Ω cm²)</th>
<th>Rf (Ω cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZnO</td>
<td>15.7±0.33</td>
<td>0.72±0.01</td>
<td>71.6±2.28</td>
<td>8.1±0.11</td>
<td>8.2</td>
<td>108.6±341</td>
<td>2.0±0.2</td>
</tr>
<tr>
<td>D2000</td>
<td>15.9±0.09</td>
<td>0.73±0.01</td>
<td>74.6±0.99</td>
<td>8.6±0.37</td>
<td>9.1</td>
<td>211.8±672</td>
<td>1.5±0.2</td>
</tr>
<tr>
<td>ED2003</td>
<td>15.4±0.06</td>
<td>0.73±0.01</td>
<td>71.4±3.00</td>
<td>8.0±0.42</td>
<td>8.3</td>
<td>104.0±632</td>
<td>2.0±0.2</td>
</tr>
</tbody>
</table>

We fabricated OPV devices having an inverted architecture with a layer structure: glass/ITO/ZnO (with or without a Jeffamine)/PTB7:PC71BM/MoO3/Ag (3 nm)/Ag (100 nm). We denote the standard cell (without the IF) as the ZnO device, and the devices containing the various IFLs as the D2000 and ED2003 devices. Table 1 summarizes the average and best OPV performance of the devices. The average values and standard deviations in Table 1 were calculated from 10 cells. The standard ZnO device had a PCE of 8.1 ± 0.11% under AM 1.5G illumination (100 mW cm⁻²), with a value of Jsc of 15.7 ± 0.33 mA cm⁻², a value of Voc of 0.72 ± 0.01 V, and an FF of 71.6 ± 2.28%. The PCEs of the devices embedding D2000, and ED2003, were 8.6 ± 0.37, and 8.0 ± 0.42, respectively. The highest PCE of 9.1% was observed with a value of Jsc of 16.8 mA cm⁻², a value of Voc of 0.73 V, and an FF of 74.2% (Fig. 2a, Table 1). Compared with the ZnO device, the PCE for the D2000 device had increased by 11%.

2. Results and discussion

In this study, we assessed two Jeffamines [average molecular weight (MW): 2000 g mol⁻¹]—D2000 and ED2003, having monoamine or diamine structures and various ratios of propylene oxide (PO) and ethylene oxide (EO)—for their suitability for use as efficient cathode-modified layers for OPV applications (Fig. 1).

Figure 1. Schematic representation of the OPV device; chemical structures of the Jeffamines.
We have successfully shown that Jeffamines can be used as ETL modified layers for high-performance OPVs. The incorporation of these materials changed the surface energy, thereby affecting the wetting properties of the active layer solution and, hence, altering the morphologies of the blend films. The PCE of the device embedding D2000 as the IF layer increased by 6.2% (from 8.1 ± 0.11 to 8.6 ± 0.37%) because of a significant increase in the FF. Because of the wide variety and low price of the Jeffamines, their judicious selection should result in the development of inexpensive cathode interlayers for large-area OPVs and other optoelectronic devices.

Acknowledgements

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References