Efficient inverted polymer solar cells based on surface modified FTO transparent electrodes

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Nano-textured transparent electrodes are commonly used to receive higher light absorption in inverted polymer solar cells (IPSC). However, the performance of the device is often restricted by the highly rough morphology of the textured transparent electrode. In this work, a Polyvinylpyrrolidone (PVP) interlayer was inserted as a surface modifier in IPSCs based on a fluorine-doped SnO2 electrode (FTO). The inserted layer facilitates electron extraction due to improved interface morphology of the AZO electron transport layer (ETL). This enhancement resulted in an approximately 63% increase in power conversion efficiency from 2.52% to 4.14% of IPSCs based on the FTO electrode compared to solar cells without PVP layer.

1. Introduction

Polymer solar cells are a photovoltaic technology that might serve as a promising alternative to conventional solar cells due to their low cost, ease of fabrication, and compatibility with large-scale roll-to-roll processing [1–3]. Inverted polymer solar cells (IPSCs) have obtained increasing attention for their high-stability and rapid efficiency improvement from 1% to 10% [4–5]. A broad range of IPSCs are built on indium tin oxide (ITO) anodes owing to their excellent optical conductivity properties. However, the scarcity of indium leads to high costs [6]. Additionally, the high work function [7–8] causes a contact barrier for electron injection in IPSCs. Aside from achieving high efficiency for IPSC, there is a need to develop an alternative low-cost transparent conductive film with superior transparency in addition to lower resistance materials for OPV devices also attract significant research effort.

Currently, various electrode materials, such as ZnO [9], oxide/metal/oxide [10–12], and fluorine-doped SnO2 (FTO) [13–16] have been explored as potential anode materials to replace ITO in PSCs. Among these transparent electrode materials, FTO is a promising alternative to ITO due to its inexpensive price, as well as superior optical conductivity property [17–19]. However, the power conversion efficiency (PCE) of IPSCs based on FTO electrode is usually lower than that of ITO device, thus, studies on FTO in inverted polymer solar cells are highly limited.

In reported IPSCs, n-type metal oxide is deposited on the top of the cathode as an electron transport layer (ETL) to lower work function of the cathode and to enhance electron extraction, which is essential for achieving high efficiency in IPSCs. [20,21] Zinc oxides (ZnO) are typically used as an ETL in IPSCs because of their high transmittance, environmental stability, and low crystallization temperature. [22–24] More recently, metals doped with ZnO, e.g., aluminum-doped ZnO, boron-doped zinc oxide and gallium-doped ZnO were proposed to overcome the thickness limitations and improve IPSCs photovoltaic performance by improving the conductivity properties. [25–30] However, the ZnO or doped ZnO film present apparent surface defects due to surface aggregations and dangling bonds, leading to weak electron transport and severe back charge recombination [31,32].

Moreover, use of ZnO or doped ZnO leads to increased surface contact resistance, thereby inducing a low fill factor (FF) [33,34]. Further improvement of PCE is constrained by surface defects of using ZnO as an ETL [35,36]. Different methods have been used to improve the inferior surface of the ZnO layer. For example, use of the self-assembled monolayer (SAM) modified with ZnO [31,37] or incorporation of fullerene derivatives, [38] could effectively improve the contact property, further increasing the efficiency of IPSCs. These research into interface modifications to achieve higher device performance and deserves further investigation.

In the FTO device, the inferior ZnO surface quality was further worsened by the rough surface of FTO substrate. In this study, IPSCs with FTO substrate were investigated using solution-processed AZO ETLs based on poly (3-hexylthiophene) (P3HT): (6, 6) –phenyl C61 butyric acid methyl ester (PCBM). In this study, we report the device performance improvement through employing a polyvinylpyrrolidone...
(PVP) as the AZO surface modifier. Devices with a structure of FTO/AZO/PVP/ P3HT: PCBM/ MoO3/Ag exhibited significant improvement of PCE from 2.52% (without PVP) to 4.14% (with PVP). This efficiency utilizing the FTO substrate is similar to most ITO electrodes, which indicate that FTO substrates are suitable alternatives to ITO for IPSCs.

2. Experimental

2.1. Device fabrication

IPSCs reported in this work were fabricated on FTO/glass substrates with a sheet resistance of ~15Ω/sq. The FTO substrates were precleaned by ultrasonication in detergent solution, de-ionized water, acetone, and isopropanol for 10 min sequentially. AZO precursor sol was prepared using an Al-to-Zn ratio of 1%. After stirring at 80°C for 3 h, the solution was spin-coated on the cleaned FTO-substrates at 2000 rpm for 30 s and subsequently heated at 300°C for 10 min. PVP (k30) was dissolved in ethanol (1.0 wt. %), stirring at 50°C for 30 min and spin coated onto an AZO layer to form a thin PVP interlayer of approximately 12 nm. A solution of the P3HT (12 mg ml⁻¹) and PCBM (10 mg ml⁻¹) blend in chlorobenzene, was spin-coated and annealed at 120°C for 10 min to form an active layer of approximately 120 nm. AZO/P3HT photovoltaic devices were fabricated by a solution of the P3HT (12 mg ml⁻¹) in chlorobenzene spin-coated on FTO/AZO.

Fig. 1. Device architecture of the inverted polymer solar cells.

Fig. 2. AFM images of the stereoscopic view of texture FTO: (a), FTO/AZO: (b) FTO/AZO/PVP: (c), FTO/AZO/PVP/ P3HT: PCBM layers: (d), FTO/AZO/PVP/ P3HT: PCBM/ Ag/ MoO3 (e).
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