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Highly Efficient Organic Solar Cell Employing a Solution Processed Hole Transporting Layer

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I. Introduction

Organic solar cells (OSCs) are remarkably growing since Tang reported the first donor-acceptor junction cell in 1986. Due to low production costs and predicted efficiencies beyond 10 %, one possible work-around is the usage of a thin layer of PEDOT:PSS underneath the top contact. PEDOT:PSS is a conductive polymer with the potential to substitute metal contacts in the future and allow low-coat production [1-2]. OSC offers the potential to compete with inorganic photovoltaic cells in the future. The most frequently used buffer layer in OSCs is poly(3,4-ethylene dioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) [3]. Due to its high work function, smooth morphological properties and good conductivity, the hole collection of the ITO anode can be facilitated via the PEDOT:PSS layer from the highest occupied molecular orbital (HOMO) of a photoactive film. However, the interface between ITO and PEDOT:PSS is not stable and the chemical reaction between ITO and PEDOT:PSS can result in degraded device performance [4-6].

In this study, we demonstrate that the thin film of transition metal oxides of V_2O_5 can be a promising hole transporting layer (HTL) in OSC cells by a solution process. A total solution process to fabricate the OSCs has been proposed. The fill factor (FF) and power conversion efficiency are discussed. Contact angle measurements to evaluate the surface status of buffer layer with discussed results and elucidate possible mechanisms and implications.

II. Experiment

The OSC cells in this study comprise a poly(3-hexylthiophene) (P3HT) and phenyl C61-butyric acid methylester (PCBM) blend thin film sandwiched between ITO and a metal cathode. The device architecture is schematically shown in Fig. 1(a), and energy level diagrams of materials used in the device are also illustrated in Figs. 1(b) – (c). The OSC cells were fabricated step-by-step as follows. ITO-coated glass substrates were sequentially washed by sonication in detergent, acetone, isopropanol and water for 20 min. The V_2O_5 layer was coated onto ITO substrates by a spin coating process. The PEDOT:PSS polymer was spin-coated onto the V_2O_5 at a spin speed of 4000 rpm for 60 sec. followed by baking at 140 °C for 5 min. The materials for active layer consists of a P3HT:PCBM (1:0.8 weight ratio) solution, which was P3HT initially dissolved in 1,2-dichlorobenzene, and then PCBM powder was subsequently added. A thin (120 nm) P3HT:PCBM active layer was then formed by spin coating the solution at 1500 rpm for 60 sec. followed by baking at 120 °C for 5 min. under N_2 atmosphere in glove box. Finally, the cathode, 0.7 nm of LiF and 150 nm of Al was thermally deposited on top of the active layer in a deposition chamber in the glove box under a vacuum of 10^{-6} Torr. The evaporation rate and thickness of the film were determined using an oscillating quartz thickness monitor (Sycon STM-100). The active area of the device was 0.24 cm^2. Current-voltage (I-V) curves were determined by a Keithley 2400 source meter. The sample was illuminated using an AM 1.5 G simulated solar spectrum from a filtered Xe arc lamp source. The light intensity of solar simulator was calibrated with a Si photodetector. Atomic force microscopy (AFM) was used in an attempt to correlate these characteristics of the surface morphology.

III. Results and discussion

The three types of OSC structures in this study are summarized as follows.

Cell 1:ITO/P3HT:PCBM/LiF/Al
Cell 2: ITO/V_2O_5 /P3HT:PCBM/LiF/Al
Cell 3: ITO/V_2O_5 /PEDOT:PSS/P3HT:PCBM/LiF/Al

Fig. 2 shows the J-V curves of above mentioned all types of OSC cells under 100 mW/cm^2 white light illumination in air. Cell 2 with a HTL of V_2O_5 exhibits the short-current density (J_{sc}) and open-circuit voltage (V_{oc}) of 3.91 mA/cm^2 and 0.52 V, respectively, as well as PCE of 0.82% and FF of 40.8%. A HTL efficiently prevents the recombination of change carriers at the active layer/ITO interface. In view of this, Cell 1 without a HTL, P3HT:PCBM straight contacts with ITO. It is possible for carriers to recombine in active layer before they arrive at the ITO electrode. Open-circuit voltages (V_{oc}) is the same for cells 2 and 3 with various HTL, irrespective of the work function of the same first HTL of V_2O_5 (4.7 eV). It has been understood that the V_{OC} corresponds to the active layer difference between the donor HOMO and the acceptor LUMO levels. Comparing of Cell 2 with Cell 3 (ITO/V_2O_5/PEDOT:PSS/P3HT:PCBM/LiF/Al) reveals that the letter has an increased J_{sc} from 3.91 mA/cm^2 to 6.03 mA/cm^2. Consequently, the PCE improves significantly, rising from 0.82% to 2.06%. We also find the surface morphology of PEDOT:PSS coated onto V_2O_5 gets better. A smooth surface for P3HT:PCBM coating will benefit current spreading in Cell 3.

Table I. Characteristics for devices with various type of HTL under 100 mW/cm^2 illumination.

Device structure	J_{sc} (mA/cm^2)	V_{oc} (V)	FF (%)	PCE (%)
Cell 1: ITO/P3HT:PCBM/LiF/Al	3.9	0.28	18.86	0.21
Cell 2: ITO/V_2O_5/P3HT:PCBM/LiF/Al	3.91	0.52	40.8	0.82
Cell 3: ITO/V_2O_5 /PEDOT:PSS/P3HT:PCBM/LiF/Al	6.03	0.587	58.12	2.06

IV. Conclusion

In summary, OSC cells with high FF and high PCE has been successfully fabricated using V_2O_5/PEDOT:PSS as a HTL between ITO and active layer. A cell in the structure of ITO/V_2O_5/PEDOT:PSS/P3HT:PCBM/LiF/Al exhibits a FF of 58.12% and a PCE of 2.06%. The solution processed V_2O_5 film plays an important role in preventing an unwanted chemical reaction between the ITO and PEDOT:PSS, as well as the active layer. The increases in the PEC and FF of the device obtained using a V_2O_5/ PEDOT:PSS HTL is attributed to the stepwise hole transporting configuration, as well as the increased optical absorption from the anode.

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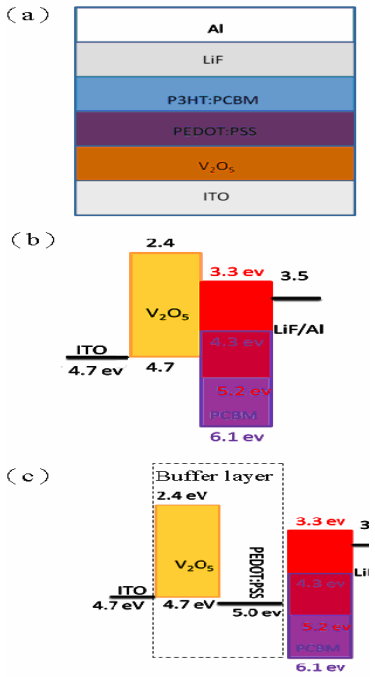

Fig. 1 (a) Device architecture used in this study. Energy band diagrams of OSC with (b)a V_2O_5 layer and (c)a V_2O_5/PEDOT:PSS layer.

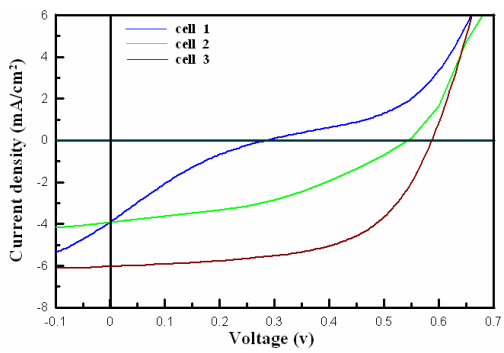

Fig. 2 The J-V characteristics of the devices under 100 mW/cm^2 white light illumination in air.