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Solution-Processed Flexible Organic Solar Cells with a Low Temperature Annealing Active Layer

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I. Introduction

In recent, polymer solar cells have attracted considerable attention. It can be mainly attributed to the expectations for possible low cost making flexibility solar devices, and using low temperature process for fabrication device [1]. Moreover, the flexible solar cells can be easily integrated in a curved plastic substrates, such as poly ethylene terephthalate (PET), poly ethylene naphthalate (PEN), and polyether sulphone (PES) [2-4]. In order to increase the power conversion efficiency (PCE) of organic solar cells (OSCs), the hole transporting layer (HTL), such as NiO, WO3, CuPc, and poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) [5-7] have been applied in the OSCs. The PEDOT:PSS has always been buffer layer among the commonly using in the OSCs. The PEDOT:PSS have high work function, high transparency, acceptability conductivity, and the smooth morphological characteristics, the hole collection of the ITO anode can be facilitated via the PEDOT:PSS layer from the highest occupied molecular orbital (HOMO) of photoactive films. Nevertheless, the ITO/PEDOT interface seems very unstable due to contact between the oxide and the hygroscopic can degrade OSCs performance [8].

In this study, flexible OSC on PET substrates with a solution-processed HTL have been fabricated. V_2O_5, PEDOT:PSS or V_2O_5/PEDOT:PSS is used as a HTL. The PCE of an OSC with the V_2O_5 HTL is superior to that of a conventional PEDOT:PSS HTL. Contact angle measurement and atomic force microscopy (AFM) are used to evaluate the surface energy and morphology of the HTL.

II. Experiment

In this study, we demonstrate the photovoltaic properties of simple bulk heterojunction solar cells based on the a poly(3-hexylthiophene) (P3HT) and phenyl C61-butyric acid methylester (PCBM) blend thin film sandwiched between indium-tin oxide (ITO) and a metal cathode. The fabrication of OSCs in this study was carried out in the following manner. Figure 1(a) schematically shows the device structure, whereas Figs. 1(b) ~ 1(d) show the energy level diagrams of various materials used to fabricate the device. ITO-coated PET substrates were sequentially washed by sonication in detergent, acetone, isopropanol, and water for 20 min. Various materials of HTL, including PEDOT:PSS and V2O5, were spin-coated onto the ITO anodes. The V_2O_5 layer was obtained by spin-coating onto the ITO substrate, followed by baking at 120 ℃ for 10 min under N_2 atmosphere. The PEDOT:PSS layer was obtained by spin-coating an aqueous solution onto the ITO at a coating speed of 1300 rpm for 30 s, followed by baking at 120 ℃ for 10 min under N_2 atmosphere. A bulk heterojunction layer was then spin-coated onto an HTL at a coating speed of 3500 rpm for 60 s, followed by various annealing temperature from 60℃ to 100℃ for 30 min under N_2 atmosphere in a glove box. For active layer films of P3HT:PCBM (1:0.8 weight ratio) solution, P3HT was initially dissolved in 1,2-dichlorobenzene, to which PCBM powder was subsequently added. Additionally, the blend was stirred for approximately 24 h at 40 ℃ in the glove box before spin coating. Moreover, the cathode, i.e., 0.7 nm of LiF and 150 nm of Al, was thermally deposited on top of the active layer in a deposition chamber under a vacuum pressure 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 0.08 cm^2.

Current density–voltage (J–V) curves were determined using a Keithley 2400 source meter. The sample was illuminated using an AM1.5G simulated solar spectrum from a filtered Xe arc lamp source. The light intensity of the solar simulator was calibrated with a Si photodetector.

III. Results and discussion

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

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

To fabricate the OSC on a PET substrate, low annealing temperature for P3HT:PCBM active layer is essential. The surface roughness of the P3HT:PCBM composite were researched by AFM, as shown in Fig. 2. The root mean square (RMS) roughness values are 0.49 nm, 0.72 nm, 1.63 nm, and 2.46 nm for P3HT:PCBM films annealed at 60 ℃, 70 ℃, 80 ℃, and 100 ℃, respectively. When the annealing temperature is higher than 80 ℃, surface morphology of active layer becomes rough. PCBM-clusters might form at high annealing temperature and lead to device degradation. In view of this, a smooth P3HT:PCBM film increases charge carriers to transfer, probably owing to its better junction to improve the PCE of OSC [9].

The J-V curves of above mentioned all types of OSC cells under 100 mW/cm^2 white light illumination in air are examined. Cell 1 with a HTL of PEDOT:PSS V_2O_5 exhibits the short-current density (J_{sc}) and open-circuit voltage (V_{oc}) of 3.97 mA/cm^2 and 0.58 V, respectively, as well as PCE of 0.59% and FF of 25.55%. The HTL of PEDOT:PSS can efficiently prevent the change carriers from recombination at the interface of active layer/ITO. It has been understood that the V_{OC} corresponds to the active layer difference between the donor HOMO and the

acceptor LUMO levels. Nevertheless, the interface between ITO and PEDOT:PSS is unstable and a chemical reaction between ITO and PEDOT:PSS can degrade device performance. Comparing of cell 1 with cell 2 reveals that the latter has an increased J_{sc} from 3.97 mA/cm^2 to 5.08 mA/cm^2. The V_2O_5 does not produce a chemical reaction with the ITO interface. Consequently, the PCE improves significantly, rising from 0.59% to 0.90%. The life-time of cell 2 is also en-longed. A stacked HTL of V_2O_5/PEDOT:PSS is used to fabricate cell 3. From the energy band diagram illustrated in Fig. 1(d), an enhancement in the PCE of cell3 can be expected, which is attributed to the stepwise hole transporting configuration.

IV. Conclusion

In summary, flexible OSC on PET substrates with a solution-processed HTL have been successfully fabricated. V_2O_5, PEDOT:PSS or V_2O_5/PEDOT:PSS is used as a HTL. On a flexible substrate, a low annealing temperature of the P3HT:PCBM active layer is essential and also studied. Experimental results reveal that an annealing temperature for P3HT:PCBM is as low as 70℃. A cell in the structure of ITO/V_2O_5/P3HT:PCBM/LiF/Al exhibits a FF of 30.80% and a PCE of 0.90%. 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. Life-time is en-longed in the OSC with V_2O_5 HTL. Moreover, a stacked HTL of V_2O_5/PEDOT:PSS is proposed. An enhancement in the PCE of the OSC using a V_2O_5/ PEDOT:PSS HTL can be expected, which is attributed to the stepwise hole transporting configuration.

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Table I. Device performance of OSCs presented in this work.

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	PCE (%)
Cell 1	0.58	3.97	25.55	0.59
Cell 2	0.59	5.08	30.80	0.90

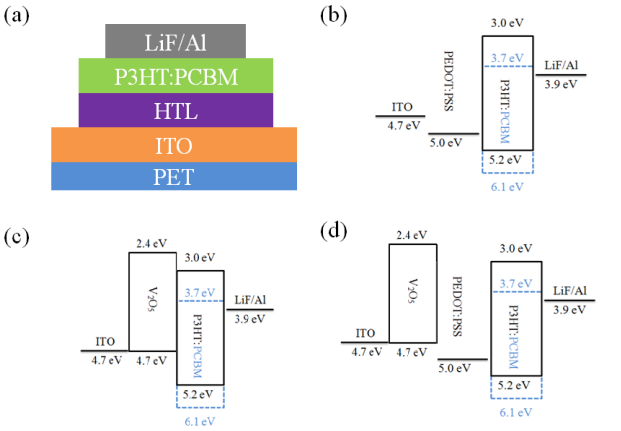

Fig. 1 (a)Device architecture used in this study. Energy band diagrams of OSC with a (b)PEDOT:PSS (c)V_2O_5, and (d)V_2O_5/PEDOT:PSS HTL, respectively.

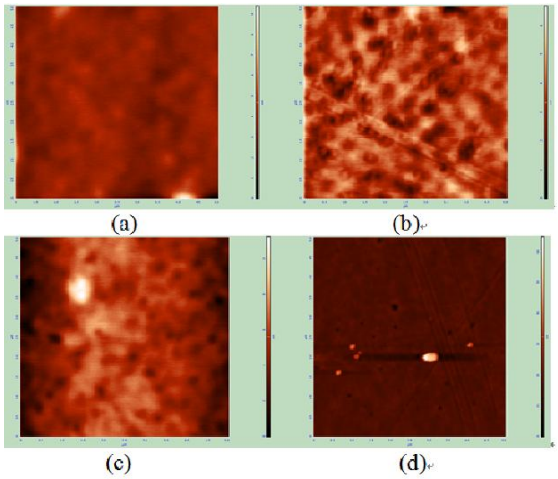

Fig. 2 AFM images of P3HT:PCBM films at the annealing temperate of (a)60℃, (b)70℃, (c)80℃, and (d)100℃, respectively.