Effect of TiO$_x$ Interlayer on Efficiency of MEH-PPV:PCBM Polymer Solar Cells

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Abstract

We fabricated the MEH-PPV:PCBM polymer solar cells with and without TiO$_x$ interlayer in order to investigate the effect of interlayer on efficiency of MEH-PPV:PCBM polymer solar cells. The TiO$_x$ interlayer (10 nm) was inserted between the photoactive layer and cathode. The control device provides open circuit voltage (V_{oc}) of 0.63 V, short circuit current (J_{sc}) of 0.67 mA/cm^2, and fill factor (FF) of 26.4, thus the efficiency of the device is 0.11%. For the device with TiO$_x$ interlayer, the V_{oc} reduced to 0.49 V, J_{sc} significantly increased to 3.00 mA/cm^2 and FF slightly decreased to 24.6, producing an efficiency as high as 0.36%.

Keywords: Polymer, photoactive, solar cells, interlayer

1. Introduction

Organic photovoltaic devices, deemed as the third generation solar technology, are currently of great interest to the research community as well as to the industry. These organic materials, specifically semiconducting polymers, have a high optical absorption coefficient, due to which maximum light absorption can be achieved under 100 nm of thickness. This, along with ease of processing and good mechanical properties, makes them highly attractive for large areas and flexible applications. Compared to conventional inorganic solar cell materials, these materials do not require the costly and energy-consuming processing, like high temperature, high vacuum conditions, resulting in low production cost with high volume. Nonetheless, the relatively low power conversion efficiency and poor air- stability of the current organic photovoltaic (OPV) devices are inhibiting them for their commercialization. The promising methods for efficiency enhancement include designing new low band-gap donor polymers [1], controlling the active layer morphology [2] and interfacial modification [3].

In interfacial modification, interfacial layers of semiconducting metal oxides and plasmonic nanostructures are usually integrated at electrode interfaces. There are two types of interfacial layers: the electron transporting layer (ETL) and the hole transporting layer (HTL). The ETL is integrated at cathode interface (between the photoactive layer and cathode) for better electron transport while the HTL at anode interface (between the photoactive layer and anode) for better hole transport. Interfacial layers also function as optical spacers that enable the light intensity redistribution across all layers in the device to maximize absorption in photoactive layers [4, 5].

2. Experiment

2.1. Preparation of MEH-PPV:PCBM Blend Solutions

The as-purchased semiconducting materials of poly poly [2-methoxy, 5-(2'-ethylhexyloxy) -1,4-phenylene-vinylene] (MEH–PPV) were mixed with weight ratio of (1:2) and blended using a solvent, dichlorobenzene (DCB) to produce a blend solution with polymer concentration of 20 mg/ml. The blend was stirred overnight to ensure a homogeneous blend.

2.2. Etching and Cleaning of ITO

Since ITO was coated throughout the glass substrate, etching had to be carried out to remove the ITO at the sides, leaving the only ITO in the center region as shown in Figure 1 (a). This is to prevent short-circuiting between the ITO and aluminum pad electrodes during probing as demonstrated in Figure 1 (b). To get the etched pattern on the substrate, thermal tape was adhered to the center of the ITO, which would protect it from the etchant during the procedure. Concentrated hydrochloric acid (37% wt) was the etchant used and zinc powder was added as a catalyst to speed up the etching process by increasing the ambient temperature due to the exothermic side reaction between HCl and zinc. With the sample fully submerged, the entire procedure should take between 1 to 5 minutes, depending on the amount of substrates etched or zinc powder added. The etched samples had to be checked visually to ensure that the ITO was thoroughly etched before proceeding to the next fabrication steps. If samples were found to have remnants ITO, etching could be continued out but at a longer duration. After etching, the thermal tape was removed and the

substrates had to be cleaned in order to remove HCl, zinc powder and adhesive residue. The first step of cleaning procedure involved the sonication of the substrates in four types of media in the corresponding order, detergent, deionized water, acetone and isopropanol (IPA) at duration of 15 seconds each. The next step is to dry the simples with N_2 blow followed by UV treatment.

2.3. Deposition of PEDOT:PSS, MEH-PPV:PCBM, TiO$_x$ Layers by Spin-Coating

Aqueous Poly (3,4-ethylenedioxy thiophene): poly (styrenesulfonate) (PEDOT:PSS) was sonicated 10 minutes ahead of spin coating to ensure a homogenous solution. The PEDOT:PSS was spun coat on the top of the ITO surface with a speed of 3000 rpm for 1 minute. Next, the coated sample was annealed at 120 °C for 15 minutes and allowed to cool for another 10 minutes. The blend solution of MEH-PPV: PCBM was spun coat onto the PEDOT:PSS layer at the speed of 1000 rpm for 1 minute and then annealed at 120 °C for 15 minutes. The diluted TiO$_x$ solution was spun coat onto the cell at 3000 rpm for 1 minute and allowed to dry for another 30 minutes.

2.4 Thermal Deposition of Metallic Interlayer (Aluminum)

A 100 nm aluminum (Al) cathode layer was deposited on the active layer as a cathode using a thermal evaporator (NTE 1000) (Figure 2) in a vacuum chamber at 2.2×10^{-6} Torr. Figure 3 (a) shows the device configuration of organic photovoltaic cells used in this study and Figure 3. (b) shows ten individual cells can be formed at one substrate and each of them has a size of about 0.07 cm^2.

I-V curve of the device was recorded using a computer controlled digital source meter (Keithley 2420) under illumination with a Newport solar simulator(A.M.1.5, 100 mWcm^{-2}). Light intensity was calibrated with a National Renewable Energy Laboratory (NREL)-calibrated monocrystalline silicon solar cell. Experimental setup for the device efficiency measurement is shown in Figure 4. The efficiency of the devices was evaluated by taking the I-V curves of the device.
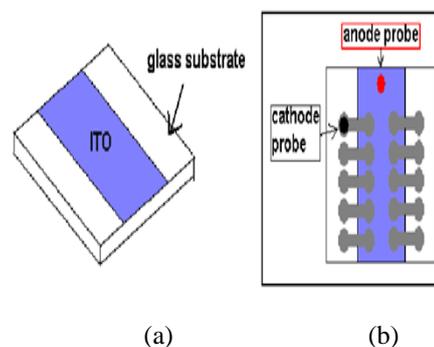

(a)　　　　　　　　(b)

Figure 1. (a) Etched ITO pattern of substrate and (b) Electrode points during data testing

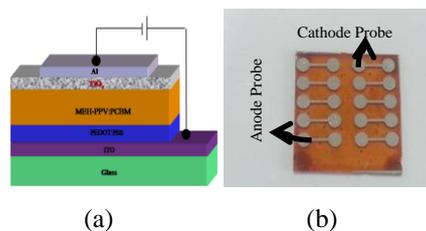**Figure 2. Thermal evaporator (NTE 1000)**

(a)　　　　　　　　(b)

Figure 3. (a) Device configuration of an organic photovoltaic cell and (b) Ten individual cells on one substrate


Figure 4. Experimental setup for the device efficiency measurement.

3. Result and Discussion

We fabricated the MEH-PPV:PCBM polymer solar cells with and without TiO_x interlayer in order to investigate the effect of interlayer on efficiency of MEH-PPV:PCBM polymer solar cells. The TiO_x interlayer (10 nm) was inserted between the photoactive layer and cathode. Figure 5 shows the J-V characteristic of MEH-PPV:PCBM solar cell (control device) and MEH-PPV:PCBM solar cell integrated with TiO_x interlayer (modified device). Their device parameters are tabulated in Table 1. The control device provides open circuit voltage (V_{oc}) of 0.63 V, short circuit current (J_{sc}) of 0.67 mA/cm^2, and fill factor (FF) of 26.4, thus the efficiency of the device is 0.11%. For the device with TiO_x interlayer, the V_{oc} reduced to 0.49 V, J_{sc} significantly increased to 3.00 mA/cm^2 and FF slightly decreased to 24.6, producing an efficiency as high as 0.36%. The thicknesses of the photoactive layer and interlayer were determined from their step-height profiles (Figure 6). The average thickness of the photoactive layer is about 230 nm and that of TiO_x interlayer (Figure 7) is about 10 nm.

The J_{sc} of the TiO_x integrated device dramatically increased from 0.67 mA/cm^2 (control device) to 3.00 mA/cm^2. From the electrical point of view, the TiO_x interlayer between active layer and cathode serves as an electron transporting layer. The conduction band minimum of TiO_x can adjust the energy levels of its neighboring layers (LUMO of n-type acceptor and work function of Al cathode) so that the electron injection at that interface would be promoted. From the optical point of view, it also serves as an optical spacer.

The FF is sensitive to morphology and series resistance of the device. The FFs of the devices with and without TiO_x layer are not significantly changed. It is speculated that introduction of TiO_x interlayer would not modulate the morphology/interfacial properties of cathode interface.
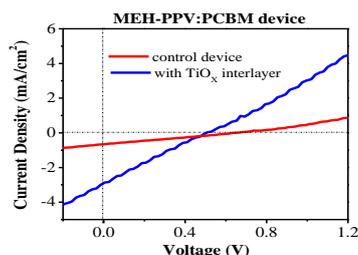
Figure 5. The current density–voltage characteristics of MEH-PPV:PCBM polymer solar cells with and without the TiO_x interlayer.
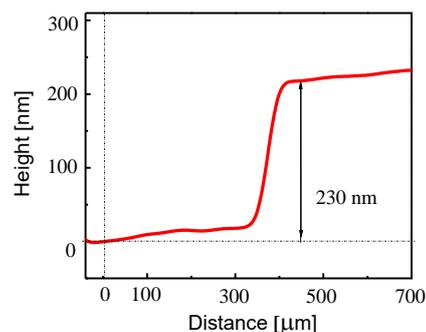
Figure 6. Step height profiles of MEH-PPV:PCBM active layer and that of thickness is about 230 nm.
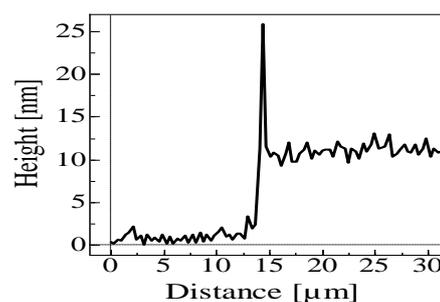
Figure 7. . Step height profiles of TiO_x interlayer and that of thickness is about 10 nm.

Table 1.　Photovoltaic device parameters of MEH-PPV:PCBM organic solar cells

	PCE (%)	J_{sc} (mA/cm^2)	V_{oc} (V)	FF
MEH-PPV: PCBM (control device)	0.11	0.67	0.63	26.4
With TiO_x interlayer (modified device)	0.36	3.00	0.49	24.6

4. Conclusion

In my research work is the fabrication of organic solar cells comprising poly [2-methoxy-5-(2'-ethylhexyloxy)-1,4 phenylen evinylene]: [6,6]-phenyl-C61 butyric acid methyl ester (MEH-PPV:PCBM) photoactive layer with and without TiO_x cathode buffer layer (thickness 10 nm). The efficiency of the control device is 0.112% and that of the modified device with TiO_x interlayer is 0.36%. This three-fold enhancement with TiO_x interlayer is mainly contributed from an increased photocurrent generation.

Acknowledgments

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