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Efficiency Improvement of Organic Solar Cells by Annealing for Active Layer

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1. Introduction

Poly(3-hexylthiophene) (P3HT) possesses a good filming and excellent semiconductor's nature such as higher carrier mobility[1-2], so that it can be applied on flexible plastic substrate to fabricate electro-optical devices and multi-layer structures according to the requirement of devices. The other related material [6,6]-phenylC61-butyric acidmethylester (PCBM) is used, too. The power conversion efficiency of organic polymer solar cells in 2005 had reached 5%, mainly using materials such as: P3HT/PCBM to produce P-N junction structure and perform as solar cells devices [3~4]. Owing to the advantages of low cost, light weight, flexibility and easy for a large area production, possessed by this kind of organic solar cells (OSC), it is worthy of our further study.

This study is divided into two parts. The first part of discussion is the effect of rotation speed of spin-coating for active layer P3HT:PCBM in OSC on the device characteristic. The second part is to discuss the effect of thin-film process, such as post annealing treatment for P3HT:PCBM, on the device characteristic. By means of the study on electro-optical characteristic of OSC and surface morphology of organic layer, the OSC conversion efficiency improving mechanisms can be understood.

2. Experiment

Take out the sample and utilize the technique of spin-coating to deposit a layer of PEDOT:PSS on ITO substrate to finish the surface of ITO and improve the hole injection from anode into P3HT:PCBM. Then take the materials of active layer of P3HT:PCBM=3:1 to be dissolved in chloroform and adjust its concentration at 1 wt%, and put the solution on the hot plate and stir for two hours and then utilize the method of spin-coating to deposit the organic layer P3HT:PCBM on PEDOT:PSS and proceed with post annealing processes in a glove box. Finally, the cathode metal, Al, is thermally evaporated onto P3HT:PCBM and the deposition rate is about 2-3 nm/sec. The device structure is shown in Fig. 1. After the fabrication of device, it was illuminated by sunshine simulator of 100 mW/cm^2 at AM-1.5 and OSC current-voltage (I-V) characteristic was measured with KEITHLEY 2400 power source electric-meter. Then the effects of rotation speed of various organic layers by spin-coating as well as the influence produced by post process on the OSC device were studied.

3. Results and Discussion

Effects of active layer spin-coating speed

Firstly fix the rotation speed and time of PEDOT spin-

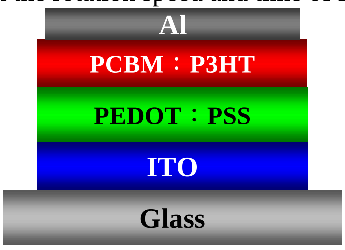

Fig. 1 The structural drawing of organic solar cells element.

coating at 2000 rpm and 30 seconds respectively and study the spin-coating speed of P3HT:PCBM active layer (spin duration 10 sec fixed) on the OSC I-V characteristic, as shown in Fig. 2. When the rotation speed of spin-coating is at 300 rpm, owing to the excessively low speed of the rotation, the film thickness of active layer is getting too thick. It will lead to the diffusion of electrons and holes be restricted, making the energy be fully consumed and caught in the traps after the electron and holes produced by light illumination prior to moving to the electrode. Consequently the electrons and holes cannot reach each side of electrode effectively. Therefore the generated photocurrent will be little. When spin-coating rotation speed is at 1300 rpm, owing to the operation of such a high rotation speed, comparatively the film thickness of active layer is getting relatively thinner. Although the electron and holes photo-excited may efficiently diffuse to the electrode, the thickness of active layer is too thin that leads to the excitons which are produced after light absorbing not as much as the photocurrent generated from the P3HT:PCBM in the rotation speed at 1000 rpm. Thus the photocurrent and power conversion efficiency are therefore not increased for 1300 rpm spin.

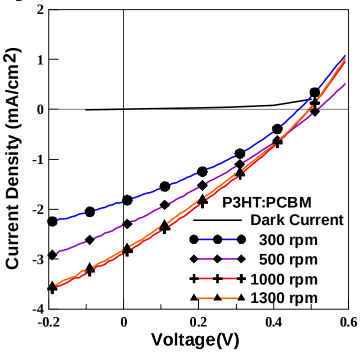

Fig. 2 I-V characteristic of OSC made with different spin-coating speed for active layer P3HT:PCBM

As may be seen in Fig. 2, when the rotation speed of spin-coating of active layer is fixed at 1000 rpm (10 seconds), it will obtain a better solar cells characteristic:

V_{oc}=0.48V, I_{sc}=2.9mA/cm^2, FF=0.3 and efficiency 0.417 %.

Effect of annealing process for active layer P3HT:PCBM

The device structure used in Fig. 3 is under ITO /PEDOT(2000rpm,30sec)/P3HT:PCBM(1000rpm,10sec)/ Al, focusing on active layer P3HT: PCBM to proceed with thermal treatment at different annealing temperatures for 10 minutes to study the effect of annealing process on the I-V characteristirs of OSC. As shown in Fig. 3, the annealing treatment enables a more complete re-arrangement for the molecular structure of active layer. Fig. 4 is a comparable measurement of absorption of P3HT:PCBM active layer before and after annealing. The absorbance of active layer after annealing is higher than that without annealing. From the result of Fig. 3, it is shown that when the temperature of annealing is at 250℃, the OSC characteristics are V_{oc}= 0.38V, J_{sc}=4.4 mA/cm^2, FF=0.35 and the conversion efficiency η =0.59%. The conversion efficiency is upgraded when compared with that of the device without annealing.

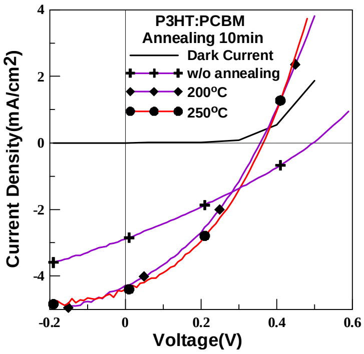

Fig. 3 I-V characteristic of solar cells by utilizing different annealing temperatures for active layer P3HT:PCBM.

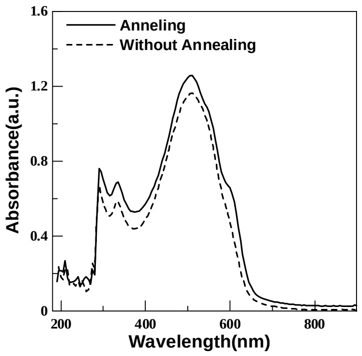

Fig. 4 Active layer before and after annealing treatment at 250℃, 10 minutes.

Continually, fix the annealing temperature of P3HT: PCBM at 250℃, and change different annealing time. It is found that when the annealing time is raised from 10 to 15 minutes, the conversion efficiency of solar cells will be slightly raised from 0.59 % to 0.614 %. Therefore when the annealing time is in the range from 10 to 20 minutes the influence to the OSC characteristic is found unremarkable.

Effect of PEDOT:PSS spin-coating speed

The device structure of Fig. 5 is ITO/PEDOT:PSS/ P3HT:PCBM(1000 rpm, 10 sec)/Al. When the annealing temperature of active layer P3HT:PCBM is fixed at 250℃ with annealing time of 15 minutes, the rotation speed of spin-coating of PEDOT:PSS layer was varied and the I-V curve of the OSC was measured. When the rotation speed of PEDOT:PSS spin-coating is at 2000-3000 rpm, the rotation speed is too low which will result in excessively thick PEDOT:PSS. Therefore the produced holes after solar illumination will not be easy to diffuse to the anode and cause the short-circuit current to become lower. When the rotation speed of PEDOT:PSS is up to 3500 rpm, the thickness of holes transport layer is getting thinner and thus the holes will easily diffuse to the anode and raise the short-circuit current and conversion efficiency of the OSC. When the spin-coating speed of PEDOT:PSS is at 3500 rpm, the optimum characteristics of OSC are: V_{oc}=0.4V, J_{sc}=6.93 mA/ cm^2, FF=0.368 with power conversion eff. η =1.02 %。

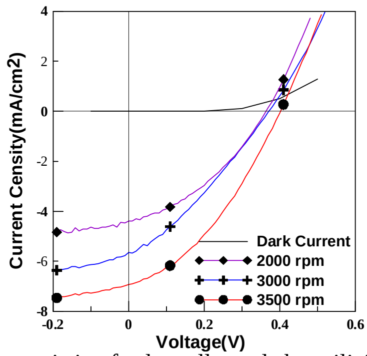

Fig. 5 I-V characteristic of solar cells made by utilizing different rotation speed of spin-coating speeds for PEDOT:PSS.

4. Conclusions

In this study, an adequate annealing treatment can eliminate the defects caused by spin-coating and improve the surface roughness of organic materials and meanwhile reduce the obstacle in the active layer to enable the excitons to easily diffuse. The optimum annealing temperature for active layer P3HT:PCBM should be fixed under 250℃ with annealing time of 15 minutes. After making sure the condition for optimum annealing, the thickness of holes transport layer will accordingly be adjusted. When the device parameters are selected as ITO/PEDOT(3500 rpm)/ P3HT:PCBM(1000 rpm) 250℃, annealing 15 min., it will obtain an optimum OSC characteristic: V_{oc}=0.4V, J_{sc}=6.93 mA/cm^2, FF=0.368 with power conversion eff. η =1.02 %.

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