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Dramatic Improvement of Bulk Heterojunction PTB7: $PC_{61}BM$ Organic Solar Cells by Adding Small Amounts of P3HT

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Abstract

Bulk heterojunction solar cells designed with a structure of glass/ITO/PEDOT:PSS/PTB7:P3HT: $PC_{61}BM$/LiF/Al were fabricated. A solar cell containing 3 and 5% P3HT weight fraction showed dramatic improvement in V_{oc}, J_{sc}, and PCE. It is assumed that the small amount of P3HT in the PTB7:$PC_{61}BM$ active layer acts as a mediator to enhance hole current from PTB7 to PEDOT:PSS anode. However, the electron and hole transfer between the PTB7 and P3HT domains were blocked at their interfaces as the P3HT fraction increases above 10%.

1. Introduction

Organic bulk-heterojunction (BHJ) solar cells are especially interesting owing to their possible low-cost production, large area, and mechanical flexibility [1,2]. An extremely high power conversion efficiency (PCE) of BHJ solar cells of 7.4% has recently been reported [3]. The cells were fabricated using a p-type semiconductor, poly[[4,8-bis[(2-ethylhexyl)oxy] benzo[1,2-b:4,5-b']dithiophene-2,6-diyl] [3-fluoro-2-[(2-ethylhexyl)carbonyl]thieno[3,4-b]-thiophenediyl] (PTB7), an n-type semiconductor, [6,6]-phenyl-C71-butyric- acid -methyl-ester ($PC_{71}BM$). The reason for the improved performance of the PTB7:$PC_{71}BM$ are considered to be due to the reduced band gap of PTB7 and the wider photon absorption range of $PC_{71}BM$. This means that these solar cells utilize photo current generation in $PC_{71}BM$ in addition to that in PTB7. However, the holes generated within the $PC_{71}BM$ also flow into the cathode. Thus, we considered utilizing $PC_{61}BM$, which has a narrower photon absorption range to reduce the hole flow into the cathode, and investigated PTB7:$PC_{61}BM$ solar cells containing different fractions of poly(3-hexylthiophene) (P3HT) to compensate the reduced photon absorption range. In this paper, we report on BHJ solar cells based on ternary blend solutions of PTB7, P3HT and $PC_{61}BM$.

2. Experimental

The device structure investigated in this research was glass/ITO/PEDOT:PSS/PTB7:P3HT:$PC_{61}BM$/LiF/Al. The active layer was deposited by spin coating a solution in which 10 mg of PTB7:P3HT and 10 mg of $PC_{61}BM$ were dissolved in 1,2-dichlolobenzene. The P3HT weight fraction was varied keeping the total weight of PTB7:P3HT. The solar cells were evaluated using a solar simulator under AM1.5 illumination.

2. Results and Discussion

Figure 1 shows the current density vs voltage (J-V) relationships for the BHJ solar cells with the different weight fractions of P3HT. The short circuit current density J_{sc} was greatly increased to 16 mA/cm^2 and the open circuit voltage V_{oc} was 0.83 V for the solar cell with a P3HT weight fraction of 5%. These values were much larger than those of the control PTB7:$PC_{61}BM$ solar cell. The performance of the solar cells gradually degraded as the P3HT fraction increased above 10%. Figure 2 shows the power conversion efficiency as a function of the P3HT weight fraction. It showed a maximum at 3-5% and continued to decrease after that. The averaged solar cell parameters are summarized in Table I. Figure 3 shows the photon absorption properties of the active layers on an ITO coated glass substrate with the different P3HT fractions. It was confirmed that the photon absorption ranges can be adjusted by changing the P3HT fraction. It should be noted that photons are mostly absorbed within the PTB7 domains below the P3HT concentration of 30%. Thus, the performance improvement is not due to the change of the photon absorption properties of the ternary blend system.

The mechanisms for the improved solar cell performance at the 5% P3HT weight fraction has not yet been clarified. However, P3HT has a HOMO level between the LUMO level of PEDOT:PSS anode and the HOMO level of PTB7, which improves the transport of the photo generated holes to the anode (see Figure 4). On the other hand, the transport of generated electrons between the PTB7 domains and the P3HT domains were blocked when the P3HT fraction was larger than 30% due to the LUMO level differences between the PTB7 domains and the P3HT domains.

3. Conclusions

We fabricated BHJ solar cells based on PTB7:$PC_{61}BM$ active layers containing different weight fractions of P3HT, and found that the solar cell containing 3 and 5% P3HT weight fraction showed dramatic improvements in V_{oc}, J_{sc}, and PCE.

References

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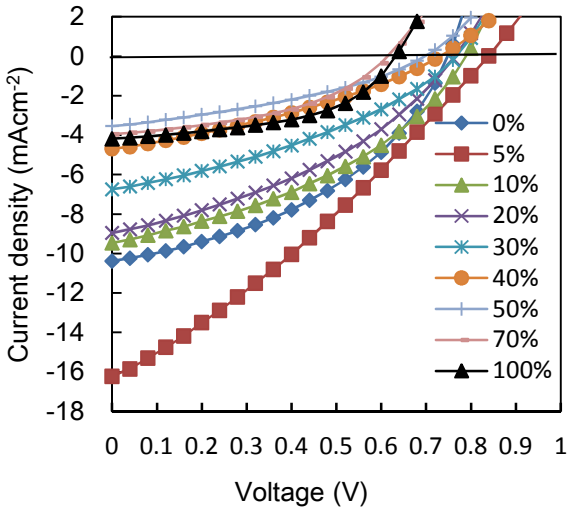

Fig. 1 Comparison of the J-V characteristics of selected BHJ solar cells with different P3HT weight fractions.

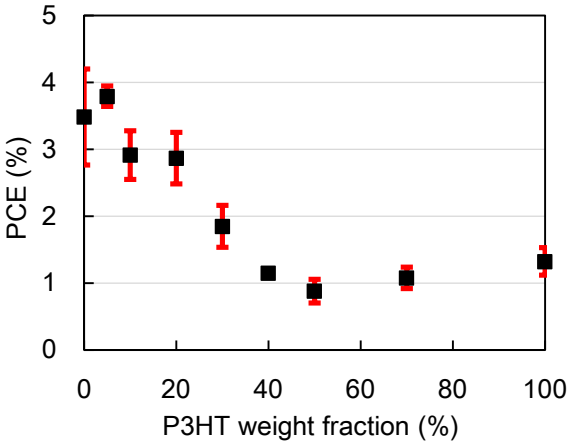

Fig. 2 Relationships between PCE and P3HT weight fraction.

Table I. Comparison of average solar cell parameters as a function of P3HT weight fraction.

P3HT fraction (%)	V_{oc} (V)	J_{sc} (A/cm^2)	FF	PCE (%)
0	0.74	10.74	0.42	3.48
3	0.81	11.81	0.44	3.95
5	0.84	16.22	0.32	3.80
10	0.74	9.88	0.39	2.91
20	0.76	9.49	0.37	2.87
30	0.75	5.86	0.33	1.76
50	0.71	3.41	0.36	0.836
70	0.61	3.44	0.44	1.08
100	0.63	3.45	0.5	1.32

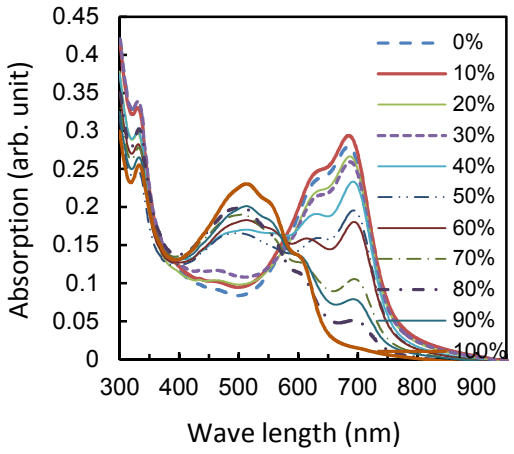

Fig. 3 Comparison of photo absorption of ternary mixed films of PTB7:P3HT:$PC_{61}BM$ with different P3HT weight fractions.

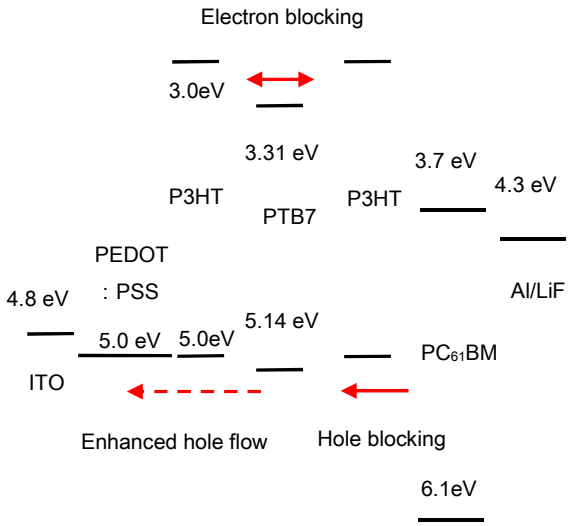

Fig. 4 Energy band diagrams for the ternary blend BHJ solar cell system.