A New Fabrication Method of Polymer Solar Cells

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Various approaches for morphology control such as thermal annealing, solvent annealing, and use of additives, have been proposed to enhance the efficiency of polymer solar cells (PSCs). These methods have been very effective to afford nano-scaled phase-separated morphology in lateral direction (parallel to film surface). However, they have a limitation to control the vertical concentration distribution of the components in active layer, although the vertical distribution is very critical for effective transport of charge carriers.

It has been agreed that an ideal bulk heterojunction (BHJ) PSC must have the vertical distribution of components where the p-type conjugated polymers are rich near the anode and n-type fullerenes are rich near the low work-function metal cathode. This ideal vertical morphology renders holes and electrons to move more efficiently to anode and cathode, respectively. However, such ideal vertical distribution in the active layer cannot be developed during film casting due to the lower surface energy of P3HT (26.9 mJ/m^2) than PCBM (37.8 mJ/m^2).

We report here enhanced performance of PSC by controlling the vertical morphology with the addition of a self-assembled additive. For the purpose, we synthesized fullerene end-capped poly(ethylene glycol) (PEG-C_{60}) and added it to P3HT/PCBM blend.

Since it has been reported that the addition of small amount of PEG in P3HT/PCBM blend induces spontaneous vertical phase separation with formation of PEG thin layer on top of the P3HT/PCBM, it is expected that PEG-C_{60} molecules also migrate to the surface of the P3HT/PCBM active layer to form a buffer layer between active layer and metal cathode. As this buffer layer with high dielectric constant induces an interfacial dipole between active layer and metal cathode, the vacuum level of the cathode is increased and thus the energy barrier for electron collection is decreased. Consequently, the exciton dissociation at the interface and the charge collection at the cathode become more efficient, affording an increased open circuit voltage (V_{OC}) and short circuit current density (J_{SC}). Another important feature with addition of PEG-C_{60} is to induce segregation of PCBM near PEG-C_{60} layer, which makes an ideal vertical distribution of PCBM in the active layer: P3HT becomes rich near the anode and PCBM becomes rich near the cathode. Furthermore, since the PEG-C_{60} layer may protect the active layer from oxygen as well as the invasion of Al to the active layer during metal deposition, the stability of PSC will be improved.

To investigate the effect of PEG-C_{60} buffer layer on the performance, the power conversion efficiencies (PCEs) of PSCs with different amount of PEG-C_{60} were compared. While the reference device (0 wt% PEG-C_{60}) exhibits 3.60% PCE, the device with 5 wt% PEG-C_{60} shows 4.41% PCE (see Table 1). The enhancement of V_{OC} by addition of PEG-C_{60} is originated from the effect of dielectric buffer layer between active layer and metal cathode, and the increase of FF is due to development of an ideal vertical-morphology. Therefore, it is concluded that both the formation of buffer layer and the development of ideal vertical-morphology in the active layer enhance the device performance.

Table 1. Performance of PSCs with different amount of PEG-C_{60}.

PEG-C_{60} [wt%]	V_{OC} [V]	J_{SC} [mA/cm]	*FF*	PCE [%]
0	0.61	10.17	0.58	3.60
5	0.66	10.27	0.65	4.41