Abstract

This research mainly focuses on the bilayer configuration of organic solar cells (OSCs) through layer-by-layer sequential deposition of conjugated polymer and fullerene derivative. The common Poly(3-hexylthiophene-2,5-diyl) (P3HT) and [6,6]-phenyl-C61-butyric acid methyl ester (PCBM) have been utilized as the main materials for the electron donor and electron acceptor, respectively. The bilayer device configuration enables the polymer layer to be favourably adjusted by rubbing. Rubbing on polymer layer was reported to bring about the favourable molecular orientation from edge-on to face-on that is beneficial for the charge transport in out-of-plane direction for enhanced photovoltaic performances. In this regards, the application of rubbing on conjugated polymer layers has been emphasized throughout the research work, aiming to achieve enhanced performances rubbed bilayer OSCs.

Initially, the understanding of the device fabrication procedures of the bilayer P3HT/PCBM OSCs were acquired by fabricating the unrubbed devices in as-deposited and annealed conditions. The photovoltaic performances of the devices were analysed via morphological studies (by atomic force microscope, AFM), optical studies (by UV-Vis spectrophotometer) and structural studies (by Fourier-transform infrared spectroscopy equipped with p-polarized multiple-angle incident resolution spectrometry, pMAIRS). Subsequently, the device fabrication parameters were optimized by considering the substrate cleaning, electron acceptor, P3HT solvent, heat treatment and the evaporation rate of the metal electrode. By taking into account the optimized device fabrication parameters, we managed to fabricate the unrubbed devices having reproducible photovoltaic performances.

In addition to the unrubbed OSCs, the rubbed devices were also fabricated by making use of enhanced rubbing technique. The efforts to improve the conventional rubbing technique were performed in order to acquire the quantitative rubbing parameters (i.e. rubbing pressure). An automatic rubbing device was developed to get better control of the parameters of rubbing processes. The unfavourable result of the automatic rubbing approach, however, has led to the use of the folded nylon cloth with a clip. The clipped nylon cloth enables the variation of the rubbing number at the consistent rubbing pressure. Including the abovementioned characterizations, thin film thickness measurement and compositional studies (by energy dispersive X-ray spectroscopy, EDS) have been performed to correlate the enhanced PV performances of the devices with the rubbing technique.

We have revealed the individual effect of rubbing and annealing mainly through the compositional studies and structural studies of the photoactive layers before and after annealing. While rubbing brings about the favourable vertical concentration gradient than facilitates the efficient charge transport, annealing further segregates the bilayers to form intimately large intermixed P3HT:PCBM layer for an adequate charge generation. Also, pMAIRS measurements indicates that the small change of P3HT molecular reorientation from edge-on to face-on by rubbing does not contribute to the enhanced photovoltaic performances of the devices. Therefore, the enhanced performances of bilayer OSCs before and after annealing have been confirmed to be mainly attributed by adequate vertical concentration gradient of the photoactive layers. This finding will open up the opportunity to further enhance the performances of bilayer OSCs using other electron donor and electron acceptor systems.

Keywords: Bilayer organic solar cells, rubbing, annealing, molecular orientation, vertical concentration gradient.