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Ternary Organic Blend for Semitransparent Solar Cells with Enhanced Short Circuit Current Density

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Abstract : Organic solar cells (OSCs) have made rapid progress and currently achieve power conversion efficiencies (PCE) of over 10%. OSCs have several merits over other direct light-to-electricity generating cells and can be processed at low cost from solution on flexible substrates over large areas. Moreover, combining organic semiconductors with transparent and conductive electrodes allows for the fabrication of semitransparent OSCs (SM-OSCs). For SM-OSCs the challenge is to achieve a high average visible transmission (AVT) while maintaining a high short circuit current (Jsc). Typically, Jsc of SM-OSCs is smaller than when using an opaque metal top electrode. This is because the non-absorbed light during the first transit through the active layer and the transparent electrode is forward-transmitted out of the device. Recently, OSCs using a ternary blend of organic materials have received attention. This strategy was pursued to extend the light harvesting over the visible range. However, it is a general challenge to manipulate the performance of ternary OSCs in a predictable way, because many key factors affect the charge generation and extraction in ternary solar cells. Consequently, the device performance is affected by the compatibility between the blend components and the resulting film morphology, the energy levels and bandgaps, the concentration of the guest material and its location in the active layer. In this work, we report on a solvent-free lamination process for the fabrication of efficient and semitransparent ternary blend OSCs. The ternary blend was composed of PC70BM and the electron donors PBDTTT-C and an NIR cyanine absorbing dye (Cy7T). Using an opaque metal top electrode, a PCE of 6% was achieved for the optimized binary polymer: fullerene blend (AVT = 56%). However, the PCE dropped to ~2% when decreasing (to 30 nm) the active film thickness to increase the AVT value (75%). Therefore we resorted to the ternary blend and measured for non-transparent cells a PCE of 5.5% when using an active polymer: dye: fullerene (0.7: 0.3: 1.5 wt:wt:wt) film of 95 nm thickness (AVT = 65% when omitting the top electrode). In a second step, the optimized ternary blend was used of the fabrication of SM-OSCs. We used a plastic/metal substrate with a light transmission of over 90% as a transparent electrode that was applied via a lamination process. The interfacial layer between the active layer and the top electrode was optimized in order to improve the charge collection and the contact with the laminated top electrode. We demonstrated a PCE of 3% with AVT of 51%. The parameter space for ternary OSCs is large and it is difficult to find the best concentration ratios by trial and error. A rational approach for device optimization is the construction of a ternary blend phase diagram. We discuss our attempts to construct such a phase diagram for the PBDTTT-C: Cy7T: PC70BM system via a combination of using selective Cy7T selective solvents and atomic force microscopy. From the ternary diagram suitable morphologies for efficient light-to-current conversion can be identified. We compare experimental OSC data with these predictions.

Keywords : organic photovoltaics, ternary phase diagram, ternary organic solar cells, transparent solar cell, lamination
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